SMARTGREENS 2014

3rd International Conference on Smart Grids and Green IT Systems



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FOREWORD

This book contains the proceedings of the 3rd International Conference on Smart Grids and Green IT Systems (SMARTGREENS 2014) which was organized and sponsored by the Institute for Systems and Technologies of Information, Control and Communication (INSTICC) and held in cooperation with IEEE TCSC Technical Area in Green Computing, IEEE Technical Committee on Green Communications & Computing and Friends of the Supergrid.

This conference was also held in collaboration with Siemens.

We expect that these proceedings, which approach areas like "Smart Grids", "Energy-Aware Systems and Technologies", "Sustainable Computing and Communications" and "Smart Cities", appeals to a global audience of engineers, scientists and business people interested in the research topics of SMARTGREENS.

We believe the proceedings here published demonstrate new and innovative solutions, and highlight challenging technical problems in each field.

SMARTGREENS 2014 received 65 paper submissions from all continents. From these, 14 papers were published and presented as full papers, 19 were accepted as short papers for 20' oral presentation and another 14 additional papers will be also presented as posters. These numbers, leading to a full-paper acceptance ratio of 21,54% and an oral paper acceptance ratio of 50,77%, shows the intention of preserving a high quality forum for the next editions of this conference. Moreover, the conference also featured a number of keynote lectures delivered by internationally known experts thus contributing to increase the overall quality of the conference and to provide a deeper understanding of the conference interest fields.

The number and high quality of the papers received imposed difficult choices in the review process. Each paper was reviewed by, at least two reviewers. From these reviews, those papers that were adequately balanced in terms of quality, originality and relevance to the conference themes were selected.

For the conference we ensured appropriate indexing of the proceedings of SMARTGREENS including Thomson Reuters Conference Proceedings Citation Index, INSPEC, DBLP, EI and Scopus. All presented papers will soon be available at the SCITEPRESS digital library.

To recognize the best submissions and the best student contributions, awards based on the best combined marks of paper reviewing, as assessed by the Program Committee, and the quality of the presentation, as assessed by session chairs at the conference venue, were conferred at the closing session of the conference.

In conjunction with a set of related conferences, namely WEBIST and CLOSER,

SMARTGREENS had a new kind of session, named The European Project Space (EPS). The EPS aimed to provide insights into the research projects that are currently going on in Europe within the fields of web-based information systems, Cloud Computing and Smart Grids and Green IT Systems. This initiative intended to facilitate opportunities for knowledge and technology sharing, and establish the basis for future collaboration networks involving current project partners and interested conference delegates.

Finally, we would like to express our thanks, first of all, to the authors of the technical papers, whose work and dedication make possible to put together a program that we believe very exciting and of high technical quality. Next, we would like to thank all the members of the program committee and auxiliary reviewers, who helped us with their expertise and time. We would also like to thank the invited speakers for their invaluable contribution and for sharing their vision in their talks. Special thanks should be addressed to the INSTICC Steering Committee whose invaluable work made this event possible.

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INVITED SPEAKERS

KEYNOTE SPEAKERS

ICT Architecture as an Engine for the Electromobility of the Future

Cornel Kleine
Siemens AG, Germany

Abstract: Electromobility is a promising approach to address the challenges of demographic change, urbanization and in particular sustainability. As shown by the rapid raise of new market players, electromobility has the potential to change markets dramatically in a disruptive way. But electric drives for the drive train are only the catalyst for the real change: most significantly, the architecture and role of in-vehicle information technology will change for the vehicle of the future. We outline existing research activities towards radically new architectures and the expected benefits in terms of functionality, such as "Plug&Play" and new functions up to fully automated driving.

BRIEF BIOGRAPHY

Cornel Klein is Software Architect and Project Manager for the Technology & Innovation Project “eCar” at Siemens Corporate Technologies in Munich. He is project manager and coordinator for RACE (Robust and reliable Automotive Computing Environment for future eCars) which aims at the development of an advanced automotive E/E architecture. In various positions at Siemens, he has been responsible for software technologies and SW based innovations. Starting his career 1998 at Siemens Public Networks, he has gained an extensive knowledge in communication networks, embedded systems, IT platforms and SW architecture as well as in application domains like eCars and smart environments. He holds a master and a PhD degree in Computer Science from the Technical University of Munich.

Making Smart Cities *Smarter*
Using Artificial Intelligence Techniques for Smarter Mobility

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Keywords: Smart Mobility, Artificial Intelligence, Semantic Data Interpretation, User Profiling, User Recommendation.

Abstract: The term *Smart City* is tipically applied to urban and metropolitan areas where Information and Communication Technologies provide ways to enable social, cultural and urban development, improving social and political capacities and/or efficiency. In this paper we will show the potential of Artificial Intelligence techniques for augmenting ICT solutions to both increase the cities competiveness but also the active participation of citizens in those processes, making Smart Cities *smarter*. As example we will describe the usage of Artificial Intellgence techniques to provide Smart Mobility in the context of the SUPERHUB Project.

1 INTRODUCTION

The term *Smart City* is a broad term that refers to the *smart* management of the cities socio-economic and environmental capital through the use of Information and Communication Technologies. These technological solutions are said to be *smart* as they provide ways to enable social, cultural and urban development, improving social and political capacities and/or efficiency. But sometimes there is some abuse on the term, converting any technological solution that eases information gathering, analysis, management or sharing as a Smart City solution, without careful analysis of its real impact on the cities efficiency or capacity, and on the users empowerment.

Mobility is one of the main challenges for urban planners in the cities. Even with the constant technological progress, it is still difficult for policy makers and transport operators to 1) know the state of the city in (near) real-time, and 2) achieve proximity with the end-user of such city services, especially with regards to communicating with the citizen and receiving proper feedback. Many Smart City solutions for mobility have focused on empowering the user with the ability to decide the best way to move through the urban or metropolitan transport network, by creating *journey planners*. But most of the existing journey planners only provide a few options to let users customize, to some extent, how the journey should look like. The reality, however, is more nuanced – different users might prefer different routes and/or combinations of modes and these may, in addition, depend on the users context (e.g. a shopping trip, travelling with small children or going back home) as well as on the environmental context: weather, traffic, crowdedness, events. Specifying all of the circumstances affecting what the user perceives as the ideal plan, however, would be overwhelming. The use of personalization in the field of journey planning is mainly focused on tourism (Ricci, 2002), although there are other domains where routes are also recommended, e.g., for sporting/leisure purposes (Diaspero et al., 2011; Knoch et al., 2012). For instance, (Diaspero et al., 2011) produces journey hiking walkways according to a set of milestones or personalize journey plans by choosing from pre-defined routes which better fit users preferences. Afterwards, the selected routes are enhanced by means of adding Points Of Interest (POI) -relevant geographical features that may be relevant to the user. In general, these approaches can be considered as aimed at providing journey plans to users on closed domains where the set of potential journey plans is already defined, and those plans are built based on a recommended set of POIs (e.g., touristic routes), meaning that first the POIs are obtained and routes designed to visit them. Other approaches try to overcome this closed domain constraint. While some solutions successfully generate this kind of routes, they do not incorporate users preferences or just a small set of generic preferences are taken into account (e.g., departure time or cost) (McGinty and Smyth, 2003).

Another aspect that is overlooked in many ICT solutions for Smart Mobility is the role citizens can play to perceive and build an up-to-date model of the city status. Thanks to smartphones, users that move in a city can potentially generate automatic data that may be hard to obtain otherwise: location, movement flow, average trip times, and so on. Moreover, network problems and incidents that affect mobility services are often documented by users in Social Networks at the same time or, in some cases, even before those are detected by the mobility operators. This phenomenon has been referred to as *humans as sensors* (Srivastava et al., 2011). Sensing the city through mobile humans potentially provides sensor coverage where events are taking place, and takes advantage of the citizen's capacity to analize the situation and evaluate its impact at the individual and even the collective level. Some proposals have recently appeared to exploit data generated by users to sense the cities' status, either from the individual sensoring perspective, closer to multi-agent based systems (Ellul et al., 2013) or from big data techniques applied to social network streams by combining statistical analysis with semantic interpretation (Gabrielli et al., 2013). However, such proposals work at a granularity level that is either too high or too low: in the former approach there is, in principle, no centralised mechanism to maintain global aggregations; in the latter, systems do not take advantage of the end-user terminals and their potential dispersion in time and space. In this paper we present a system that can work at both levels, leveraging global aggregations with local awareness to have the best possible picture of the context of the city whenever possible.

In this paper we will present some of the results of the EU SUPERHUB project(Carreras et al., 2012), describing how, by the usage of some Artificial Intelligence techniques (knowledge representation, machine learning, natural language processing, sentiment analysis, semantic inference, information diffusion models and knowledge mining techniques), interactions of users in certain social networks -i.e.: Twitter and Foursquare- are combined with knowledge of the city, city events calendars and geospatial data to learn local behavioural patterns in the city, capture those deviations that may reflect events that affect mobility in the city and then provide better travel recommendations, taking advantage of a richer city model and a more accurate user profiling.

2 THE CASE OF SUPERHUB

SUPERHUB (Carreras et al., 2012) is a project co-funded by the European Commission that aims at realizing a new services mobility framework supporting an integrated and eco-efficient use of multi-modal mobility systems in an urban setting. The main goal of the project is to provide an open platform able to consider in real time various mobility offers and to provide a set of mobility services able to address user needs, promote user participation, and foster environmental friendly and energy-efficient behavioural changes.

To achieve this SUPERHUB is developing:

1. a persuasive engine based on captology principles to facilitate the voluntary adoption of environmentally-friendly multi-mobility habits,
2. novel methods and tools for real-time reasoning on large data streams coming from heterogeneous sources,
3. new algorithms and protocols for inferring traffic conditions from mobile users by coupling data from mobile operator networks with information coming from both GPS based mobile phones and social network streams,
4. mechanisms for dynamic matchmaking of resources, and
5. a journey planner with the goal of best fulfilling user mobility needs and preferences while minimizing negative environmental impact.

The concept of the project builds on the notion that citizens are not just mere users of mobility services, but represent an active component and a resource for policy-makers willing to improve sustainable mobility in smart cities. In SUPERHUB, users play an active, consumer and producer role (prosumer), acting, on the one hand, as providers of mobility offers, such as in car-pooling negotiations, and on the other hand, as consumers of mobility resources, such as taking the bus, using a public parking, or renting a bike).

The SUPERHUB travel planner employs the state of the art user modelling and recommender systems techniques – by observing the past users' choices and the context in which these choices were made, SUPERHUB gradually learns the model that accurately reflects the multifaceted nature of each users preferences and constraints. During a journey plan search, the user model is used, in addition to the automatically acquired contextual information, to guide the search process in order to provide highly-tailored journey plan recommendations that best reflect the unique needs and situational context of each user. Technically, the personalization process relies on a mixture of contextual content-based filtering plus the use of semantics applied to contextual data, thus being able to assess different contexts, even if these have not been experienced by the user yet.

In addition, journey plans are further personalized by means of opportunistic recommendation. The SUPERHUB opportunistic recommender enhances journey plans by adding points of interest that might be interesting for the user during the journey. For example, if the user is going back home and she has to wait to take the train, the recommender may suggest having a coffee or doing some small shopping. In some circumstances, the recommender may even suggest alternative destinations (e.g. a different cinema or supermarket) if the original destination is difficult to reach in a current traffic.

2.1 From City Sensing to City Interpretation

In a real-world setting, the SUPERHUB journey planner has to be ready to receive high amounts of journey plan requests and deliver multimodal recommendations that best fit a wide range of criteria, including the user preferences. However, the evaluation of such criteria is continuously dependent on factors that occur in the external world, what we call the context of the request. But the context, given the same external conditions, is always city-dependent. For instance, a request for a journey plan made in January in a day that it is snowing defines different contexts if the user is in Helsinky (where snowing is considered a normal situation and public transport is prepared) or if the user is in Barcelona (where snowing is considered an extraordinary case that has numerous, unpredictable consequences on the transport networks). Therefore, weather sensor data may be useful to detect a context, but not sufficient by itself.

Another issue is aggregating heterogeneous situational data in a common model when such data is specified at different levels of abstraction. For instance, a subset of the SUPERHUB sensor adaptors belong to the field of web-based social networks, with content typically expressed in plain text. Some intermediate steps (based in Natural Language Processing (NLP) semantic extraction techniques) must be followed in order to extract a structured concept representation of the meaning of the raw data. More generally, data has to be normalised, so that values used in the representation of the data belong to the same abstract data type ranges; and aggregated, so that data that comes from potentially unreliable sources can be contrasted and therefore reinforced or discarded. Expert knowledge in the form of input models, such as the model of the city, designed by mobility experts, is converted into rules that will be used to infer a first abstraction of knowledge.

Both data homogeneisation and the inference of the state of mobility in a city are made by the Semantic Interpreter. We take advantage of state-of-the-art semantic interpretation techniques in order to infer knowledge from both situational and historical data. Via the Semantic Interpreter, raw data is filtered, normalised and interpreted into high-level concepts. Such concepts can be merged and analysed to generate derivative concepts that are not explicit in the sensor data but implicit in the aggregation of large instances of it. The analysis relies in applying expert knowledge and information about the city and is based in semantic methods rather than statistical ones. The obtained knowledge can be then applied by other SUPERHUB components for several diverse purposes, such as managing mobility high-level contexts to generate more fine-grained user models, or being able to understand normality with respect to policy fulfillment and thus derive and predict unexpected situations.

2.2 Inferring City Context from Social Networks

In SUPERHUB, situational data is retrieved not only from sensors such as weather or traffic sensors, but also from the social networks. Twitter (microblogging), Instagram (microblogging) and Foursquare (location-based) data are combined in order to automatically model the normal situations in the city and detect abnormal ones. Based on user's geolocated posts, the Semantic Interpreter is able to identify: which are the main points of interests, how the people move along the city on their daily basis or before/after an event occurs (trajectories), and specific mobility user profiles (e.g. tourists). Besides that, other data sources are cross referenced with social networks data in order to filter noisy information, provide reliability and add explanations about events and validate the results of the detection system.

In the case of tweets, text content related to mobility concepts are aggregated and analysed in time windows in order to find located trends (Weng and Lee, 2011). In information diffusion, reliability of data obtained is a big concern, and our solution is to filter bots and spammers by analysing the topology of the individual social networks of the users (Boccaletti et al., 2006), and by calculating their influence on other users (Gomez et al., 2012). The Foursquare API adds to the reliability score of the aggregated data by contrasting the detected trends against area-based collections of check-ins in the same time windows.

One interesting usage of social network data is for the detection of disruptive (un-expected) events. Disruptive events and incidents in the mobility city field

are abnormal situations that have a negative impact on the city mobility, for instance: traffic or metro service. In order to maintain a reliable mobility city behaviour, it is necessary to detect and predict these kind of events. Basically, a normal situation in the city can be modelled under a spatio-temporal context; which can be defined as any information that characterize a situation. It means that a day of a week, weather conditions, city zone (geolocation) and the type of road could be part of this context. For instance: traffic could be different on Monday at 7:00 am compared to Saturday at the same time; between two different weather conditions (rainy or sunny); or the type of road (highway or boulevard). However, to monitor an entire city with several type of sensors for discovering disruptive events and incidents may not be affordable. Alternatively, a *human as a sensor* approach brings a new opportunity to minimize the cost and reveal information that cannot be extracted directly from others sensors. Users can inform and provide context about events having real impact on them in real-time. The identification of recurrent events allow the classification of what is normal and what it is not.

2.3 Context-aware Travel Recommendendation

SUPERHUB aims to generate journey plans taking into consideration both a rich user behavioural model and an up-to-date context model. Users select a destination and plans are designed accordingly, using different modes of transport, including carpooling. The Intelligent Mobility Recommender is composed by three main components: the IMR Manager, which manages mobility requests and keeps user behavioural profiles; the Journey Plan Recommender (JPR), which incorporates the user preference to support journey plan design; and the Opportunistic Recommender (OR), which provides opportunistic recommendations.

In SUPERHUB, Journey Plans are dynamically generated by the JPR with regards to different criteria (among them the user preference). The generation of Journey Plans is done iteratively, searching for suitable Journey Legs and using critics to reduce search space. Finally, once the set of Journey Plans have been found, the OR selects POIs along the route that may be appealing and may represent opportunities for the user to improve his experience. Semantic relations and interpretations of items are used to enhance the OR results, to obtain semantically similar POIs which are described in SUPERHUB's City Model. Then, the selected POIs are added to the Journey Plan to enhance it. Given that the domain of POIs is not as large as Journey Plans it is feasible to consider collaborative-filtering approach, which has proven to be effective and requires less information about items (venues in this case). Nevertheless, collaborative-filtering can suffer from data sparsity, thus we use Matrix Factorization to find latent factors and reduce sparsity.

Both the IPR and OR recommenders contribute to build and maintain a user model and make use of contextual data to perform context-aware recommendations. When context matters, as is the case of mobility domain (e.g., when it is raining people prefer to avoid walking or riding a bike), it is sensible to use a user model that has been learnt with feedback acquired in the same context as the target user because only that feedback is relevant for the prediction. This allows improving results and dynamically adapt to the real situation in the city and to user's needs, goals and current context (e.g., in a rush, going to work, with children). Both recommenders use context to pre-filter the learned user models and exploit contextual user models which are built taking into account the contextual information obtained from situational data.

Both approaches, using contextual information and semantics, provide novelty to the state of the art beyond the use of recommenders in the mobility domain. The closest approach to ours is the one by (Diaspero et al., 2011) which incorporates the user preference to support journey plan design. SUPERHUB differs from that approach that routes are not taken from a pre-defined set, but are dynamically generated according to contextual situation in the city. Thus, (Diaspero et al., 2011) adds a set of POIs to enhance the routes which is similar to SUPERHUB's approach for opportunistic recommendation, although it does not take into consideration contextual information.

3 CONCLUSIONS

In this paper we have outlined the usage of a combination of Artificial Intelligence techniques (knowledge engineering, machine learning, sentiment analysis, semantic inference, information diffusion) to enhance mobility in the cities, by empowering users not only with means to plan their routes through the transport network smartly but also to act as sources of event information that can help build a better snapshot of the city status. On one hand SUPERHUB's Semantic Interpreter receives interactions of users in certain social networks and combines them with city-specific knowledge, city events calendars and geospatial data. Data is analysed in two stages, on-line and off-line, in order to learn behavioural patterns and capture those

deviations that may reflect events that affect urban mobility. On the other hand SUPERHUB's Intelligent Mobility Recommender, by having a strong focus on the use of semantically-enhanced contextual information, provides better route recommendations more suitable for the current user needs and situation.

The Semantic Interpreter is currently running and producing results for Barcelona, Milan and Helsinki, the three trials cities for the SUPERHUB project evaluation. Depending on the periodicity of the aggregation set in the configuration of the Semantic Interpreter instance, the delay between the start of the event in the city and the instant at which it is detected by the SUPERHUB platform may vary, but we have empirically proven it can be as low as 5 minutes. Early versions of the Intelligent Mobility Recommender have been tested with real users in the three cities, and the final version will be tested and validated in the third quarter of 2014.

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Open Protocols Are the Basis of the Most Cost Effective Charging Infrastructure

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Abstract: First of all open standards contribute to interoperability. By using open standards the (digital) communication between different actors improves.
In addition, open standards ensure that freedom is guaranteed. Open standards are by their very nature, not software-specific and can be installed by each supplier. They are necessary for achieving vendor independence.
This leads to high-quality and cost-effective information exchange.
Open standards involves creating and applying agreements on specifications of the interfaces between the co-operating applications, services, systems and networks. Characteristic of open standards is that there are no barriers to the use of the standards.
Besides vendor independence and interoperability Open standards also lead towards transparency, accountability and manageability. This is also a very important aspect in de development of the 'smart ecosystem'. De different building blocks e.g EVSE development, smart charging, smart grids, smart energy, smart traffic, etc. have to come together one day.

BRIEF BIOGRAPHY

Arjan Wargers is responsible for Innovation and Development in the area of EV charging infrastructure at the e-laad Foundation. This means innovation of the e-laad back-end system, making sure that this system is state-of-art and allowing open innovation (for third parties) by creating and aligning international open interfaces. Arjan is responsible for specifying and purchasing the charging stations which are installed in The Netherlands. In this area, Arjan is also making sure that 'open innovation' and maximal cost efficiency is reached. Arjan has great knowledge of all relevant EV aspects, from technical interfaces to market model development and clearing and settlement. Arjan Wargers contributed to the European standardization of EVSE's and (further) development of open 'EV-protocols' such as OCPP, OCHP and OSCP, and was also responsible for the creation of an European 'roaming organization' (e-clearing.net). Arjan supports innovation through knowledge sharing, transparency and implementation of innovation projects.

SMART GRIDS

FULL PAPERS

A New Two-Degree-of-Freedom Space Heating Model for Demand Response

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Abstract: In today's fast changing electric utilities sector demand response (DR) programs are a relatively inexpensive means of reducing peak demand and providing ancillary services. Advancements in embedded systems and communication technologies are paving the way for more complex DR programs based on transactive control. Such complex systems highlight the importance of modeling and simulation tools for studying and evaluating the effects of different control strategies for DR. Considerable efforts have been directed at modeling thermostatically controlled appliances. These models however operate with only one degree of freedom, typically, the thermal mass temperature. This paper proposes a two-degree-of-freedom residential space heating system composed of a thermal storage unit and forced convection system. Simulation results demonstrate that such system is better suited for maintaining thermal comfort and allows greater flexibility for DR programs. The performance of several control strategies are evaluated, as well as the effects of model and weather parameters on thermal comfort and power consumption.

1 INTRODUCTION

The electric utilities sector currently faces a number of challenges: how to manage electricity prices in an unregulated market (Spees and Lave, 2007), how to cope with more distributed and intermittent generation such as wind power (Kondoh et al., 2011), as well as how to cope with ever increasing peak demands (Ericson, 2009). Demand response (DR) programs are an effective means for alleviating such issues. When consumers can respond in real time to high electricity prices, they naturally tend to reduce peak-time usage, and consequently help equalize demand and prices (Spees and Lave, 2007). In addition, DR programs provide a more flexible and efficient option for fast-response ancillary services (Kondoh et al., 2011).

Albadi *et al.* concisely summarized a hierarchy of current incentive- and price-based utility DR programs (Albadi and El-Saadany, 2007). Incentive-based residential programs often take the form of direct control, wherein a utility can directly apply an on/off duty cycle to customer appliances in order to adjust aggregate customer demand. Often, such programs are used for load shedding during high-demand periods. In return for taking part in such programs customers are rewarded with an incentive, such as a discount on their electricity bill. Incentive-based DR has been considered in works such as (Mohsenian-Rad et al., 2010).

Price-based programs, on the other hand, persuade customers to change their electricity consumption behavior by adjusting prices throughout day. Price adjustments occur either in response to current demand or are based on a predetermined time-of-use schedule. Participating customers may therefore avoid high electricity prices by modifying their behavior, such as reducing consumption during peak-periods. Price-based DR has been considered in works such as (Fuller et al., 2011).

Current developments in embedded system technologies and communications make it possible to implement home energy management (HEM) systems that not only react to but also interact with the grid through mechanisms like transactive control (Schneider et al., 2011), (Chassin et al., 2008). In the future, distributed HEM systems will be an integral part of DR programs (Pipattanasomporn et al., 2012). Modeling and simulation tools are essential in understanding and evaluating the effects of different DR control strategies prior to large scale deployment. In this context, it is important to create residential load models

that simulate the physical behavior of appliances participating in DR programs (Shao et al., 2013).

Thermostatically controlled appliances (TCA), such as water heaters and HVAC systems, are of particular interests because they can store thermal energy. Intelligent control strategies can make use of this storage capacity in order to avoid operating during peak periods with little inconvenience to the customer. A 2001 survey by the Office of Energy Markets and End Use (RECS, 2001) reported that 9.1% of household electricity consumption was due to water heaters. Another considerable amount, 10.1%, was due to space heating. Several pilot programs have been conducted that employ hot water heaters as the DR appliance, particularly in the U.S. states of Washington and Oregon (Kondoh et al., 2011), (Chassin et al., 2008), (Diao et al., 2012), as well as in Norway (Saele and Grande, 2011).

Considerable efforts have been directed to modeling thermostatically controlled loads. The thermodynamic behaviors of electric water heaters and HVAC system are normally described by differential equations (Lu, 2012), (Du and Lu, 2011), (Molina-Garcia et al., 2011). Often, the system presents two behaviors: on or off. When the appliance is on, the temperature of the thermal mass increases following a negative exponential curve ($c - e^{-\tau}$); when then appliance is off, the temperature of the thermal mass decreases exponentially ($c + e^{-\tau}$) (Lu et al., 2005). The time constant τ relates to the thermal capacitance of the thermal mass.

However, the above mentioned models present only one degree of freedom (DoF) for control, typically, the desired indoor temperature or the minimum and maximum acceptable temperatures for the thermal mass (Pipattanasomporn et al., 2012). This paper introduces a two-DoF space heating model composed of a heat pump, a thermal storage unit (hot water tank) and a forced convection system. The heat pump transfers thermal energy to the thermal storage and heats up the water. The hot water is circulated through coiled pipes, transferring heat to it surrounding air, which is in turn circulated through the house by the forced convection system. Such systems contain, in effect, two thermal masses: the thermal storage unit and the thermal mass of the house (air and structures). These systems are not new, they are common in Canada and in Nordic countries, however, they have not yet been considered in DR studies.

This paper demonstrates that two-DoF systems are better adapted for maintaining thermal comfort and allow greater flexibility for DR programs. The DR performance of the proposed system is compared to a traditional one-DoF system through simulations. The systems are evaluated with respect to their ability to maintain indoor temperature within a comfortable range (Peeters et al., 2009). Simple control strategies are proposed for the forced convection system coupled to on-off, and multistage compressors. Simulation results show the importance of considering two-DoF models for DR.

The contributions of this paper may be summarized as follows.

- The description of a two-DoF heating system model composed of an insulated thermal storage unit and a forced convection system (FCS);
- The comparison and evaluation of two-DoF and one-DoF systems for price-based DR;
- The evaluation of different control strategies for two-DoF systems, and their effect on thermal comfort for on/off, and multistage compressors as well as three different weather profiles;

The remainder of the paper is organized as follows. Thermodynamic model and control strategies are described in Section 2. Model and simulation parameters used for the study are explained in Section 3. Simulation results are presented in Section 4 and discussed in Section 5. Finally, Section 6 concludes this paper.

2 MODELS

2.1 Thermodynamic Model

The proposed system consists of:

- A rectangular volume with insulated walls representing the house.
- An insulated thermal energy storage unit (hot water tank).
- A heat pump directly coupled to the thermal mass.
- A forced convection system (FCS) that transfers heat from the thermal mass to the house.

This thermodynamic model can be represented as a thermal circuit, as shown in Figure 1. The equivalent mathematical model is shown in Equation (2), where T_H is the indoor temperature; T_{TM} is the thermal mass temperature; and T_O is the ambient outdoor temperature. The mass of the water in the storage tank is m_{TM} and its specific heat is C_{TM}. The heat storage capacity of the house is represented by the capacitance of value $C_H m_H$, which includes the heat capacity of the air contained in the house as well as it's structure and materials. The heat conductivity between the thermal mass and the house is represented

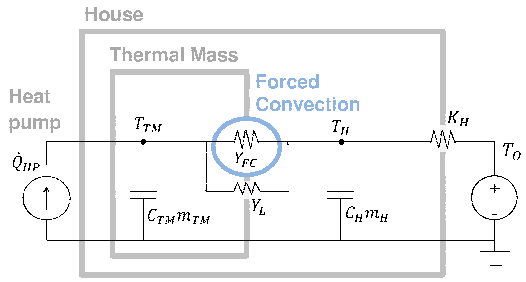


Figure 1: Thermal circuit representation of the thermodynamic model. T_H is the indoor temperature; T_{TM} is the thermal mass temperature; and T_O is the ambient outdoor temperature. The mass of the water in the storage tank is m_{TM} and its specific heat is C_{TM}. The heat storage capacity of the house is represented by the capacitance of value C_Hm_H, which includes the heat capacity of the air contained in the house as well as it's structure and materials. The heat conductivity between the thermal mass and the house is represented by Y_{TM-H}, which depends on the heat transfer coefficient created by the FCS, Y_{FC}, and the thermal mass heat loss, Y_L, according to equation 1. The conductivity of the house insulation is represented by K_H; and $\dot{Q}_{HP}$ is the heat pump's thermal power output.

by Y_{TM-H}, which depends on the heat transfer coefficient created by the FCS, Y_{FC}, and the thermal mass heat loss, Y_L, according to Equation 1. The conductivity of the house insulation is represented by K_H; and $\dot{Q}_{HP}$ is the heat pump's thermal power output.

It is worth noting that, if the conductivity between the thermal mass and the house Y_{TM-H} is kept constant, this model is qualitatively no different from previously proposed models (Lu, 2012), (Du and Lu, 2011), (Molina-Garcia et al., 2011). However, by considering an insulated thermal mass coupled with a FCS, the indoor temperature is introduced as a new degree of freedom, in addition to the temperature of the thermal mass.

$$Y_{TM-H} = Y_{FC} + Y_L \tag{1}$$

$$\dot{T}_H = \frac{K_H(T_O - T_H) - Y_{TM\text{-}H}(T_H - T_{TM})}{m_H C_H} \tag{2a}$$

$$\dot{T}_{TM} = \frac{\dot{Q}_{HP} - Y_{TM\text{-}H}(T_{TM} - T_H)}{m_{TM} C_{TM}} \tag{2b}$$

2.2 Forced Convection System Model and Control

Consider a FCS that can operate in two fan speed modes, low and high. The two modes are modeled as different heat transfer coefficients between the thermal mass and the house, $Y_{FC\text{-}low}$ and $Y_{FC\text{-}high}$ respectively. The output of the FCS is controlled by a set of if-then rules based on the ambient indoor temperature, T_H, as shown in Equation (3). The total heat transfer between the thermal mass and the house is computed from Equation 1.

$$Y_{FC} = \begin{cases} 0 & \text{if } T_H > T_{H\text{-}goal} \\ Y_{FC\text{-}low} & \text{if } T_{H\text{-}goal}-1 < T_H \leq T_{H\text{-}goal} \\ Y_{FC\text{-}high} & \text{if } T_H \leq T_{H\text{-}goal}-1 \end{cases} \tag{3}$$

2.3 Heat Pump Model and Control

We consider a multistage heat pump capable of three modes of operation: low, medium and high. The thermal power supplied by each operation mode will be referred to as $\dot{Q}_{HP\text{-}low}$, $\dot{Q}_{HP\text{-}med}$ and $\dot{Q}_{HP\text{-}high}$ respectively.

In order to avoid modeling a short-cycled compressor, we assume that the heat pump may not be switched on and off in less than 5 minutes.

Operation is also affected by the demand response program, which requires the pump to switch off during peak periods, represented by the time-of-use rate $TUR_{on\text{-}peak}$.

Four different control scenarios are considered:

- **Case I**: A traditional one-DoF system where the indoor temperature is directly coupled to the thermal storage temperature, and consequently, to the heat pump output. The heat transfer coefficient between the thermal mass and house is constant, $Y_{TM\text{-}H} = Y_{FC\text{-}low} + Y_L$. This scenario considers a heat pump with only on/off operation. The heat pump output is controlled based on the indoor temperature as shown in Equation (4).

$$\dot{Q}_{HP} = \begin{cases} 0 & \text{if } T_H > T_{H\text{-}goal} \text{ or } TUR_{on\text{-}peak} \\ \dot{Q}_{HP\text{-}high} & \text{if } T_H \leq T_{H\text{-}goal}-1 \end{cases} \tag{4}$$

- **Case II**: A simple two-DoF system where the indoor temperature and the thermal storage temperature are controlled separately. The FCS is responsible for regulating the indoor temperature and the heat pump is responsible for regulating the thermal mass temperature. The heat pump is either on or off, and its output is controlled based on the thermal mass temperature as shown in Equation (5). The FCS operates as shown in Equation (3).

$$\dot{Q}_{HP} = \begin{cases} 0 & \text{if } T_{TM} > T_{TM\text{-}goal} \text{ or } TUR_{on\text{-}peak} \\ \dot{Q}_{HP\text{-}high} & \text{if } T_{TM} \leq T_{TM\text{-}goal} - 2 \end{cases} \quad (5)$$

- **Case III**: This scenario considers the previous two-DoF system but with a multistage heat pump that can operate in three different modes: low, medium or high. The operation mode selection is done through a collection of if-then rules based on the thermal mass temperature as shown in Equation (6). The FCS operates as shown in Equation (3).

$$\dot{Q}_{HP} = \begin{cases} 0 & \text{if } T_{TM} > T_{TM\text{-}goal} \text{ or } TUR_{on\text{-}peak} \\ \dot{Q}_{HP\text{-}low} & \text{if } T_{TM\text{-}goal} - 1 < T_{TM} \leq T_{TM\text{-}goal} \\ \dot{Q}_{HP\text{-}med} & \text{if } T_{TM\text{-}goal} - 3 < T_{TM} \leq T_{TM\text{-}goal} - 1 \\ \dot{Q}_{HP\text{-}high} & \text{if } T_{TM} \leq T_{TM\text{-}goal} - 3 \end{cases} \quad (6)$$

- **Case IV**: This final scenario considers the previous two-DoF system with a multi-stage heat pump. The heat pump output selection, however, is done with the help of a PD controller as shown in Equation (7). The FCS operates as shown in Equation (3).

$$\dot{Q}_{ctrl} = k_P(T_{TM\text{-}goal} - T_{TM}) + k_D \dot{T}_{TM} \quad (7a)$$

$$\dot{Q}_{HP} = \begin{cases} 0 & \text{if } \dot{Q}_{ctrl} \leq \dot{Q}_{HP\text{-}low} \text{ or } TUR_{on\text{-}peak} \\ \dot{Q}_{HP\text{-}low} & \text{if } \dot{Q}_{HP\text{-}low} < \dot{Q}_{ctrl} \leq \dot{Q}_{HP\text{-}med} \\ \dot{Q}_{HP\text{-}med} & \text{if } \dot{Q}_{HP\text{-}med} < \dot{Q}_{ctrl} \leq \dot{Q}_{HP\text{-}high} \\ \dot{Q}_{HP\text{-}high} & \text{if } \dot{Q}_{ctrl} > \dot{Q}_{HP\text{-}high} \end{cases} \quad (7b)$$

2.4 Thermal Comfort

Acceptable upper and lower temperatures for residential buildings, as suggested by Peeters *et al.* (Peeters et al., 2009), are given by Equations (8a) and (8b), respectively, where T_n is the indoor temperature, w is the width of the comfort band in °C, and α is a constant ≤ 1. The study suggests that $w = 5$ and $\alpha = 0.7$ incur in 90% acceptability. T_n is computed as shown in Equation (8c), where T_{O-avrg} is the daily average of the ambient outdoor temperature. The total time (in hours) during which the indoor temperature is ourside the comfort band, t_{Disc}, can be computed as shown in Equation (9), where i indicates each simulation time step and J is the duration of the simulation time step in seconds. Variations in temperature also affect thermal comfort. Regarding cycling temperature, ASHRAE standard 55-2004 (ANSI/ASHRAE 55-2004, 2004) states that, if the peak variation exceeds 1.1 °C, the rate of temperature change shall not exceed 2.2 °C/h.

$$T_{upper} = T_n + w\alpha \quad (8a)$$

$$T_{lower} = T_n - w(1-\alpha) \quad (8b)$$

$$T_n = 20.4 + 0.06\, T_{O\text{-}avrg} \quad (8c)$$

$$Disc(i) = \begin{cases} 0 & \text{if } T_{lower} \leq T_H(i) \leq T_{upper} \\ 1 & \text{if } T_H(i) < T_{lower} \text{ or } T_H(i) > T_{upper} \end{cases} \quad (9a)$$

$$t_{Disc} = \frac{J}{3600} \sum_{i=1}^{24(3600/J)} Disc(i) \text{ (time in hours)} \quad (9b)$$

2.5 Power Usage and Cost Assessment

The electric power, P_{HP}, consumed by the heat pump at every simulation time step, i, is computed using Equation (10), relating heat transfer to electrical power consumption via the heat pump coefficient of performance (COP). The total cost, C_{total}, for operating the system for one day can be computed based on the time of use rates (TUR), as shown in Equation (11). Where J is the duration of the simulation time step in seconds. Electricity consumption by the FCS is not included in the cost analysis.

$$P_{HP}(i) = \frac{\dot{Q}_{HP}(i)}{COP(\dot{Q}_{HP}(i), T_O(i))} \quad (10)$$

$$C_{total} = \sum_{i=1}^{24(3600/J)} P_{HP}(i) TUR(i) T \quad (11)$$

3 SIMULATION SETTINGS

3.1 Model Parameters

We consider a 600 m^3 house (21188.8 cubic feet). The heat capacity of the house, $C_H m_H = 37968\ kJ.K^{-1}$, includes the heat capacity of its structure and volume of air. The heat capacity of the air contained in the house was calculated from its volume, density (1.2041 $kg.m^{-3}$), and specific heat (1.005 $kJ.kg^{-1}.K^{-1}$). The heat capacity of the house

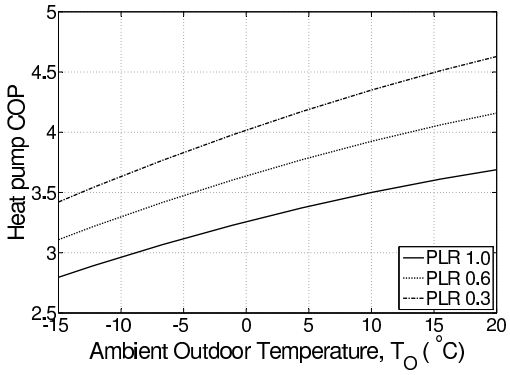


Figure 2: Heat pump coefficient of performance (COP) as a function of ambient outdoor temperature, T_O, and part-load ratio (PLR).

structure was calculated based on the method described in (Olsen and Rode, 2008); considering Gypsum plasterboard walls and ceilings 0.05 m thick, and concrete and tile flooring 0.1 m thick.

We consider a thermal storage unit of 150 gallons (approximately 568 L). The thermal capacitance of the thermal storage unit, $C_{TM}m_{TM} = 2376\ kJ.K^{-1}$, was calculated from its volume, the density of water (1.00 $kg.L^{-1}$), and the specific heat of water (4.185 $kJ.kg^{-1}.K^{-1}$). The thermal conductance of the storage insulation, $Y_L = 0.003\ kW.K^{-1}$, was calculated based on the typical electric water heater properties described in (DOE, 1998) (Table 8); considering a cylindrical storage of 35 inches in diameter.

The heat transfer coefficient related to the insulating properties of the house, $K_H = 0.2530\ kW.K^{-1}$, derives from the surface area and thermal resistivity of the home, and was calculated using the Oak Ridge National Laboratory Online Simple Whole Wall R-value Calculator (www.ornl.gov).

The heat transfer coefficients used for the FCS, $Y_{TM\text{-}H}$, was derive from Equation (2a), considering there is no heat exchange with the outside, i.e. $K_H = 0$; and the thermal mass is at a constant 65 °C. The values for $Y_{FC\text{-}high}$ and $Y_{FC\text{-}low}$ were chosen so as to increase the indoor temperature from 16 to 20 °C in 30 and 60 minutes respectively.

We consider a three-ton multistage heat pump, adopting a COP model from Jeter *et al.* (Jeter et al., 1987) that allows for COP to vary as a function of both ambient outside temperature and compressor speed. COP ranges represent a typical multi-speed heat pump. The three operation modes, $\dot{Q}_{HP\text{-}low}$, $\dot{Q}_{HP\text{-}med}$ and $\dot{Q}_{HP\text{-}high}$, correspond to 0.3, 0.6 and 1 part-load ratios (PLR) respectively. Figure 2 shows the COP curves for each PLR.

The target indoor temperature, $T_{H\text{-}goal}$, was 21 °C. This temperature is the approximate center of comfort range for the chosen weather profiles. The target thermal mass temperature, $T_{TM\text{-}goal}$, was 65 °C, which is high enough to kill harmful bacteria in the water, but not so high as to risk scalding in case of accident.

Model parameter values are summarized in Table 1.

Table 1: Model parameters.

parameter	value	unit
$C_{TM}m_{TM}$	2 376	kJ/K
C_Hm_H	37 968	kJ/K
K_H	0.2530	kW/K
$Y_{FC\text{-}high}$	1.800	kW/K
$Y_{FC\text{-}low}$	0.900	kW/K
Y_L	0.003	kW/K
$\dot{Q}_{HP\text{-}low}$	3.15	kW
$\dot{Q}_{HP\text{-}med}$	6.30	kW
$\dot{Q}_{HP\text{-}high}$	10.5	kW
$T_{H\text{-}goal}$	21	°C
$T_{TM\text{-}goal}$	65	°C
k_P	1	kW/K
k_D	5	kJ/K

Table 2: Time of use rates for winter months.

	time	rate [cents/kWh]
on-peak	06:00 to 10:00 17:00 to 20:00	13.266
mid-peak	10:00 to 17:00 20:00 to 22:00	7.500
off-peak	22:00 to 06:00	4.422

3.2 Simulation Parameters

The TUR reflect the winter rates in use by Portland General Electric, as shown in Table 2, and were applied equally to all three locations. Three weather profiles are considered: the average hourly temperatures for January 1st in Portland, OR; Halmstad, Sweden; and Colorado Springs, CO; as shown in Figure 3.

Temperature control cases I through IV are simulated for each of the three outdoor temperature profiles. The demand response program requires the heat pump to switch off during peak time-of-use rates (TUR). Total power usage and cost were calculated for each scenario. Initial values for T_H and T_{TM} were 21 and 65 °C respectively. The chosen simulation time step J is 60 seconds, and the total simulation time is 24 hours. Simulations are performed using Acumen (www.acumen-language.org) (Taha et al., 2011), a modeling language where models are defined through differential equations and simulations are generated automatically.

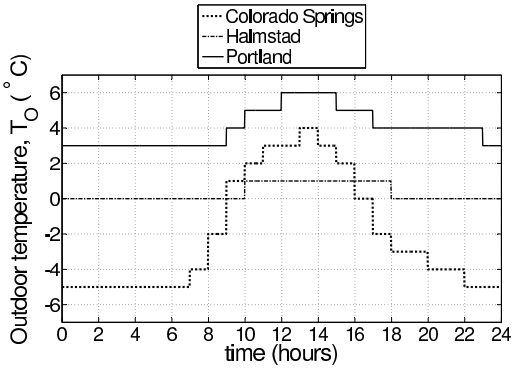


Figure 3: Weather profiles for Portland, Colorado Springs and Halmstad. Average hourly outdoor temperature for the month of January in each of the locations.

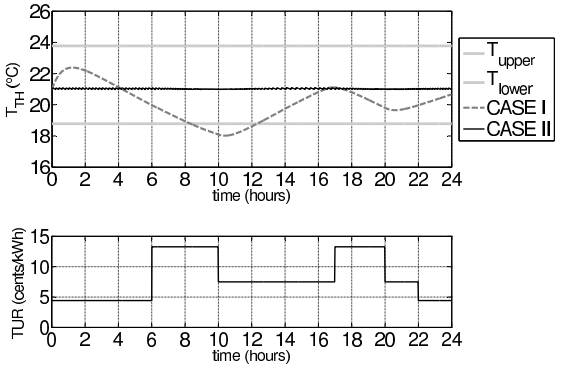


Figure 4: Indoor temperature, T_H, and time-of-use rates (TUR) for cases I and II, Colorado Springs weather profile.

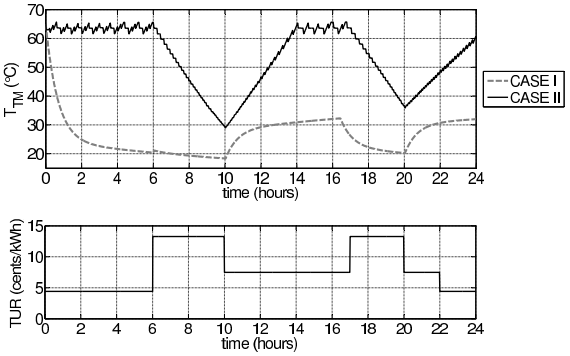


Figure 5: Thermal mass temperature, T_{TM}, and time-of-use rates (TUR) for cases I and II, Colorado Springs weather profile.

4 RESULTS

Control cases I and II represent a typical one-DoF system and the proposed two-DoF system respectively, both under similar on/off control strategies. The simulation results for indoor and thermal mass temperature, contrasting these two cases under the Colorado Springs weather profile, are shown in Figures 4 and 5 respectively. Very similar results were obtained for simulations under Halmstad and Portland weather profiles.

Table 3: Thermal comfort.

	Case I	Case II	Case III	Case IV
Colorado Springs				
t_{Disc} [hours]	4.02	0	0	0
mean T_H [°C]	20.11	21.02	21.02	21.01
cyclic ΔT_H [°C]	4.37	0.12	0.12	0.10
cyclic $\dot{T}_H$ [°C/h]	0.58	-	-	-
Halmstad				
t_{Disc} [hours]	1.45	0	0	0
mean T_H [°C]	20.44	21.03	21.02	21.02
cyclic ΔT_H [°C]	3.79	0.12	0.12	0.10
cyclic $\dot{T}_H$ [°C/h]	0.50	-	-	-
Portland				
t_{Disc} [hours]	0	0	0	0
mean T_H [°C]	20.66	21.04	21.03	21.03
cyclic ΔT_H [°C]	3.29	0.12	0.12	0.10
cyclic $\dot{T}_H$ [°C/h]	0.60	-	-	-

Results show that the response of the one-DoF system (Case I) varies greatly and slowly. The indoor temperature starts considerably high because the initial thermal mass temperature is 65°C. The thermal mass temperature must decrease considerably in order to maintain the indoor temperature within the comfortable range. Another drawback of the one-DoF system is that during peak-hours, when the heat pump is off, the temperature of the house falls considerably below the limits of thermal comfort Figure 4. The additional DoF introduced by the FCS (Case II) allows the thermal mass temperature to vary considerably from 65 down to approximately 30 °C, Figure 5, while the indoor temperature strays very little from the goal temperature of 21 °C, Figure 4.

A summary of the indoor temperature results for each of the simulated scenarios is shown in Table 3. Note that the traditional one-DoF system simulated in Case I results in indoor temperatures outside the comfortable limits for both Colorado Springs and Halmstad weather profiles. The two-DoF system simulated in Cases II through IV, on the other hand, maintain the indoor temperature very close to 21°C with less than 0.2 °C of peak-to-peak cyclic variations.

Figure 6 shows the heat pump output, Q_{HP}, and thermal mass temperature, T_{TM}, for cases II through IV for the Colorado Springs weather profile. In all cases, the thermal mass temperature profile is very similar. Case II shows slightly larger cyclic oscillations due to the on/off duty cycles. The same patterns were observed for simulations under Halmstad and Portland weather profiles.

A summary of the thermal mass temperature be-

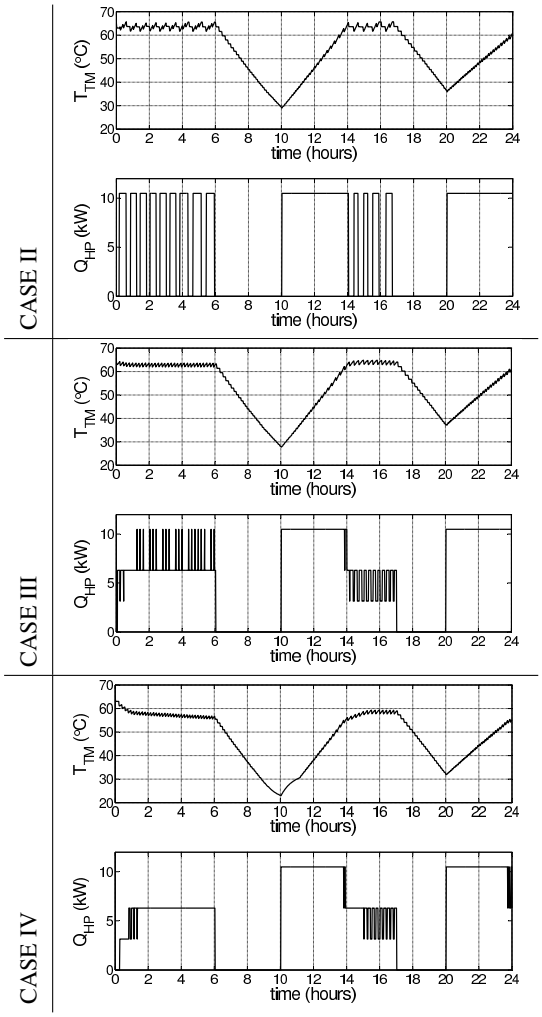


Figure 6: Thermal mass temperature, T_{TM}, and heat pump output, Q_{HP}, for cases II though IV, Colorado Springs weather profile.

Table 4: Thermal storage.

	Case I	Case II	Case III	Case IV
Colorado Springs				
max T_{TM} [°C]	65.00	65.69	65.00	65.00
min T_{TM} [°C]	18.37	28.99	27.76	22.95
mean T_{TM} [°C]	26.15	53.32	53.07	47.48
Halmstad				
max T_{TM} [°C]	65.00	65.78	65.00	65.00
min T_{TM} [°C]	19.13	31.08	32.14	26.90
mean T_{TM} [°C]	26.02	55.36	55.53	50.19
Portland				
max T_{TM} [°C]	65.00	65.78	65.14	65.00
min T_{TM} [°C]	19.65	36.93	37.70	31.98
mean T_{TM} [°C]	25.34	57.91	58.35	53.04

havior for all control cases is shown in Table 4. Note that the mean temperatures for Case I are considerably below the intended temperature of 65 °C.

Table 5: Power consumption and cost.

	Case I	Case II	Case III	Case IV
Colorado Springs				
Power [kWh]	33.447	41.940	42.806	40.935
Cost [USD]	2.31	2.56	2.63	2.56
Halmstad				
Power [kWh]	30.312	37.726	42.806	35.858
Cost [USD]	2.07	2.40	2.63	2.31
Portland				
Power [kWh]	23.543	29.505	30.364	28.502
Cost [USD]	1.57	1.90	1.94	1.85

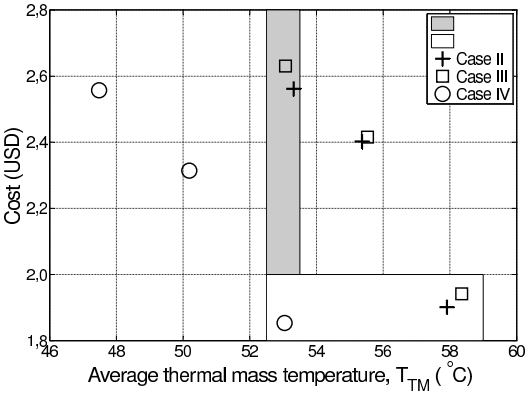


Figure 7: Average thermal mass temperature versus cost for control cases II, III, and IV. The gray box highlights that cases I and II incur a cost of approximately 2,6 USD to maintain a mean temperature of about 53 °C, whereas case IV maintains the same mean temperature for only 1,85 USD. The clear box highlights that control cases II and III are able to achieve an average temperature approximately 5 °C higher than case IV for an increased cost of less than 0,10 USD.

The power usages and costs for each simulated scenarios are shown in Table 5. Case I consumes considerably less energy than the other cases, however, it does not fulfill the thermal comfort requirements. Figure 7 shows a plot of mean thermal mass temperature against cost for control cases II through IV under all three weather profiles. The gray box in Figure 7 highlights that cases I and II incur a cost of approximately 2,6 USD to maintain a mean temperature of about 53 °C, whereas case IV maintains the same mean temperature for only 1,85 USD. Note also that control cases II and III are able to achieve an average temperature approximately 5 °C higher than case IV for an increased cost of less than 0,10 USD, highlighted by the clear box in Figure 7.

5 DISCUSSION

The proposed two-degree-of-freedom system provides more flexibility for DR programs. By decoupling the heat pump output from the indoor temperature, the thermal storage can be used to store more energy, as evidenced by the higher thermal mass temperatures for Cases II through IV. The direct coupling of the heat pump output and the indoor temperature in Case I suggests that there is need for more advanced predictive control strategies, specifically ones that can pre-heat the structure in anticipation of peak time-of-use rates or extreme weather. Such predictive control, however, would not be able to cope with accidental power loss or other unforeseeable issues. Having a thermal storage, able to operate at higher temperatures, makes the system more robust and more flexible.

Simulation results show that a heat pump operates at maximum output when switching on immediately after peak pricing hours end. This occurs because the heat pump must compensate for the large thermal energy loss incurred during peak pricing hours. This reconnection effect may increase power consumption overall, and shift the peak periods instead of lessening them. The effects of reconnecting appliances after a forced disconnection has been studied, e.g. (Ericson, 2009), and control strategies have been designed to minimize this reconnection effect for water heaters, e.g. (Nehrir et al., 1999). In the case of space heating, the reconnection spike may be reduced by making the controller aware of current and predicted weather, or pre-heating in anticipation of peak TUR. Reconnection costs and mitigating strategies will be investigated in future works.

It is important to note that the control strategies proposed here were not optimized in any way. Lower goal temperatures for the thermal mass, for example, are likely to result in lower power consumption. However, we implemented very simple and intuitive controllers for the purpose of comparing different control strategies that resulted in similar thermal mass and house temperature profiles. There are many research opportunities for optimization schemes that take into account real-time pricing, weather predictions, and other factors.

This paper investigates the behavior of single isolated systems, where the only outside inputs were weather and time-of-use rates. This facilitated an understanding of system properties. The next step is to understand the impact of thousands of such systems being used for DR. Monte Carlo methods can be used to simulate a large number of these systems with slightly different parameters so as to model the slight differences between real houses. However, in order to develop a practical system model, parameters must be validated against practical experiments. Future works will focus on more realistic and large scale simulations.

Customer willingness to participate in DR programs increases as the benefits they derive exceed the cost of the inconvenience (Fahrioğlu and Alvarado, 2000). Minimizing or eliminating discomforts should lead to increased participation in such programs. Despite the simplifications made in this study, our results show that an insulted thermal storage unit coupled to a heat pump and forced convection system for space heating may be used in price-based demand response programs without either compromising the thermal comfort of the residents nor requiring they modify their behavior by deferring consumption to a later time period. This proposed system, therefore, could be a means by which to increase participation levels within utility DR programs.

6 CONCLUSION

Demand response programs are effective and relatively inexpensive ways to cope with peak demands; balance demand and generation; and stabilize electricity prices. Water heaters and HVAC systems are commonly used for DR. This paper introduces a space heating system composed of an insulated thermal mass and forced convection system with two degrees of control freedom that can be used for DR. The thermodynamic model was presented as well as four different temperature control strategies. Simulations were used to evaluate the performance of the system based on thermal comfort and power consumption in three different weather regions. Results show that the FCS introduces an important degree of freedom that improves indoor temperature control while at the same time allowing the temperature of the thermal mass to vary more freely. The power consumption of the system can vary greatly according to the control strategy and the insulating properties of the house. Future research avenues include investigating optimized control strategies that account for real-time pricing, weather forecasts, occupancy patterns, among others; and, investigating the aggregate demand response of large numbers of homes equipped with heat pumps, forced convection and controllable thermal masses.

ACKNOWLEDGEMENTS

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Increasing Self-consumption of Photovoltaic Electricity by Storing Energy in Electric Vehicle using Smart Grid Technology in the Residential Sector

A Model for Simulating Different Smart Grid Programs

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Keywords: Smart Grid, Photovoltaic Electricity, Self-consumption, Electric Vehicle, Energy Storage.

Abstract: In this paper a model has been developed which intends to simulate the increase of self-consumption of photovoltaic (PV)-power by storing energy in electric vehicle (EV) using smart grid technology in the residential sector. Three different possible smart grid control algorithms for a micro-grid consisting of solar panels, a household and an EV are presented that manage the (dis-)charging profile of an EV, either in real-time or using linear optimization using predictions for PV-power and electricity demand. The different control algorithms are simulated for a year using data for PV-power and electricity demand from the Netherlands and one specific EV. Preliminary results of the model are presented, showing that all control algorithms could significantly increase self-consumption and reduce peaks in electricity demand from the main grid. Although the difference in performance of the control algorithms for self-consumption is marginal, we find that linear optimization works better than the real-time algorithms for peak reduction.

1 INTRODUCTION

The worldwide increase of electricity demand poses major challenges in the energy sector. Since 1971, the final consumption of electricity has increased four-fold to 60 PJ in 2010 (IEA, 2012) and is expected to further increase due to growing global population and welfare. Issues related to this development include availability, cost and environmental issues such as global warming and depletion of resources. While the industrial sector has the highest demand for electricity, demand in the residential sector shows the highest increase in Europe (Bertoldi and Atanusiu, 2008) and is therefore an important sector for changes in electricity provision and distribution.

Another important sector contributing to global warming is the transport sector. Globally the contributions of the transport sector to greenhouse gas (GHG)-emissions amounted to nearly 20% in 2009 (Hoen et al., 2009). According to the European Federation for Transport and Environment (2011) CO_2 emissions from the European transport sector have increased by 29% since 1990.

Electric vehicles (EVs) are a promising technology for reducing the environmental burden of road transport (Essen, et al. 2011). If EV sales increase it can be beneficial for reducing GHG-emissions, but it also creates another issue; electricity demand will increase even further. Also, the typical charging pattern of EVs without a control system coincides roughly with that of households (E-laad, 2012), which is high in the morning and the evening and low in the afternoon; it thus contributes to existing peaks in electricity demand in the residential sector.

PV technology can be part of the solution to problems relating with electricity and transport, since there are no emissions of greenhouse gasses during electricity production. If PV electricity is used to power EV's, transport with EV will cause even less or zero GHG emissions. An important advantage of PV for the residential sector is its scalability; even single households can use this technology.

However, the mismatched production and load curve for PV for domestic use poses a challenge. PV installations produce most electricity around noon, when solar insulation is high, while electricity demand is usually low then. In addition, solar power supply may be variable due to variations in cloud coverage.

Strategies to deal with these issues are for instance demand response (DR) and electricity storage (Castillo-Cagigal et al., 2011): in their paper DR is defined as shifting load demand in order to optimize electricity demand. Optimization goals are for instance peak-shifting (flattening load demand curve) or increasing self consumption (consumption of locally produced electricity behind the meter) .

Smart grid technology combines the traditional electricity grid or microgrid (a local, low-voltage distritibution system) with information and communication technologies in order to add 'intelligence' to the grid (Verbong et al., 2012). DR is an essential aspect of smart grids, and is achieved by turning appliances on and off within a certain timeframe.

The main power grid can be used as virtual storage for electricity. When supply is higher than demand, electricity can be fed back and sold to the grid and vice versa. This is an interesting option, because in that case an expensive battery is not needed. However, with increasing numbers of PV-installations this strategy can become problematic, because of the increased power transport over the electricity grid. This will cause the need for more investments in the grid in order to prevent overloads. In response to this threat, several countries in Europe have started implementing policies to stimulate self-consumption (Castillo-Cagigal et al., 2011).

PV electricity could also be stored in EV batteries. This way EVs can help increase self-consumption. Furthermore, by using PV electricity to power EVs GHG emissions for personal transportation are reduced.

In this paper the potential of combining smart grid technology with electricity storage in EVs for increasing self-consumption in the residential sector is investigated. This is done by creating a model of a microgrid containing a household, solar panels and an EV and simulating the effect on self-consumption of PV-power of the system using smart grid technology. The baseline for the potential is the absence of a smart grid and is called "Uncontrolled Charging". The strategies investigated are "Real-time Controlled Charging", "Real-time Controlled Charging and Discharging", and "Linear Programming".

In section 2 the methodology is presented: it includes the structure of the microgrid (2.1), the proposed smart grid systems (2.2) and evaluation method (2.3). In section 3 the first simulation results are presented, analyzed and compared. Section 4 concludes the paper.

2 METHODOLOGY

The potential of increasing self-consumption by storing PV energy in EVs is investigated by performing computer simulations and evaluating the results on performance indicators for self-consumption and peak-reduction.

The basic input for the model is the total electricity demand of households per time-step, the supplied PV power per time-step and the technical specifications and planned use (average trip duration, distance and number of trips per week) of the EVs. Based on these inputs the electricity distribution for each time-step *t* is decided.

2.1 Micro-grid Model

The micro-grid contains a PV-installation, a household with electricity demand, an EV and a connection to the main grid; all elements are connected. The PV-power and household electricity demand are considered uncontrollable, Demand Side Management is not taken into account here, while the EV loading pattern is partly controllable and partly uncontrollable (when energy is needed for trips).

2.1.1 PV and Electricity Demand

The PV-installation provides electricity to the microgrid. Data for PV-power profiles per time-step is provided by Robin Berg from the company LomboXnet. The dataset relates to a PV-installation of 10 kWp in Utrecht, the Netherlands and is available at hourly time resolution from July 6th 2011 to December 31st 2012. For this paper it is assumed that the simulated household has 8 panels of 250 Wp available, which leads to an estimated annual yield of 1700 kWh assuming an annual yield of 850 kWh/kWp, typical for the Netherlands.

The household has a certain electricity demand profile that must be met at all times. Data for household electricity demand is provided by Felix Claessen and is based on measurements by Liander (Claessen, 2012). The dataset relates to 400 households in the Netherlands and is available per 15 minutes for a week in February 2008. The weekly data is repeated for a year multiplied by a factor per week based on measurements from Liander in 2007. In this research only the households are selected that use 3500 ± 20% kWh per year.

2.1.2 Electric Vehicle

The battery of the EV is used as storage for excess PV-power and energy can be extracted from it when there is shortage of PV-power. The EV is also used to make trips; energy needed to make trips is considered inelastic demand and must be met at all times. When an EV is on a trip it is not available to exchange energy with the micro-grid. It is assumed that on average three trips per week are made with the EV, lasting between 4 and 8 hours, taking place between 8:00 and 22:00 and using between 20% and 80% of the battery capacity.

Without a smart grid program, the EV, if connected, will always charge until its full. This strategie is called "Uncontrolled Charging" and is represented by equation (1).

$$\begin{aligned} &\text{If } E_{EV}(t-1) < C_{EV} \wedge t \in t_l \\ &\rightarrow P_{EV,in}(t) = P_{EV,in,max} \end{aligned} \tag{1}$$

With $E_{EV}(t)$ the energy contained in EV-battery, C_{EV} the battery capacity, t_l the time-steps for which the EV is at the loading station, $P_{EV,in}(t)$ the EV charging power and $P_{EV,in,max}(t)$ the maximum EV charging power.

One EV is simulated, with technical specifications based on Tesla Model S (Tesla, 2013). The technical specifications are presented in table 1.

With $E_{EV,min}$ the minimum energy in EV-battery, $P_{EV,out,max}(t)$ the maximum EV discharging power and $\eta_{EV,in}$ and $\eta_{EV,out}$ *the* (dis-)charging efficiency.

Table 1: Technical specifications of simulated EV.

C_{EV} (kWh)	85
$E_{EV,min}$	20% C_{EV}
Energy consumption (kWh/km)	0.2
Typical range (km)	340
$P_{EV,in,max}$ and $P_{EV,out,max}$ (kW)	22
$\eta_{EV,in}$ and $\eta_{EV,out}$	80%

2.2 Smart Grid Programs

In this section several control algorithms for electricity distribution within the micro-grid are proposed. All control algorithms require trips to be planned in advance. The minimum amount of energy in the battery is 20% allowing for short emergency trips.

2.2.1 Real-time Controlled Charging

"Real-time controlled charging" uses the difference between P_{PV} and P_{load} for every time-step t. Based on the energy content of the EV the loading pattern is decided. In this algorithm, it is not possible to extract energy from the EV in order to cover electricity demand of the households.

First $E_{EV,req}$, the minimum amount of energy in the EV taking into account energy needed for trips and maximum charging power, is defined in equation (2).

$$\begin{aligned} &\text{If } t \in \left(t - \frac{E_{EV,trip}}{P_{EV,in,max}}, t_{trip}\right) \rightarrow E_{EV,req} = \\ &E_{EV,trip} - P_{EV,in,max} \cdot (t_{trip} - t) + E_{EV,min} \\ &\text{If } t \notin \left(t - \frac{E_{EV,trip}}{P_{EV,in,max}}, t_{trip}\right) \rightarrow E_{EV,req} = E_{EV,min} \end{aligned} \tag{2}$$

With $E_{EV,trip}$ the total energy used for the trip and t_{trip} the start-time of the trip.

The loading pattern is then defined by equations (3), (4), (5) and (6).

$$P_{EV,in}(t) = P_{EV,in,PV}(t) + P_{EV,in,grid}(t) \tag{3}$$

$$\begin{aligned} &\text{If } P_{load}(t) < P_{PV}(t) \wedge E_{EV}(t-1) < C_{EV} \wedge t \in t_l \\ &\rightarrow P_{EV,in,PV}(t) = \eta_{EV,in}(P_{PV}(t) - P_{load}(t)) \end{aligned} \tag{4}$$

$$\begin{aligned} &\text{If } E_{EV}(t-1) + P_{EV,in,PV}(t) < E_{EV,req}(t) \wedge t \in t_l \\ &\rightarrow P_{EV,grid}(t) = E_{EV,req}(t) - E_{EV}(t-1) - P_{EV,in,PV}(t) \end{aligned} \tag{5}$$

$$P_{EV,in}(t) \leq P_{EV,in,max} \tag{6}$$

With $P_{EV,in,PV}(t)$ the PV-power used for charging the EV, $P_{EV,in,grid}(t)$ the power from the main grid used for charging the EV, $P_{PV}(t)$ the available PV-power and $P_{load}(t)$ the total load demand of the household.

Equation (3) denotes that the EV is charged with power from the PV-installations and from the grid. If there is more PV-power than electricity demand, the EV starts to charge until it is full or until there is no more excess PV-power, see equation (4). The EV only extracts energy from the grid when there is shortage of PV-power in order to make a trip, see equation (5). Finally, equation (6) makes sure the total power into the EV cannot exceed the maximum charging power.

2.2.2 Real-time Controlled Charging and Discharging

This program uses the same equations as "real-time controlled charging", but is also able to extract energy from the EV in order to cover electricity demand of households. The additional equations are presented in (7) and (8).

$$\text{If } P_{load}(t) > P_{PV}(t) \wedge E_{EV}(t-1) > E_{EV,req}(t) \wedge t \in t_l \rightarrow P_{EV,out}(t) = \eta_{EV,out}^{-1}\left(P_{load}(t) - P_{PV}(t)\right) \quad (7)$$

$$P_{EV,out}(t) \le P_{EV,out,max} \quad (8)$$

2.2.3 Linear Programming

Increasing self-consumption of PV-power by controlling the loading pattern of an EV can be described as a linear optimization problem and solved by using linear programming. Linear programming is a method to solve constrained optimization problems. Constrained optimization is a technique used often in research on smart grids. Recent examples are Guo et al. (2012), Silva et al. (2012), Tanaka et al. (2011), González Vayá and Andersson (2012).

The variables used in the linear program are $P_{EV,in,PV}(t)$, $P_{EV,grid}(t)$, $P_{EV,out}(t)$, for every time-step *t*. In order to maximize self-consumption, the PV-power used to charge the EV is maximized. This results in the following problem:

$$\max \sum_t P_{EV,in,PV}(t) \quad (9)$$

subject to the following constraints:

$$P_{EV,in,PV}(t) + P_{EV,in,grid}(t) \le P_{EV,in,max}, \quad t \in t_l \quad (10)$$

$$P_{EV,out}(t) \le P_{EV,out,max}, \quad t \in t_l \quad (11)$$

$$\sum_{t'=1}^{t} \eta_{EV,in}\left(P_{EV,in,PV}(t') + P_{EV,in,grid}(t')\right) - \sum_{t'=1}^{t} \eta_{EV,out}^{-1} P_{EV,out}(t') \ge E_{EV,req}(t) + E_{EV,trip}(t) - E_{EV}(0), \quad t \in t_l \quad (12)$$

$$\sum_{t'=1}^{t} \eta_{EV,in}\left(P_{EV,in,PV}(t') + P_{EV,in,grid}(t')\right) - \sum_{t'=1}^{t} \eta_{EV,out}^{-1} P_{EV,out}(t') \le C_{EV}(t) + E_{EV,trip}(t) - E_{EV}(0), \quad t \in t_l \quad (13)$$

$$P_{EV,in,PV}(t) \le P_{PV}(t) - P_{load}(t), \quad t \in t_l \quad (14)$$

$$P_{EV_i,out} \le P_{load}(t) - P_{PV}(t), \quad t \in t_l \quad (15)$$

With dummy variable t'. Constraints (10) and (11) ensure that the maximum (dis-)charging power is not exceeded. Constraints (12) and (13) ensure that the energy in the EV is sufficient for trips and does not exceed the battery capacity. Constraints (14) and (15) ensure that not more energy is (dis-)charged then there is excess or shortage of PV-power (when there is not enough PV-power for trips energy is extracted from the grid). Furthermore, all variables are non-negative.

Contrary to the real-time programs linear programming is based on perfect information; all the constraints are known for all time-steps *t*. However, PV-supply and electricity demand are not known exactly in advance. In order to provide realistic prediction of how effective this program would be in reality, some assumptions have been made. In this paper, the method is called "realistic linear programming".

It is assumed that the calculations are made at midnight and are based on the load pattern from the previous day. An exception is made for weekends, since weekend load demand differs significantly from weekdays. However, the data is only available for a week. Because of this predictions for Saturdays will be based on data for Sundays and vice-versa. The input for PV is based on PV-power predictions. It is assumed that prediction deviates from the real value with a standard deviation σ of 10%. This results in the following equations:

$$P_{load,prediction}(t) = P_{load,real}(t - 24\text{h}) \quad (16)$$

$$P_{PV,prediction}(t) = P_{PV,real}(t) \pm 10\% \quad (17)$$

The linear program is then executed with the predicted values, while it is evaluated with the real values.

2.3 Evaluation

All programs are simulated for each month of the year. Based on the simulations the potential of increasing self-consumption (SC) is calculated. Self-consumption is defined as the relative amount of PV-power for period T, with starting point T0, used by either the households or the EV, see equation (18).

$$\text{SC}(T) = \sum_{t=T0}^{T} \frac{\min\left[P_{PV}(t), P_{load}(t) + P_{EV}(t)\right]}{P_{PV}(t)} \quad (18)$$

A second indicator, relative peak reduction (RPR) is also used for evaluation. RPR compares the deviation from the average of the load demand for the main grid $P_{grid,tot}(t)$, defined in equation (19), with a control algorithm, denoted as $P_{grid,tot,control}(t)$, to "uncontrolled charging", denoted as $P_{grid,tot,no\ control}(t)$, and is defined in equation (20):

$$P_{grid,tot}(t) = P_{load}(t) + P_{EV}(t) - P_{PV}(t) \quad (19)$$

$$\mathrm{RPR}(T) = \frac{\sum_{t=T0}^{T} \left| P_{grid,tot,control}(t) - \overline{P_{grid,tot,control}(t)} \right|}{\sum_{t=T0}^{T} \left| P_{grid,tot,no\,control}(t) - \overline{P_{grid,tot,no\,control}(t)} \right|} \quad (20)$$

So for example, an RPR-score of 1 indicates no relative peak reduction compared to "uncontrolled charging", a RPR-score of 0 means load demand is totally flat for that day and a RPR-score above 1 would mean that there are higher peaks compared to "uncontrolled charging".

3 RESULTS

In this section, the first results from simulations are shown. The results are based on 20 simulations per month for each smart grid program. In figure 1, examples of individual runs for each program are given. They are based on the same load and PV profile and EV-trip.

In the case of "uncontrolled charging", the EV arrives home in the evening and starts charging when there is no PV-power available. In the cases of "Controlled charging" and "Controlled charging and discharging" the EV only loads in times of excess PV-power, but there is still a large peak in the charging profile, since the EV needs to load much

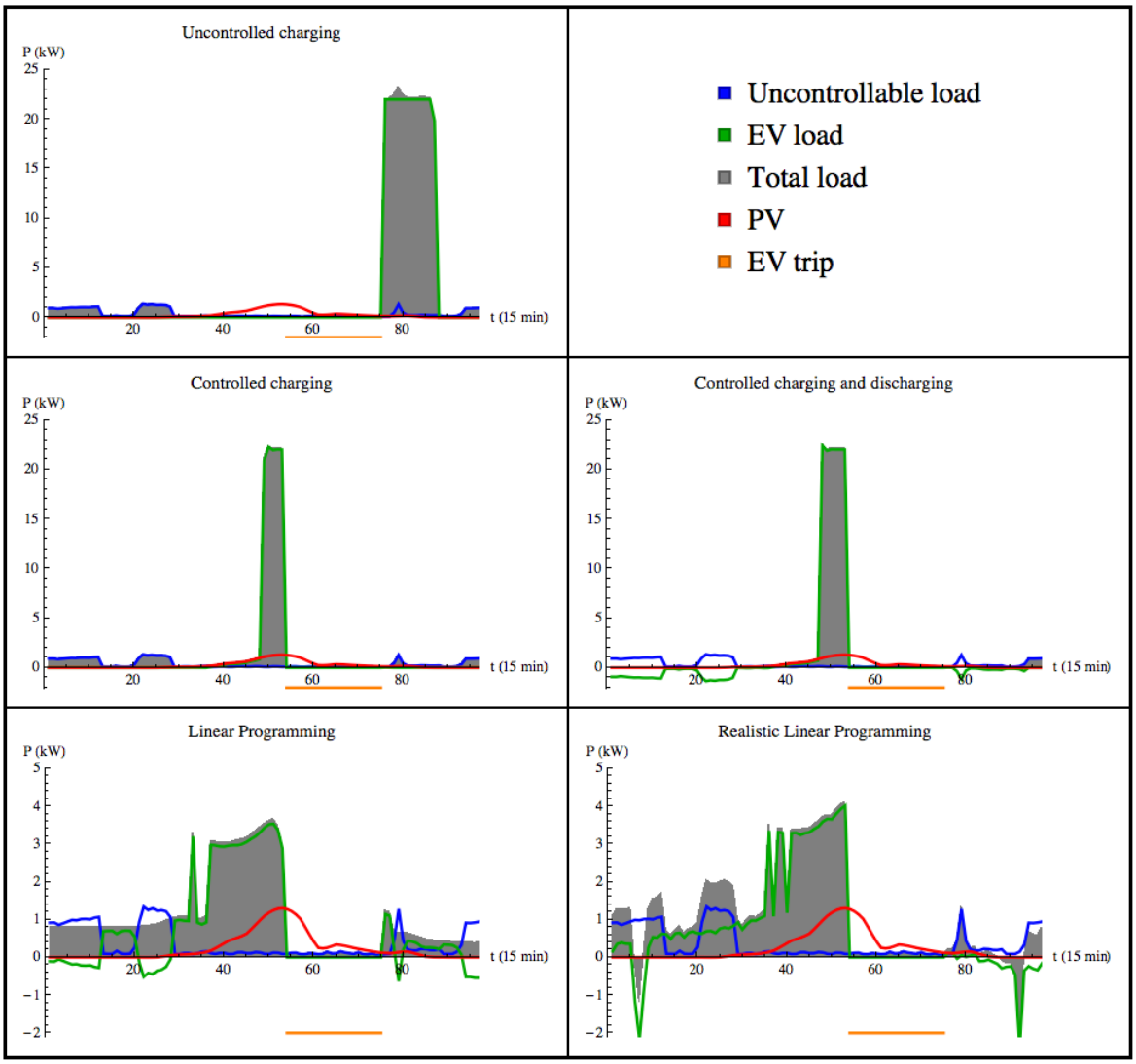


Figure 1: Results of an individual full day run for each control algorithm. The orange bar shows the period during which the EV is being used for a trip.

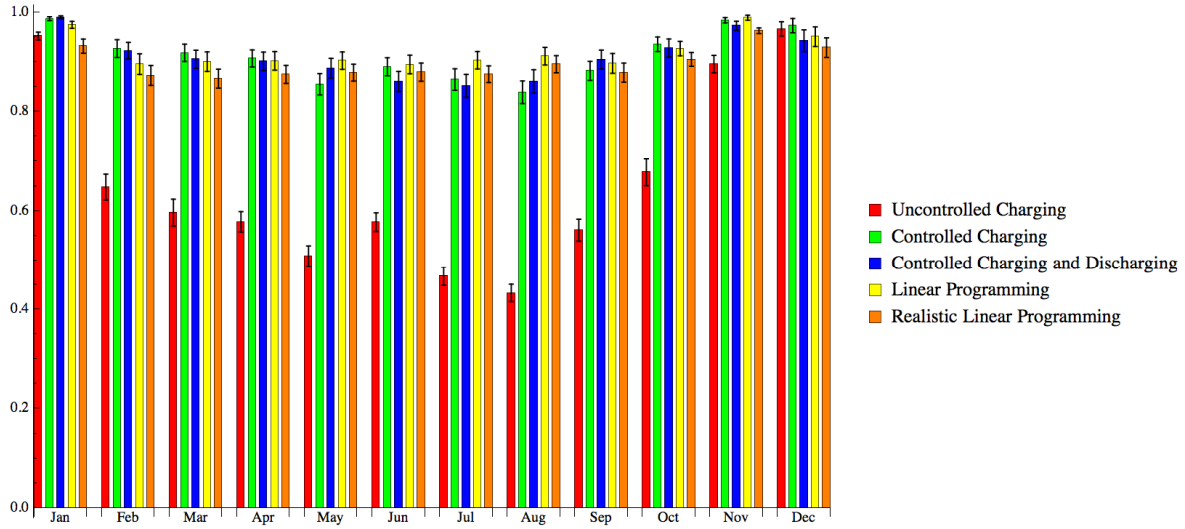


Figure 2: Mean self-consumption and standard deviation of 100 simulations of each control algorithm for each month.

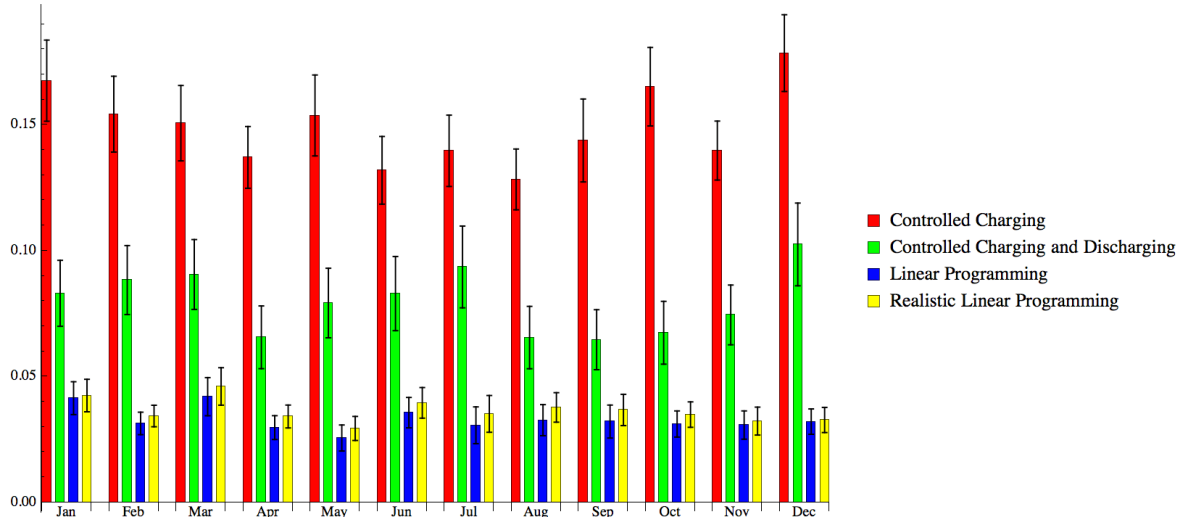


Figure 3: Mean peak reduction and standard deviation of 100 simulations of each control algorithm for each month.

more than there is PV-power available. Note that the latter total load is very small outside the peak.

For both programs using linear optimization the peaks in energy use are much smaller than for the other programs, since the EV never charges at full power, but at 20-25%. Because the requirements for the trip are still exactly planned in the realistic case, there are no problems for EV-use. However, it does not perform as well as the idealistic case, since electricity is fed back to the grid when it could by used to cover load demand.

In figure 2, results from 100 24 hour simulations per month for each program evaluated for self-consumption are shown. It can be seen that even though all systems perform much better than a system without a smart grid, it is difficult to tell which system performs best for self-consumption. The differences between the programs are large when compared for peak reduction (figure 3), showing that "linear programming" flattens the load demand for the main grid significantly better than the real-time algorithms.

4 CONCLUSIONS

In this paper several control algorithms for increasing self-consumption of PV-power in the residential sector, using smart grid technology and electricity storage in an EV, were proposed. The first simulations show that all proposed systems could

significantly increase self-consumption. Though the systems have distinctive characteristics for the resulting EV charging profile, it is unclear which system performs best based on the proposed indicator for self-consumption. In order to investigate this issue, more simulations must be carried out.

However, when evaluated on peak reduction, the differences are much more clear. "Linear programming" is superior to the real-time algorithms for peak reduction.

As a follow-up of this paper, an extensive sensitivity analysis will be performed for the following parameters: (a) amount of solar panels (kWp), (b) average yearly household electricity use, (c) technical specifications of the EV, (d) EV trips, and (e) the standard deviation in PV-power predictions. Nevertheless, based on our preliminary results, it is shown that a microgrid using smart grid technology and electricity storage in an EV could significantly increase self-consumption of PV-power in the residential sector.

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Demand Management for Home Energy Networks using Cost-optimal Appliance Scheduling

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Abstract: This paper uses problem decomposition to show that optimal dynamic home energy prices can be used to reduce the cost of supplying energy, while at the same time reducing the cost of energy for the home users. The paper makes no specific recommendations on the nature of energy pricing, but shows that energy prices can normally be found that not only result in optimal energy consumption schedules for the energy provider's problem and are economically viable for the energy provider, but also reduce total users energy costs. Following this, the paper presents a heuristic real-time algorithm for demand management using home appliance scheduling. The presented algorithm ensures users' privacy by requiring users to only communicate their aggregate energy consumption schedules to the energy provider at each iteration of the algorithm. The performance of the algorithm is evaluated using a comprehensive probabilistic user demand model which is based on real user data from energy provider E.ON. The simulation results show potential reduction of up to 17% of the mean peak-to-average power estimate, reducing the user daily energy cost for up to 14%.

1 INTRODUCTION

The emergence of *smart* homes enables energy providers to develop sophisticated energy management solutions, in attempt to optimise energy production while providing home users with increased comfort and potential cost reduction. The future smart homes will be equipped with a range of control devices and sensing/actuating systems capable of working together in automatic way to perform some pre-defined functions. Over the past decade, the majority of technical challenges for the home hardware and software solutions have been solved, and a range of commercial products is available. For energy providers, the greatest remaining challenges lie in: (1) development of intelligent resource management algorithms to optimise the energy consumption, both at the single-household level and at the large-scale level; (2) establishing increased level of trust with the user by ensuring that the users' energy consumption data is kept secret. This paper addresses both of these issues by providing an optimal distributed algorithm for home appliance scheduling without the need for sharing detailed information on daily use of home appliances.

The process of resource optimisation in home energy networks has been generating research interest for several decades now, and in the recent years it has been accelerated by the technological advances in sensor networks, smart meters and actuator systems. In an ideal smart home model, the historical consumption data, real-time measurements, pricing, ambient and social aspects are all used as inputs to optimisation algorithms which calculate the optimal home appliance energy consumption schedule. Traditionally, the problem of optimal use of home energy has been approached in two ways: (1) reducing consumption, or (2) shifting consumption. The process of consumption shifting, also called demand management, or load management, has been practices by the industry for several decades, using different forms of load control (Fahrioglu, 2000, Palensky 2011, Siano 2014). The existing solutions use variable pricing to generate incentives to home users to shift their consumption from peak periods, thus reducing the need to start additional generators, which presents a

major cost factor for energy providers.

There is a number of research works that take on this challenge, and develop algorithms and network protocols for optimal demand management. For example, Li, Chen and Low (Li, 2011) show that there exist time-varying prices that can align individual optimality with social optimality. In their model, the utility company collects forecasts of total demands from all customers, and then sets the prices to the marginal cost. Each customer updates its demand and charging schedule. Similarly, Pedrasa, Spooner and MacGill (Pedrasa, 2010) present a solution which enables end-users to assign values to desired energy services, and then schedule the resources to maximise the users' benefits. They propose the use of particle swarm optimisation, because of simple implementation. They do not, however, test their solution on large-scale systems and do not prove the optimality of the solution. Zakariazadeh, Jadid and Siano (Zakariazadeh, 2014) propose a multi-objective framework, based on augmented ε-constraint method, to minimize the total operational costs and emissions and to generate Pareto-optimal solutions for the energy and reserve scheduling problem. In the work of Ramchurn et al (Ramchurn, 2011, Vytelingum, 2010) decentralised demand side management is realised through the process of cooperation between the smart meters ('agents'). The meters receive the costs of generating electricity to the consumers, and use learning mechanisms to gradually adapt the agents' deferrable energy load based on the predicted market prices for the next day. Similar approach is also taken by (Mohsenian-Rad, 2010), (Ganu, 2012), and (Ibars, 2010) . In these solutions the end-users are somehow made to voluntarily adjust their consumption. (Mohsenian-Rad, 2010) formulates an energy consumption scheduling game, where the players are the users and their strategies are the daily schedules of their household appliances and loads. Similarly, (Ibars, 2010) bases the solution on a network congestion game, which can be demonstrated to converge in a finite number of steps to a pure Nash equilibrium solution. (Jain, 2013) goes one step further, by applying the concept of bargaining / auctioning of energy resources on the smart grid including electric vehicles.

It is important to stress that most of these works, including ours, rely on consumer's willingness to act. In other words, the end-user benefit is always modelled through cost, and optimality of the scheduling is based on the process of cost minimisation. The mechanism of costing allows the users to react, in their own interest. Dynamic pricing and its drawbacks are analysed in great detail in the past research, e.g. in (Borenstein, 2002) and (Roozbehani, 2010). In a response to this, (Wijaya, 2013) proposes an interesting approach to cut the peak to average energy ratio explicitly from the supply side. The resulting load cuts are then distributed among consumers by the means of a multiunit auction which is done by an intelligent agent on behalf of the consumer.

In this paper, we decompose the provider and the user optimization problem to prove that, if energy prices are set as optimal consistency prices, the energy provider's revenue at optimal energy consumption levels is greater than the variable cost of supplying energy. This motivates the design of a heuristic real-time algorithm where at every timeslot each appliance energy consumption is updated according to the real-time energy price and estimated price of operating each appliance. The home can then use this to calculate the optimal energy consumption schedule. The paper makes no specific recommendations on the nature of energy pricing, but shows that energy prices can normally be found that not only result in optimal energy consumption schedules for the energy provider's problem and are economically viable for the energy provider, but also reduce total users energy costs. The paper shows that optimal dynamic energy prices can be used to pass on the reduction in the cost of supplying energy to the users, when sufficiently scaled down. This provides financial incentives to users to subscribe to the smart home scheme. The presented algorithm ensures users' privacy by requiring users to only communicate their aggregate energy consumption schedules to the energy provider at each iteration of algorithm.

To evaluate the performance of the optimisation algorithm, we use a comprehensive consumer demand model to compute the quantitative benefits of the algorithm. The model is described in section 4; it is based on appliance definition, user profile generation and daily appliance use determination, and is based on real user data from energy provider E.ON and the UK Government Report on home energy use (Zimmermann, 2012). The performance evaluation of the new algorithms is done using simulation, the details of which are given in section 5.

The simulation results show that applying the new optimisation algorithm, it is possible to reduce the mean power peak to average ratio (PAR) between 0.16 and 0.35 with 99% probability. That is between 7.83% and 17.02% of the original time series mean PAR estimate. Furthermore,

optimisation reduces average user daily energy cost between 3.54% and 14.72% of its original time series mean estimate with 99% probability.

It is worth noting that reading and understanding the simulation results for the large-scale home energy networks is very difficult, as averaging the benefits of optimal energy supply gives only a part of the full picture. It is for this reason that we believe that the best practical use of the research results presented in this paper is to integrate them in the development of energy consumption visualisation tools for the individual users and for the energy supplier. Visualisation of energy consumption (Goodwin, 2013) will enable better understanding of the pattern of energy use and the consequence of optimisation and optimal appliance schedules.

2 SYSTEM MODEL

We start by presenting a model for energy users and energy provider. The user is modeled as an operator of a set of home appliances which operate over a finite scheduling time horizon. The user's objective is to choose feasible energy consumption schedule so as to minimize the cost of energy. The provider, on the other hand, benefits from selling units of energy to the users. Critically, the objective of the provider is to minimize the cost of supplying the energy consumed by the users by shifting the total energy consumed during the time horizon.

We consider a smart power network comprising a set of N users served by an energy provider who participates in the wholesale energy market. Each user is equipped with a smart meter capable of scheduling energy consumption of appliances, and smart meters are connected to the energy provider via a communication link. In the following sections, we describe how users and the energy provider are modeled.

Users: We assume each user $n \in N$ operates a set of A_n appliances including photovoltaic (PV) appliances, which are operated over a finite scheduling time horizon (e.g. a day) divided into timeslots (e.g. 15 minutes). We denote by T the set of timeslots in the scheduling time horizon. For each user $n \in N$, we denote by $x_{n,a}^t$ the energy consumption scheduled for appliance $a \in A_n$ at time $t \in T$, where negative values of $x_{n,a}^t$ represent power generation. Let $x_{n,a} \triangleq \left(x_{n,a}^t, t \in T\right)$ be the energy consumption schedule vector for appliance $a \in A_n$, and $x_n \triangleq \left(x_{n,a}, a \in A_n\right)$ be the energy consumption schedules for all appliances. We also denote the cardinality of sets by capital letters, e.g. $\mathrm{N} = |N|$ and $\mathrm{T} = |T|$. We assume that each appliance $a \in A_n$ requires a total energy of $E_{n,a}$ during the scheduling horizon, i.e.

$$\sum_{t \in T} x_{n,a}^t = E_{n,a} \quad \forall a \in A_n \tag{1}$$

In addition, we assume that each appliance $a \in A_n$ can use a minimum power level of $\gamma_{n,a}^{t,min}$ and a maximum power level of $\gamma_{n,a}^{t,max}$ at timeslot $\in T$, i.e.

$$\gamma_{n,a}^{t,min} \le x_{n,a}^t \le \gamma_{n,a}^{t,max} \quad \forall t \in T, a \in A_n \tag{2}$$

Clearly, if appliance $a \in A_n$ is non-controllable then $\gamma_{n,a}^{t,min} = \gamma_{n,a}^{t,max} \triangleq \gamma_{n,a}^t$, $\forall t \in T$ and $\sum_{t \in T} \gamma_{n,a}^t = E_{n,a}$.

User Optimisation Problem: Let p_t be the unit price of energy at time $t \in T$, which is set by the energy provider. We assume that users cannot sell their excess generated energy to the energy provider. Given the energy price vector $\mathbf{p} = (p_t, t \in T)$, the objective of user $n \in N$ is to then choose feasible energy consumption schedules x_n so as to minimize total energy costs, i.e. to solve the following optimization problem:

$$\min_{x_n} \sum_{t \in T} p_t \max\left(\sum_{a \in A_n} x_{n,a}^t, 0\right) \tag{3}$$

s.t. (1) and (2)

Evidently, optimal solution of (3) is dependent on the energy prices set by the energy provider.

Energy Provider: The energy provider is characterized by its energy cost function and its optimization objectives. The cost function $C_t(X)$ represents the cost for the energy provider to supply $X \ge 0$ units of energy at time $t \in T$ and is widely assumed to be increasing and strictly convex (see e.g. (Li, 2011) and (Mohsenian-Rad, 2010) As an example, the energy cost function for thermal generators is shown to be quadratic as follows (Mohsenian-Rad, 2010):

$$C_t(X) = a_t X^2 + b_t X + c_t \quad t \in T \tag{4}$$

where $a_t, b_t > 0$ and $c_t \ge 0$.

Optimisation Objectives: Since by constraint (1) users' energy demands during the scheduling horizon are fixed, we define the energy provider's objective as to minimize the cost of supplying the energy consumed by the users by shifting the total energy consumption at each time slot, i.e. to solve the following optimization problem

$$\min_{\mathbf{x}} \sum_{t\in T} C_t\left(\sum_{n\in N} max\left(\sum_{a\in A_n} x_{n,a}^t, 0\right)\right) \quad (5)$$

s.t. (1) and (2) $n \in N$

where $\mathbf{x} = (x_n, n \in N)$. The optimization problem (5) is convex and can be solved by the energy provider in a centralized fashion, providing that users energy demand constraints are available to the energy provider. Alternatively, (5) can be solved jointly by the energy provider and users using a distributed algorithm. In either way, appropriate energy pricing schemes have to be designed to ensure user participation by providing financial incentives.

3 OPTIMISATION ALGORITHM

Since the objective function in the energy provider's optimisation problem (5) is not strictly convex in x, computation of primal optimal solutions from the dual optimal solutions may not be possible (Boyd, 2004). As here we adopt a dual decomposition approach, we use the generalization of proximal minimization algorithm proposed by (Lin, 2006) that can be applied to the problems with similar form as (5). First, using the auxiliary vector $\boldsymbol{z} \triangleq (z_n, n \in N)$, where $z_n \triangleq (z_{n,a}, a \in A_n)$, $z_{n,a} \triangleq (z_{n,a}^t, t \in T)$, we transform the optimization problem (5) into the following equivalent form

$$min_{x,z} \sum_{t\in T}\left(C_t\left(\sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t\right) + \frac{1}{2c_t}\sum_{n\in N}\sum_{a\in A_n}\left(x_{n,a}^t - z_{n,a}^t\right)^2\right) \quad (6)$$

s.t. (1) and (2) $n \in N$

where $c_t > 0$ $t \in T$. Let $\mathbf{x}^*$ be the optimal solution of (5). Then $\mathbf{x} = \mathbf{x}^*$ and $\mathbf{z} = \mathbf{x}^*$ is the optimal solution of (6). The optimization problem (6) can then be solved using the algorithm as presented in (Lin, 2006):

Algorithm A: Fix K ≥ 1. At jth iteration:

1. Fix z = z(j) and estimate the solution of the dual problem of (6) by applying gradient method on dual variable ρ for K iterations.
2. Let $\rho(j+1, 0) = \rho(j, K)$. Let $x(j)$ be the primal variable associated with the dual variable $\rho(j, K)$. Set

$$z_{n,a}^t(j+1) = z_{n,a}^t(j) + \beta_t\left(x_{n,a}^t(j) - z_{n,a}^t(j)\right)$$
$$\forall t \in T, a \in A_n, n \in N \ , \quad (7)$$

where $0 < \beta_t \leq 1, \forall t \in T$.

We now focus on development of a distributed algorithm for step 1 of algorithm **A** at jth iteration. Note that optimization problem (6) is strictly convex when z is fixed. Introducing the auxiliary variable

$$y_t = \sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t \quad \forall t \in T \quad (8)$$

The optimization problem becomes

$$min_{y,x} \sum_{t\in T}\left(C_t(y_t) + \frac{1}{2c_t}\sum_{n\in N}\sum_{a\in A_n}\left(x_{n,a}^t - z_{n,a}^t(j)\right)^2\right) \quad (9)$$

s.t. (1), (2) $\forall n \in N$ and (8)

The Lagrangian after relaxation of constraint (8) is $L(\boldsymbol{\rho},\mathbf{y},\mathbf{x}) = \sum_{t\in T}\left(C_t(y_t) + \frac{1}{2t}\sum_{n\in N}\sum_{a\in A_n}\left(x_{n,a}^t - z_{n,a}^t(j)\right)^2 + \rho_t\left(\sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t - y_t\right)\right)$, where $\boldsymbol{\rho}$ is the vector of consistency prices. The dual problem is then

$$\max_{\rho} g(\boldsymbol{\rho}) \quad (10)$$

where

$$g(\boldsymbol{\rho}) = \min_{y,x} L(\boldsymbol{\rho}, \boldsymbol{y}, \boldsymbol{x}) \ ,$$

s.t. (1) and (2) $\forall n \in N$ (11)

Since (9) is strictly convex, the dual function (11) is differentiable and its gradient is given by (Bertsekas, 1999):

$$\nabla g(\boldsymbol{\rho})_t = \sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t(\boldsymbol{\rho}) - y_t(\boldsymbol{\rho}) \ \forall t \in T \quad (12)$$

where $\left(y(\boldsymbol{\rho}), x(\boldsymbol{\rho})\right)$ is the solution of (11) given $\boldsymbol{\rho}(j,k)$. The dual problem (10) can then be solved using gradient method as follows

$$\rho_t(j, k+1) = \rho_t(j,k) + \alpha_t\left(\sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t(j,k) - y_t(j,k)\right), \forall t \in T \quad (13)$$

where $\left(y(j,k), x(j,k)\right)$ denote the solution of (11) given $\boldsymbol{\rho}(j,k)$. Let the primal-dual pair (z^*, ρ^*) denote the stationary point of algorithm A defined by

$$z^* = \arg\max_{x} L(\boldsymbol{\rho}^*, \mathbf{z}^*, \mathbf{y}^*, \mathbf{x})$$

s.t. (1), (2) $\forall n \in N$

$$y_t^* = \sum_{n\in N}\sum_{a\in A_n} z_{n,a}^{t,*} \quad \forall t \in T$$

By KKT optimality conditions (Boyd, 2004) for any stationary point $(\boldsymbol{z}^*, \boldsymbol{\rho}^*)$ $\boldsymbol{z}^*$is the optimal solution of (6). It is shown in (Lin, 2006) that when α_t in (13) is small enough, algorithm *A* converges to

a stationary point $(\boldsymbol{z}^*, \boldsymbol{\rho}^*)$.

The dual function $g(\rho)$ can be decomposed into two subproblems $g(\rho) = g_1(\rho) + g_2(\rho)$, where

$$g_1(\rho) = \min_y \sum\nolimits_{t\in T} (C_t(y_t) - \rho_t y_t) \tag{14}$$

and

$$g_2(\rho) = \min_x \textstyle\sum_{t\in T}\sum_{n\in N}\sum_{a\in A_n}\Big(\rho_t x_{n,a}^t + \frac{1}{2c_t}\Big(x_{n,a}^t - -z_{n,a}^t(j)\Big)^2\Big), \text{ s.t. (1), (2) } \forall n \in N \tag{15}$$

Subproblem (6) is an unconstrained convex minimisation problem and due to the strict convexity of $C_t, t \in T$, has a unique solution. Let $y(\rho)$ be the unique solution of (14). Then

$$\rho_t = C_t'\big(y_t(\rho_t)\big) \quad \forall t \in T \tag{16}$$

Thus

$$y_t(\rho_t) = C_t'^{-1}(\rho_t) \ \forall t \in T \tag{17}$$

Equation (17) can be computed by the energy provider for each timeslot $t \in T$ independently, given the associated consistency price ρ_t. Subproblem (15) can be decomposed into optimisation problems for individual users:

$$g_2(\rho) = \textstyle\sum_{n\in N} g_{2,n}(\boldsymbol{\rho}), \text{ where}$$
$$g_{2,n}(\boldsymbol{\rho}) = \min_{x_n} \textstyle\sum_{t\in T}\sum_{a\in A_n}\Big(\rho_t x_{n,a}^t + \frac{1}{2c_t}\Big(x_{n,a}^t - z_{n,a}^t(j)\Big)^2\Big) \text{ s.t. (1), (2)} \tag{18}$$

It can be noted that at the stationary point of algorithm ***A*** the quadratic term in the objective function of (18) is zero and (18) is equivalent to the user optimization problem (3) with $\mathbf{p} = \boldsymbol{\rho}^*$. Hence, optimal consistency prices can be interpreted as energy prices that encourage users to opt for optimal energy consumption schedules for the energy provider's problem (5), in order to minimise their energy costs under these prices. We will show later in the next section that reduction in the cost of energy supply as a result of solving (5) can be passed on to the users, if energy prices **p** are based on adequately scaled down optimal consistency prices $\boldsymbol{\rho}^*$.

The user optimization problem (18) can be further decomposed into optimisation problems for individual appliances as

$$g_{2,n}(\boldsymbol{\rho}) = \textstyle\sum_{a\in A_n} g_{2,n,a}(\boldsymbol{\rho}), \text{ where}$$
$$g_{2,n,a}(\boldsymbol{\rho}) = \min_{x_{n,a}} \textstyle\sum_{t\in T}\Big(\rho_t x_{n,a}^t + \frac{1}{2c_t}\Big(x_{n,a}^t - z_{n,a}^t(j)\Big)^2\Big) \text{ s.t. (1), (2)} \tag{19}$$

Using dual decomposition, (19) can be decoupled into appliance optimization problem for each time slot. The Lagrangian after relaxation of constraint (1) is

$$L(\sigma_{n,a}, \mathbf{x}_{n,a}) = \sum_{t\in T}\left(\rho_t x_{n,a}^t + \frac{1}{2c_t}\Big(x_{n,a}^t - z_{n,a}^t(j)\Big)^2\right) + \sigma_{n,a}\left(E_{n,a} - \sum_{t\in T_{n,a}} x_{n,a}^t\right)$$

where $\sigma_{n,a}$ is the Lagrange variable associated with constraint (1) or price of operating appliance $a \in A_n$. The dual problem is then

$$\max_{\sigma_{n,a}} h_{2,n,a}(\sigma_{n,a}) \tag{20}$$

where

$$h_{2,n,a}(\sigma_{n,a}) = \min_{\mathrm{x}_{n,a}} L(\sigma_{n,a}, \mathrm{x}_{n,a}) \text{ s.t. (2)} \tag{21}$$

The dual function (21) can be decoupled into appliance optimization problems for each time slot:

$$h_{2,n,a}(\sigma_{n,a}) = \textstyle\sum_{t\in T} h_{2,n,a}^t(\sigma_{n,a}) + \sigma_{n,a}E_{n,a}, \text{ where}$$
$$h_{2,n,a}^t(\sigma_{n,a}) = \min_{x_{n,a}^t}(\rho_t - \sigma_{n,a})x_{n,a}^t + \frac{1}{2c_t}\Big(x_{n,a}^t - z_{n,a}^t(j)\Big)^2 \text{ s.t.(2)} \tag{22}$$

Let $x_{n,a}^t(\sigma_{n,a})$ be the solution of (22). Then

$$x_{n,a}^t(\sigma_{n,a}) = \big[c_t(\sigma_{n,a} - \rho_t) + z_{n,a}^t(j)\big]_{\gamma_{n,a}^{t,min}}^{\gamma_{n,a}^{t,max}} \tag{23}$$

We consider two measures of performance, namely, peak- to-average ratio (PAR) and average user daily energy cost, to evaluate the benefits of optimization to the energy provider and users, respectively. PAR is defined as the ratio of daily peak to average load, and used here as a measure of variation of aggregate daily energy consumption. It is defined by

$$PAR = \frac{T\max_{t\in T}\big(\sum_{n\in N}\sum_{a\in A_n} x_{n,a}^t\big)}{\sum_{n\in N}\sum_{a\in A_n} E_{n,a}} \tag{24}$$

The average user daily energy cost is defined as the daily cost of supplying energy divided by the number of users, and used to measure the minimum possible daily energy cost that can be passed on to a user on average:

$$\frac{\sum_{t\in T} C_t\big(\sum_{n\in N}\max\big(\sum_{a\in A_n} x_{n,a}^t, 0\big)\big)}{N} \tag{25}$$

Considering this solution, the proposed approach for solving the energy provider's optimization problem (5) can then be summarized as the following distributed algorithm:

Algorithm A: Fix $K \geq 1$. At j^{th} iteration:

1. Fix $z = z(j)$ and run algorithm **S** for K

iterations.

2. Let $\rho(j+1,0) = \rho(j,K)$. Let $x(j)$ be the primal variable associated with the dual variable $\rho(j,K)$. Set

$$z_{n,a}^t(j+1) = z_{n,a}^t(j) + \beta_t\left(x_{n,a}^t(j) - z_{n,a}^t(j)\right) \quad \forall t \in T_{n,a}, a \in A_n, n \in N \tag{26}$$

Where $0 < \beta_t \leq 1, \forall t \in T$.

Algorithm S: At k^{th} iteration:

1. Given the consistency prices $\rho(j,k)$, each user $n \in N$

computes:

- the price of operating each appliance $\sigma_{n,a}(j,k)$, $a \in A_n$, by solving (20)
- appliance energy consumption schedule $x_{n,a}^t(j,k)$, $a \in A_n$, $t \in T_{n,a}$, using (23), and communicates its aggregate energy consumption schedule $\sum_{a \in A_n} x_{n,a}^t(j,k)$, $t \in T_{n,a}$, to the energy provider.

2. Given the consistency prices $\rho(j,k)$, the energy provider computes:

- the auxiliary variable $y_t(j,k)$, $t \in T$, using (17),
- updates the consistency price $\rho_t(j,k)$, given the aggregate energy consumption schedules for all users $\sum_{n \in N}\sum_{a \in A_n} x_{n,a}^t(j,k)$ and $y_t(j,k)$, $t \in T$, according to the gradient algorithm (13).

Note that the proposed algorithm ensures users' privacy by requiring users to only communicate their aggregate energy consumption schedules to the energy provider at every iteration of algorithm **S**. Note also that, with the exception of computation of $\sigma_{n,a}(j,k)$, $a \in A_n$, all the computations can be further decoupled across individual timeslots. This motivates the heuristic real-time algorithm presented in the following sections where at every timeslot each appliance energy consumption is updated according to the real-time energy price and estimated price of operating each appliance $\sigma_{n,a}(j,k)$, $a \in A_n$.

As discussed in the previous section, optimal energy consumption schedules for the energy provider's problem (5) can be attained if energy prices are set as optimal consistency prices ρ^*, i.e. setting $\mathbf{p} = \rho^*$, energy consumption schedules that are minimizers of the users optimization problem (3) are also minimizers of the energy provider's problem (5). Moreover, as stated in the following theorem, the energy provider's revenue based on energy prices ρ^* is greater than the variable cost of supplying energy, at optimal energy consumption levels.

Theorem 1. If energy prices are set as optimal consistency prices ρ^*, the energy provider's revenue at optimal energy consumption levels is greater than the variable cost of supplying energy, i.e.

$$\rho^* y_t^* > C_t(y_t^*) - C_t(0), \forall t \in T \tag{27}$$

Proof. Since we assumed that C_t is increasing and strictly convex, it follows from the first order condition for strict convexity (Boyd, 2004) that

$$C_t'(y_t^*)y_t^* > C_t(y_t^*) - C_t(0) \quad \forall t \in T \tag{28}$$

replacing (16) in the above inequality then yields (27).

However, we are interested in energy pricing scheme that not only results in optimal energy consumption schedules for the energy provider's problem (5) and covers the variable cost of supplying energy, but also reduces or ideally minimizes users energy costs, in order to ensure users participation in the smart home scheme.

To examine the existence of such scheme note that by the mean value theorem (Bertsekas, 1999) there exists $\widehat{y_t} \in [0, y_t^*)$ for all $t \in T$ such that

$$C_t'(\widehat{y_t})y_t^* = C_t(y_t^*) - C_t(0) \quad \forall t \in T \tag{29}$$

It follows from (28) that there exists 0 < t < 1, for all $\in T$, such that

$$\gamma_t C_t'(y_t^*) = C_t'(\widehat{y_t}) \quad \forall t \in T \tag{30}$$

Let $\gamma_{max} = max_{t \in T}\{\gamma_t\}$. Then,

$$C_t'(y_t^*) > \gamma_{max} C_t'(y_t^*) \geq C_t'(\widehat{y_t}) \; \forall t \in T \tag{31}$$

So,

$$\begin{aligned} \sum_{t \in T} C_t'(y_t^*)y_t^* &> \gamma_{max}\sum_{t \in T} C_t'(y_t^*)y_t^* \\ &\geq \sum_{t \in T} C_t'(\widehat{y_t})y_t^* \\ &= \sum_{t \in T} C_t(y_t^*) - C_t(0) \end{aligned} \tag{32}$$

The term on the right side of the above equality is the minimum daily cost of supplying energy and hence is the lower bound on the viable total users energy costs at optimal energy consumption levels. Note that users optimization problem (3) with energy prices $\rho = \gamma_{max}\rho^*$ is equivalent to the case when $\rho = \rho^*$ and thus result in optimal energy consumption schedules for the energy provider's problem (5). The above inequality states that there exist energy prices that lead to optimal energy consumption schedules for the energy provider's problem (5), economically viable for the energy provider and result in lower viable total users energy

costs than with energy prices ρ^*, but not necessarily the minimum viable level. This implies that, unless the current energy consumption schedules are very close the levels that optimize the energy provider's problem (5), energy prices can normally be found that not only result in optimal energy consumption schedules for the energy provider's problem (5) and are economically viable for the energy provider, but also reduce total users energy costs. In the case of quadratic cost function (4), it follows from (29) that $\widehat{y_t} = \frac{1}{2} y_t^*$, $t \in T$. If $b = 0$ in (4), then $\gamma_t = \gamma_{max} = \frac{1}{2}$, for all $t \in T$. Thus, in this case energy prices $\rho = \frac{1}{2}\rho^*$ results in minimum total users energy costs at optimal energy consumption levels, while still economically viable for the energy provider.

Notice that if the objective function in the energy provider's problem (5) is scaled by a positive constant $\gamma > 0$, the resulting optimization problem is equivalent to (5) and hence the minimum cost of supplying energy, and by (16), optimal consistency prices ρ^* are also scaled by $\gamma > 0$.

4 CONSUMER DEMAND MODEL

To evaluate the algorithm performance in detail, it is necessary to use a comprehensive household consumer energy demand model. The model – developed specifically for this project - generates artificial consumption data, both for a single household and an entire neighbourhood. The model has been developed on the basis of real home user data generated at the E.ON testbed facility in the UK in 2012.

The model generates the consumption data of the households in the following three main steps (Figure 1): (1) determining the household configuration (i.e. which appliances can be found in a household); (2) computing the daily use of each appliance (i.e. how many times is an appliance used on a certain day); (3) calculating the exact energy demand of each appliance (i.e. at what time is the appliance used on a certain day)

The different steps of the consumer energy demand model are based on probabilistic approaches using basic appliance definitions for the generation of the consumption data. The general model structure uses some basic appliance definitions to generate the synthetic consumption data in three main steps: (1) Basic appliance definition; (2) User profile generation; (3) Daily appliance use determination.

The most common household appliances can be classified according to a reduced number of simplified power level patterns (Yao, 2012, Richardson, 2010, Carpaneto, 2007). In the proposed model three different power level patterns for the approximation of the demand curve have been considered (Figure 2). Pattern 1 represents continuously running appliances with a constant power level, such as fridges or freezers. Pattern 2 allows the approximation of occasionally operated appliances with possible non-zero energy consumption in standby operation such as washing machines or TVs. Finally, pattern 3 is used to approximate the power curve.

The three simplified power level patterns were used in the development of a classification scheme based on different usage types. These usage types take into account factors such as frequency, duration and time of use of the considered appliances and allow a classification closely related to the customer habits.

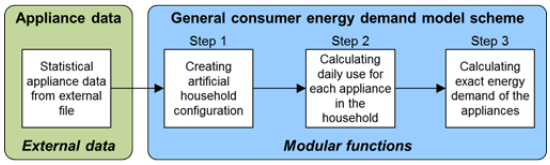


Figure 1: General structure of the developed consumer energy demand model.

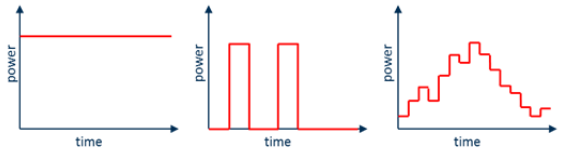


Figure 2: Classification of household appliances by power level patterns.

The consumer energy demand model determines in the first step the configuration of one or several households. For most appliance types, the number of devices is computed using a probabilistic approach. However, exceptions have been considered for a few appliances. The computation of the number of devices of a certain appliance type is based on a binomial distribution in order to obtain certain variation around a desired average value.

Finally, an important aspect of the model is consideration of exceptions. In our case, special care was taken: (1) to accurately represent lighting, (2) to exclude appliances which exist with gas and electricity connections; (3) to limit the sum of electric and gas space heaters to one device per

household (This limitation is also used in the case of water heating appliances). For a detailed description of the developed usage types and a complete list of the considered appliances the reader is referred to (Gruber, 2012).

The household consumer energy demand model is used in the remainder of the paper to simulate the representative households in order to evaluate the performance of the optimal algorithms presented in section 3. Figure 3 shows the link between consumer demand model and aggregated demand optimisation algorithm, at each simulation replication. The appliance total daily energy requirements $\mathrm{E} \triangleq \left(E_{n,a}, a \in A_n, n \in N\right)$ is computed from the daily energy consumption time series x generated by the proposed consumer demand model.

5 IMPLEMENTATION AND SIMULATION RESULTS

Having defined the model and the theoretical optimisation algorithm in the previous sections, in this section we focus on the actual implementation of the algorithm.

Using the controllability and power level data from the basic appliance definition, minimum and maximum power levels $\gamma^{min} \triangleq \left(\gamma_{n,a}^{t,min}, a \in A_n, n \in N, t \in T\right)$ and, $\gamma^{max} \triangleq \left(\gamma_{n,a}^{t,max}, a \in A_n, n \in N, t \in T\right)$ are set equal to the energy consumption time series for non-controllable appliances, and to the minimum and maximum power level for fully controllable appliances. Here, we refer to appliances with no operational timing constraints as fully controllable appliances. For partially controllable appliances the values of these parameters are set according to their specific constraints, as will be explained later in the simulation results. Given the values of parameters $\boldsymbol{E}, \gamma^{min}, \gamma^{max}$, the optimal energy consumption schedules x^* are computed using the algorithm described in Section 3. Finally, daily estimates of mean performance measures are computed for the original energy consumption time series and its optimisation, given the values of x and x^*, respectively.

The simulation experiment involved generation of energy consumption time series and its optimization for 100 users for 12 independent weeks during a typical winter season. For each week, energy consumption time series and its optimized version were generated separately for every weekday with sampling time of 15 minutes. The Peak to Average Ratio (PAR) and the average user daily energy cost were subsequently measured for each weekday and used to estimate their mean values for the week. In the optimisation model, the operation time of washing appliances were assumed to be flexible throughout the day and hence treated as a control variable.

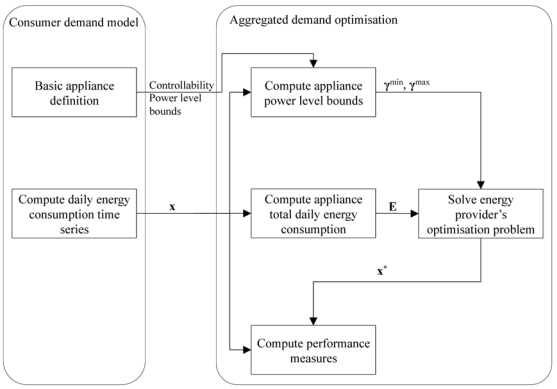


Figure 3: Interface between consumer demand model and aggregated demand optimization results.

Table 1: PAR Values.

PAR values	weekday	weekend
original	2.16	1.78
optimised	2.05	1.65

Furthermore, the power level of heating and cold appliances were assumed to be adjustable within the range of 10% of their original time series values and treated as additional control variables. The daily energy requirement of these types of appliances was assumed to be fixed and equal to their daily usage generated by the consumer demand model. Power levels and operation times of the remaining appliances were set equal to their original time series values. The energy cost function was assumed to be of the form (4) with parameters $a_t = 0.1, b_t = 0, c_t = 0,$ for all $t \in T$.

The simulation results indicate that the original time series peak loads during the late afternoon/early night at weekday are significantly higher than weekend as indicated by their respective PAR values of 2.16 and 1.78. In these examples, optimisation reduces the load variation resulting in PAR values of 2.05 and 1.65 for the example weekday and weekend, respectively (Table 1).

Figure 4 shows the resulting aggregate energy consumption time series and its optimisation for a typical weekday (similar results for weekend exist, the figure is omitted because of the space constraints). Figure 5 gives a better visualization of the benefit of optimization, using the load duration

curve to show the gains made in the peak demand using out optimization algorithm. The load duration curve shows the energy consumption data by 15-minute intervals, sorted in descending order. Results presented in Figures 4 and 5 show average values for 100 households, with individual household gains greatly depending on the household model.

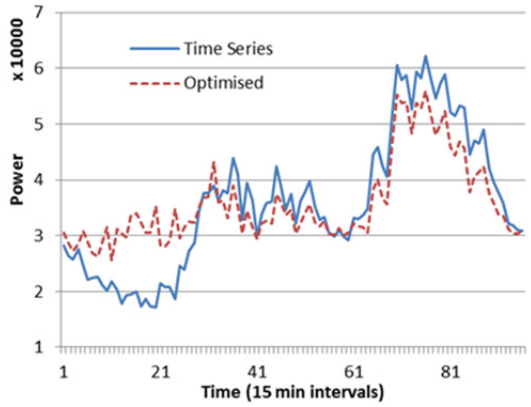


Figure 4: Aggregate energy consumption time series and its optimisation for 100 users for a typical weekday.

The overall simulation results indicate that optimisation reduces mean PAR between 0.16 and 0.35 with 99% probability. That is between 7.83% and 17.02% of the original time series mean PAR estimate. Notice that this is despite the fact that the optimisation objective was to minimise the quadratic energy cost function, rather than to minimise the PAR explicitly. Furthermore, optimisation reduces average user daily energy cost between 3.54% and 14.72% of its original time series mean estimate with 99% probability, for all γ>0 multiples of parameters $a_t, t \in T$.

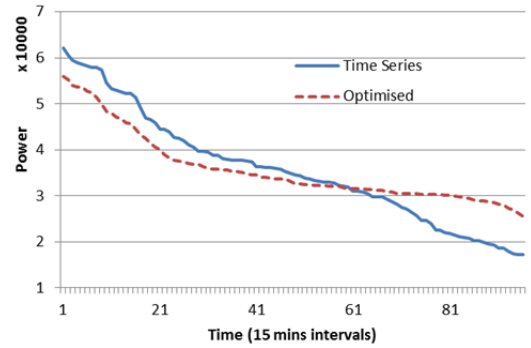


Figure 5: Load Duration Curve for aggregate energy consumption for 100 users on a typical weekday.

As it was mentioned in the Introduction section, averaging the benefits of optimal energy supply rarely gives the full picture. The optimisation presented in this paper can be used in the design and development of user visualisation tools. These tools can be used by home users to understand better the benefits of optimal appliance schedule at their home. For more details about the potential use of data visualisation in energy networks the reader is referred to (Goodwin, 2013).

6 CONCLUSIONS

This paper looks into the problem of optimal use of energy in homes. The paper uses problem decomposition to show that optimal dynamic home energy prices can be used to reduce the cost of supplying energy, while at the same time reducing the cost of energy for the home users. We provide a proof that if energy prices are set as optimal consistency prices, the energy provider's revenue at optimal energy consumption levels is greater than the variable cost of supplying energy. This is then used to design a heuristic real-time algorithm for demand management using home appliance scheduling. The performance of the algorithm is evaluated using simulation, where a comprehensive model of home energy consumption is used.

In terms of the future work, the focus will be on two issues: (1) the detailed performance evaluation of the presented algorithm, using concrete pricing idea, a larger variety of objective functions, including peak minimisation and optimisation of user comfort/discomfort, and realistic models of user reaction; (2) utilising the linear time complexity (O(n)) of our algorithm, which makes it suitable for performing simulation on very large sets of data (entire city or country) using cluster/cloud computing in a very short time for interactive energy data analysis and visualisation. In our future work, we will aim to experiment with the efficiency of the algorithm for large-scale optimisation and visualisation of household energy use, to understand better the nature of the energy price from the user point of view.

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Practical Risk Assessment Using a Cumulative Smart Grid Model

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Abstract: Due to the massive increase of green energy, today's power grids are in an ongoing transformation to smart grids. While traditionally ICT technologies were utilized to control and monitor only a limited amount of grid systems down to the station level, they will reach billions of customers in near future. One of the downsides of this development is the exposure of previously locked down communication networks to a wide range of potential attackers. To mitigate the risks involved, proper risk management needs to be in place. Together with leading manufacturers and utilities, we focused on European smart grids and analyzed existing security standards in the Smart Grid Security Guidance $(SG)^2$ project. As our study showed that these standards are of limited practical use to utilities, we developed a cumulative smart grid architecture model in a joint approach with manufacturers and utilities to represent both current and future European smart grids. Based on that model, we developed a practical, light-weight risk assessment methodology covering a wide range of potential threats that have been evaluated and refined in course of expert interviews with utility providers and manufacturers.

1 INTRODUCTION

Over the last years, the electrical power grid has undergone a tremendous change. The traditional power grid could be described as a producer-consumer model. The producers generate electricity and the electricity is transferred by utilities to the consumers. As a result, the amount of employed ICT technologies was limited. Today, there is a strong trend in the direction of sustainable green energy, energy saving and higher efficiency. Energy is no longer only produced at the top and delivered to the bottom; instead, everyone can become an energy producer. Consumers change to "prosumers" by running their own solar or wind power stations. Businesses and communities specializing on independent energy production through wind turbines, heating, or biogas plants emerge and grow. The boundaries in the traditional power grid model start to fade. On the other hand, large-scale energy producers and utilities can save energy and achieve higher energy efficiency by having the ability to influence or control devices in the user domain. To make this possible, energy grids are heavily expanded with ICT technologies – the traditional power grid is being transformed into the *smart grid*. On the downside, these technologies bear unforeseen risks for critical infrastructures. Smart grid ICT technology providers and utilities have limited experience with these new technologies and market pressure may force them to throw new products on the market before they have undergone quality assurance processes suitable for critical infrastructures. While traditionally access to smart grid ICT networks was limited to energy producers and utilities, new smart grid ICT technologies allow the massive amount of consumers to participate in these networks. Communication infrastructures in energy grids and especially in power grids are thus also exposed to a wide range of potential adversaries. To mitigate the security risks involved, there have been significant international efforts in terms of smart grid cyber security standards, risk assessment and security mechanisms (see Section 2). However, focusing on smart grids in the European Union and especially in Austria, it quickly turned out that many architectural or technological assumptions do not hold for the smart grid systems currently being rolled out in large quantities. For instance, within the European Union, the Smart Me-

tering Protection Profiles (BSI, 2013b; BSI, 2013c) are widely known for their security requirements and definitions. Yet, smart metering is only one of many areas within the smart grid, and today's advanced metering infrastructure (AMI) typically does not correspond to the *gateway* and *security module* design concept suggested in those Protection Profiles. As a result, in the Smart Grid Security Guidance $(SG)^2$ joint project (AIT, 2013) with leading smart grid component manufacturers and utilities, we set out to create a cumulative smart grid landscape model representing both current and future European smart grids. Based on established industry security standards and in close cooperation with manufacturers and utilities, we identified a comprehensive set of threats that are applicable within our cumulative smart grid model. To foster practical usability, we clustered both identified threats and smart grid systems to form the two dimensions of a threat matrix. This threat matrix allows practical threat assessment for both current and future European smart grids, and forms the basis for an according risk assessment determined by probability and impact. In summary, the main contributions of our work are:

- A cumulative smart grid model representing both current and near-future European smart grids as a basis for sound risk assessment
- A thoroughly designed threat catalog for modern smart grid architectures
- An accompanying practical risk assessment approach evaluated and refined in course of expert interviews with utility providers and manufacturers

The remainder of this paper is organized as follows. Section 2 provides an overview of related work. In Section 3 we explain how we developed the cumulative smart grid model. In Section 4 we describe our risk assessment approach, while Section 5 covers the evaluation and our results. The conclusions and suggestions on further work can be found in Section 6.

2 RELATED WORK

Mainly focusing on U.S. smart grids and technology, NIST has developed Guidelines for Smart Grid Cybersecurity (NIST, 2013b). In Europe, the German Federal Office for Information Security (BSI) has come up with a Common Criteria Protection Profile for the Gateway of a Smart Metering System and its Security Module (BSI, 2013b; BSI, 2013c). In contrast to our approach, the NIST guidelines do not allow an integrated approach. They are based on technologies employed in U.S. smart grids and give high-level recommendations only. Similarly, the BSI protection profiles do not provide a holistic approach either. Instead, they focus on smart metering only (which is only one building block of a smart grid), and their Target of Evaluation is a very specific smart metering implementation that does not reflect deployed smart metering systems.

Regarding risk assessment, Lu et al. outline security threats in the smart grid (Lu et al., 2010). In comparison, our approach is targeted on the broad range of system components in European smart grids. Ray et al. provide a more formal approach to smart grid risk management (Ray et al., 2010) while one of our goals was to develop a practical risk assessment approach usable for utilities. Varaiya et al. show various ways to manage security critical energy systems (Varaiya et al., 2011). However, they rather focus on formal methods, and their smart grid model does not reflect current European smart grids. Finally, Hou et al. outline the differences in risk modeling between traditional grids and smart grids (Hou et al., 2011), while we focus on the smart grid landscape that is currently deployed or will be deployed in the near future. In addition, existing risk assessment approaches are covered in more detail in Section 4.1.

Regarding smart grid security mechanisms, Yan et al., Mohan et al. and Vigo et al. provide an overview of security mechanisms for smart grids and smart meters (Yan et al., 2012; Mohan and Khurana, 2012; Vigo et al., 2012). While their work provides an overview of how security mechanisms should be realized, in our approach, we focus on the security mechanisms that are either implemented in current implementations or will be part of near-future implementations. Finally, Wang et al. (Yufei et al., 2011) present smart grid standards covering security, but rather target U.S. standards like those published by NIST.

3 CUMULATIVE SMART GRID MODELING USING SGAM

In our joint approach to identify technological risks in current and future European smart grids, it turned out that leading experts, utilities and even manufacturers have a very different view and definition of what *the smart grid* is. Focusing on European smart grids and the Austrian power grid in particular, on a high-level view, the smart grid domains and actors within those domains are comparable to existing standards such as the NIST Smart Grid Framework (NIST, 2013a) or the European Smart Grid Reference Architecture (Smart Grid Coordination Group, CEN-CENELEC-

ETSI, 2012b). In a first task, we asked utilities to compare their deployed smart grid systems, model regions, pilot projects and concepts with existing reference models. Since, unlike the NIST framework, the European smart grid reference architecture focuses on European smart grid technologies, it was chosen as a basis for the comparison. Specifically, we used the Smart Grid Architecture Model (SGAM) (Smart Grid Coordination Group, CEN-CENELEC-ETSI, 2012b) to allow for a well-structured comparison. Overall, 45 different projects could be identified and prioritized according to project size, project relevance, and both amount and quality of available information. The study showed that, in general, the SGAM model is usable with some limitations, but the reference model is only applicable on a high level. While it sketches the general structure of European smart grids, it does not contain detailed information on the technologies implementing smart grid components in this structure. For that matter, it is not adequate for qualified risk modeling suitable for utilities. To close this gap, we combined seven national and four international projects within the SGAM model to form a cumulative architecture model allowing us to deduce threats and risks for both current and future smart grid installations in Europe. The following sections describe our approach in more detail.

3.1 The Smart Grid Architecture Model (SGAM) Framework

The SGAM model had its original motivation in identifying gaps in standardization and locating these gaps in the SGAM model space. The model is structured in zones and domains (see Fig. 1). While the *zones* are derived from the typical layers of a hierarchical automation system (from field via process, station towards operation and enterprise level (Sauter et al., 2011)), the *domains* reflect power-system specific fields of different actors such as transmission system operators, distribution system operators, and customers. In contrast to the NIST model, the European approach has a dedicated DER (Distributed Energy Resources) domain, which captures small distributed generators with their special infrastructure. Finally, in the third dimension, SGAM features *interoperability layers*. With these layers, the different aspects of networked smart grid systems are aligned. The base layer is the component layer, where physical and software components are situated. On top of that, communication links and protocols between these components can be placed. The information layer holds the data models of the information exchanged. On top of that, the function layer holds the actual functionalities, and the uppermost layer describes the business goals of the system.

Today, SGAM serves three major purposes: first of all, it is a means to visualize and compare different smart grid automation architectures. This also allows the identification of gaps in all layers. Finally, SGAM can serve as a useful model to support model-driven architecture development. In this work, SGAM was applied for the first two purposes: comparison and identification of gaps.

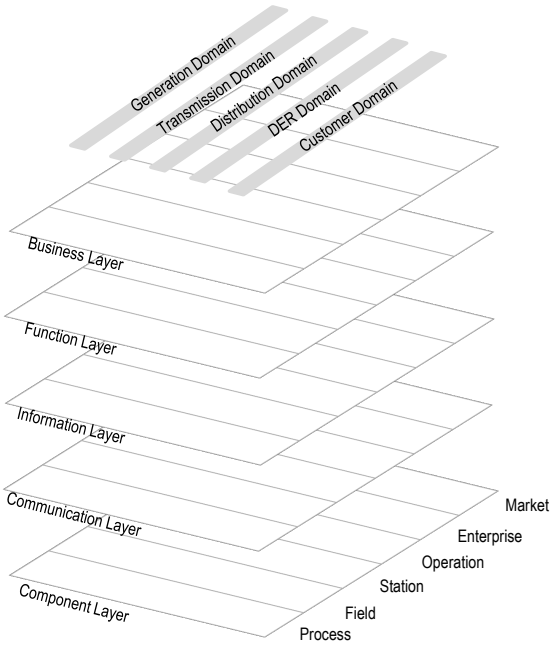


Figure 1: Smart Grid Architecture Model (SGAM) Framework.

3.2 Current and Future Smart Grid Technologies within SGAM

Within the project, a holistic architecture was derived, which reflects the short- to mid-term extension of today's power grid IT technology towards future smart grid functionalities. The methodology used to achieve this architecture is based on individual SGAM modeling of national and international smart grid projects that significantly build on the use of ICT systems. From 45 project candidates, seven significant national smart grid research projects were selected for modeling:

- IEM: Intelligent Energy Management
- Smart Web Grids (Smart Grid Modellregion Salzburg, 2011)
- DG DemoNetz Smart LV Grids (Klimafonds, 2012)

- ZUQDE: Zentrale Spannungs- und Blindleistungsregelung mit dezentralen Einspeisungen in der Demoregion Salzburg (Smart Grid Modellregion Salzburg, 2010)
- EMPORA: E-Mobile Power Austria (E-Mobile Power Austria, 2010)
- AMIS Smart Metering Rollout

A similar approach was applied to international projects. The selected significant projects were:

- The European FP7 Project OpenNode (OpenNode, 2012)
- The European FP7 Project EcoGrid EU (EcoGrid, 2012)
- The US Demand Response Automation Server (DRAS) (DRAS, 2008)
- The German ICT Gateway Approach OGEMA (OGEMA, 2012)

For SGAM modeling, detailed information about the technical implementations had to be requested from the projects under analysis. The availability of information (or contacts to the projects) was an additional selection criterion for the international projects.

3.3 European Smart Grid View according to the Cumulative SG Model

The derived architecture (Fig. 2) includes a harmonized cumulative view of the components found in all analyzed projects. The SGAM domains transmission and bulk generation were not covered by the selected projects since in the Austrian or, respectively, European view, the smart grid is primarily related to distribution systems. The architecture shows the component and communication layer of the SGAM model. On the bottom, the field devices can be found (such as smart meters or dedicated sensors and actuators). On the station level, both primary and secondary substation are situated with their current and prospective automation components. On the customer side, mainly residential customers, commercial buildings, and electric mobility can be found. On the top of the architecture, the enterprise level and market components are located.

However, one of the main differences to existing models is the addition of detailed communication technology descriptions allowing a more in-depth risk assessment approach. The communication protocols and technologies underlined are the ones that are predominantly used in the projects we analyzed. For instance, in future smart grids the broad use of Web Services is anticipated for communicating with the energy market. Nevertheless, as depicted in our architecture, the predominant way to achieve this in current smart grids is to use personal communication via email or phone calls. From a risk assessment perspective, this results in a significant difference as Web Services can potentially be more easily compromised than a phone call made between a group of persons who probably know each other well from their daily work routine.

3.4 Evaluation of the Model

After a first draft of the architecture model had been developed, it was subject to a number of feedback rounds with members of the consortium (utilities and manufacturers). Improvements and additional information were integrated into the architecture. The $(SG)^2$ architecture model serves as an anchor point for further analysis and as a common document of energy, IT and security experts. The main benefit of the model is that questions between the different expert domains can clearly be formulated and therefore easily be answered by referring to individual elements of the architecture.

4 SMART GRID RISK ASSESSMENT

4.1 Existing Approaches

Smart grid cyber security and risk assessment in particular has been addressed in several standards, guidelines and recommendations. The U.S. National Institute of Standards and Technology (NIST) has developed a three-volume report on “Guidelines for Smart Grid Cyber Security (NIST-IR 7628)” (NIST, 2013b): Volume two focuses on risks related to customer privacy in the smart grid, and gives high-level recommendations on how to mitigate these risks. However, no general approach for assessing security risks in the smart grid is provided. The European Network and Information Security Agency (ENISA) has issued a report on smart grid security. It builds on existing work like NIST-IR 7628 or ISO 27002 and provides a set of specific security measures for smart grid service providers, aimed at establishing a minimum level of cyber security (ENISA, 2012). Each security measure can be implemented at three different “sophistication levels”, ranging from early-stage to advanced.

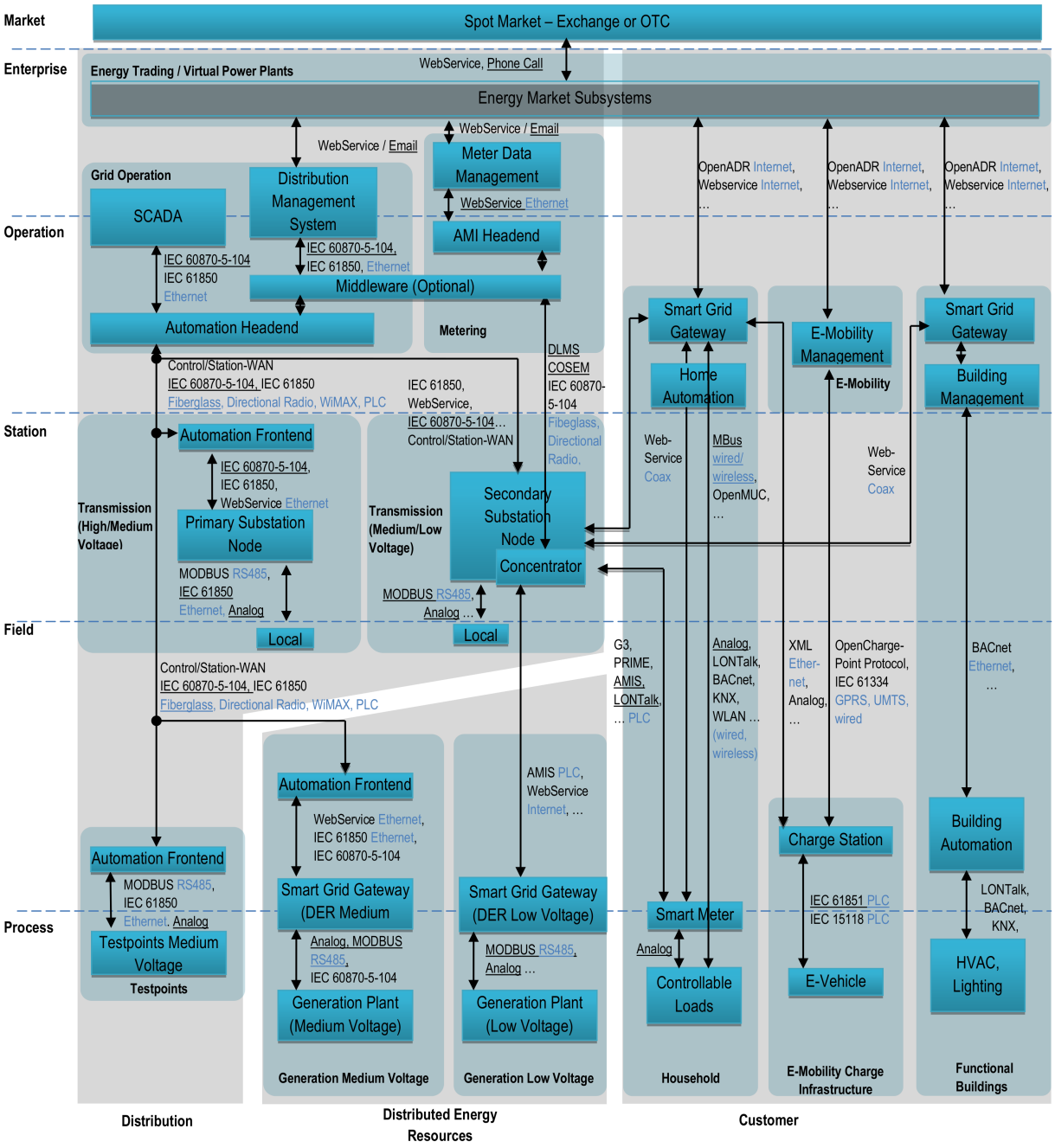


Figure 2: Cumulative Smart Grid Model.

The importance of a risk assessment to be performed before deciding the required sophistication levels is pointed out, but no specific risk assessment methodology is identified within the report.

The German Federal Office for Information Security has come up with a Common Criteria Protection Profile for the Gateway of a Smart Metering System and its Security Module (BSI, 2013b; BSI, 2013c). Both define minimum security requirements for the corresponding smart grid components based on a threat analysis. However, the Common Criteria approach, which focuses on a specific, well-defined Target of Evaluation, cannot provide a holistic view on cyber security threats in future smart grids. Another drawback is that the implementation of many smart metering systems currently being rolled out does not correspond to the defined gateway and security module design concept.

The CEN-CENELEC-ETSI Smart Grid Coordination Group has provided a comprehensive framework on smart grids in response to the EU Smart Grid Mandate M/490 (Smart Grid Coordination Group, CEN-CENELEC-ETSI, 2012a). As part of that framework, the "Smart Grid Information Security (SGIS)" report defines five SGIS Security Levels to assess the criticality of smart grid components by focusing on power loss caused by ICT systems failures. Moreover, five SGIS Risk Impact Levels are defined that can be used to classify inherent risks in order to assess the importance of every asset of the smart grid provider. This means that the assessment is carried out under the assumption that no security controls whatsoever are in place. While this is a valuable approach, it is not suitable for a more practical scenario that focuses on actual, currently deployed or foreseeable implementations.

Risk assessment methodologies have also been addressed by the FP7 project EURACOM, which considered protection and resilience of energy supply in Europe and aimed at identifying a common and holistic approach for risk assessment in the energy sector. As part of a project deliverable[1], existing risk assessment methodologies and good practices have been analyzed in order to identify a generic risk assessment method which could be customized to suit the specific needs of the energy sector.

While most of the existing risk assessment methods are asset-driven, the $(SG)^2$ project required an architecture-driven approach for developing a risk catalog. This approach is described more closely in the following.

4.2 Our Approach: Threat Matrix and Risk Catalog

The risk assessment approach taken in $(SG)^2$ focused on the ICT architecture model initially developed within the project (see Section 3). The goal was to come up with a comprehensive catalog of ICT-related risks for smart grids in Europe from a Distribution System Operator's perspective. The following steps were taken to achieve that goal:

1. Compile a *threat catalog* for smart grids focusing on ICT-related threats and vulnerabilities
2. Develop a *threat matrix* by applying the threat catalog to the ICT architecture model, i.e., identify which threats apply to which components of the model
3. Assess the potential risk for each element within the threat matrix by estimating the probability and the impact of an according attack, thus eventually producing a *risk catalog*

These steps are explained in more detail in the following paragraphs.

4.2.1 Compiling the Threat Catalog

The $(SG)^2$ threat catalog was not to be developed from scratch, but should build upon a well-established source of ICT-related security threats. To that end, the IT Baseline Protection Catalogs developed by the Federal Office for Information Security (BSI, 2013a) were chosen to form the main source of input as they provide a comprehensive list of security threats that could possibly apply to an ICT-supported system. Additionally, the threats specified in the smart-grid-specific Protection Profiles (BSI, 2013b; BSI, 2013c) were taken into account. Non-technical threats, i.e., threats related to organizational issues or force majeure, were not considered due to the scope and focus of the $(SG)^2$ project. Thus, out of a list of initially 500 threats accumulated from the identified sources, the ones without any relevance to smart grids or without any relation to ICT were eliminated at first, yielding roughly half of the initial threats for further consideration. While certain threats listed in the BSI Catalogs are very generic, others apply to very specific settings only; therefore, it was necessary to merge some of the threats that remained in our list after the "weeding" step. This resulted in a list of 31 threats, which were grouped into the following clusters:

- Authentification / Authorization
- Cryptography / Confidentiality
- Integrity / Availability
- Missing / Inadequate Security Controls
- Internal / External Interfaces
- Maintenance / System Status

Since the BSI Baseline Protection Catalogs are not tailored for any specific use case, the relevant threats had to be adapted to the smart grid scenario, i.e., they were interpreted in the smart grid context.

4.2.2 Developing the Threat Matrix

The next step on the path to the $(SG)^2$ risk catalog was to apply the threats identified in the first step to the components of the $(SG)^2$ architecture model (see Section 3), i.e., to state which threats are relevant for which of the components and why. To answer that question, the functionality and the characteristics of

[1]The EURACOM project deliverables can be downloaded at `http://www.eos-eu.com/?Page=euracom`.

the individual architecture components had to be assessed first. For feasibility reasons, the granularity of the components to be considered was set to the level of the boxes depicted in dark grey in Fig. 2:

- Functional Buildings
- E-Mobility & Charge Infrastructure
- Household
- Generation Low Voltage
- Generation Medium Voltage
- Testpoints
- Transmission (High/Medium Voltage)
- Transmission (Medium/Low Voltage)
- Grid Operation
- Metering

The Energy Markets domain was not considered due to lack of current ICT utilization and lack of information on future functionalities.

For each element of the threat matrix, it was first decided whether the threat could be relevant to that particular component or not. If potential relevance was assessed, the reason for that decision was noted, and possible attack scenarios were developed. Since the architecture model considered also smart grid developments for the near future, reasonable assumptions regarding the implementation had to be made in certain cases. These assumptions were discussed and verified by the involved manufacturers and utilities.

4.2.3 Assessing the Risk Potential

The final step of the $(SG)^2$ risk assessment involved estimating the risk potential for each element of the threat matrix, thus providing a comprehensive risk catalog. To that end, the probability and the impact of each of the threats occuring was rated for each of the components of the architecture model. A semi-quantitative approach was chosen for the risk assessment, which had previously been applied and practically assessed by one of the member organizations of the project consortium: both probability and impact were measured on a five-level scale ranging from very low (level 1) to very high (level 5). The probability level was determined by the number of successful attacks per year, ranging from less than 0.1 incidents (level 1) to multiple incidents (level 5) per year. The impact of a successful attack was determined by monetary loss, customer impact, and geographic range of the effects (e.g., local, regional, global). The outcome of this step is a comprehensive catalog of cyber security risks on smart grids in Europe. The steps taken to evaluate the catalog as well as the main findings are described in the following section.

5 EVALUATION AND RESULTS

A good threat and risk assessment model delivers useful results, i.e., captures specific threats appropriately, is easy to use, and well applicable in reality. With these targets in mind, we evaluated and revised the model in a series of workshops, where domain experts from both areas of information technology and energy rated the proposed risk assessment approach.

5.1 Evaluation Methodology

The evaluation, partly integrated in the overall creation of our cumulative smart grid model for risk assessment, included in the following three steps:

- *Step 1: Evaluation of Threat Catalog.* In order to evaluate our threat catalog, we set up end user workshops with experts from utility providers, device manufacturers, and academic institutions to evaluate both the relevance and completeness of the identified threats. During that evaluation, additional threats were added that are unique to the smart grid domain.
- *Step 2: Threat Relevance.* Experts surveyed the applicability of identified threats to the various domains in the SGAM model. This step enabled the identification of the most important threats per domain as well as their interdependencies, and further allowed to focus on most relevant threats. The result was again discussed and refined with major utility providers in Austria in end user centric workshops.
- *Step 3: Probability and Impact Assessment.* In a last step, we had experts independently rate the probability of occurrence of identified threats and the impact from their point of view. These experts represent the opinions of different utility providers, ranging from small and locally operating organizations, to larger ones. In a joint workshop, the individual results were again discussed and consolidated to ensure the broad use of the resulting threat and risk catalog.

5.2 Main Findings

Dealing with proper risk assessment in the smart grid domain is indeed challenging, mainly because of the novelty, complexity, and multidisciplinarity of this topic. Here, we present some of the main findings, derived from the application of our approach in a real user context. We foresee these qualitative statements as a major contribution for future improvements of our smart grid risk assessment approach.

5.2.1 Unbalanced Risk Distribution

Essentially, the probability of a security breach is comparatively low on the upper levels of the cumulative smart grid model, because components are small in numbers and easy to protect. An attacker typically has no physical access to components, and well-trained experts acting under rigid policies maintain the grid's backend. Furthermore, protection mechanisms on the upper levels do not suffer from cost pressure on this level; for instance, redundant systems and hot stand-by sites are state-of-the-art here. However, once an attacker manages to get access to critical systems, the negative impact will eventually be high; for instance, shutting down a primary substation node could affect whole city districts. This makes the security of higher level smart grid components a first priority for utility providers. On the other hand, the probability of a security incident on the bottom level of the cumulative smart grid model is much higher. The reason is that attackers can easily get hold of components (e.g., a concentrator or a secondary substation node) or have them installed on their own premises (e.g., a smart meter). The impact of an attack towards these components is expected to be (geographically) limited at a first glance. The situation may however change tremendously if someone publishes a successful smart meter mass attack on the Internet. This could lead to unanticipated cascading effects in the power grid. Hence, smart grid security on the lower levels of the smart grid is of major importance for utility providers as well.

5.2.2 Evolution of the Grid

Security challenges arise from the fact that the current power grid architecture is just step-wise transformed to a smart grid. While neither a pure legacy system nor a completely new system designed from scratch is too hard to be properly secured, while a mixture of both *is*. We identified that during the transmission of the current power grid into a smart grid, we are facing many security challenges: (i) the mix of legacy protocols and new protocols; (ii) the usage of wrappers, data converters, and gateways to make devices interoperable; (iii) short innovation cycles and rapid pace with which technologies advance clash with the traditional views of grid investments, where components have been designed to last for decades.

5.2.3 Technological Diversity

Not only the transformation phase, but also the final smart grid architecture foresees the application of a wide variety of different technologies (Skopik and Langer, 2013). Many security specialists argue that this diversity leads to a large attack surface, meaning that in hundreds of different protocols and implementations, a security relevant flaw is much more likely compared to only a small set of well-tested standardized technologies. This technological diversity and the need for seamless interoperability mostly avoids rigid designs and the setup of a uniform and secure architecture. On the other side, systems may be designed with different goals in mind so that the intermediary interfaces between them may lead to security vulnerabilities. Although standardization bodies, such as the NIST and BSI, have published (vendor-independent) viable technology recommendations and guidelines, there are no obligations for device vendors and utility providers to stick to them. However, we must not negate the positive aspects of technological diversity. Combining different technologies and products can help to prevent cascading effects caused by a specific vulnerability prevalent in a single technology or series of devices. As a consequence, an attack that has been successful at one utility provider is not necessarily successful at another one, if different technologies are deployed.

5.2.4 Risk Assessment Complexity

The complexity of risk assessment in the energy domain increases rapidly with the introduction of ICT components. This situation will become even worse, once smart grid technology is rolled out on a large scale, because systems become more and more coupled, even across geographical borders, resulting in strong interdependencies among components. The utility providers' concerns are therefore mainly centered around the understanding, detection, and mitigation of complex attack scenarios, where similarly to highly distributed computer systems, a multitude of vulnerabilities may be exploited in course of a complex attack. Estimating risks for such cases is extremely difficult, since numerous mostly unknown variables need to be considered. An example for such a complex attack case is the potential intrusion of malicious users into the metering backend through an exploitation of the smart meter communication network. Here, we argue that our architecture model, which clearly documents existing communication links as well as utilized protocols, is of significant help.

6 CONCLUSION AND FUTURE WORK

In this work we analyzed existing smart grid standards with respect to smart grid security and risk assessment together with leading manufacturers and utilities. Our study indicated that standards like NIST-IR 7628 (NIST, 2013b) or the Protection Profiles published by the The German Federal Office for Information Security (BSI, 2013b; BSI, 2013c) are only of limited practical use to utilities. As a consequence, in a joint approach with leading manufacturers and utilities, we analyzed seven national and four international smart grid projects to form a cumulative smart grid model representing both current and future European smart grids. In comparison to existing models like the U.S. NIST Smart Grid Framework (NIST, 2013a) or the European Smart Grid Reference Architecture (Smart Grid Coordination Group, CEN-CENELEC-ETSI, 2012b), our model is technically more detailed and includes a description of predominant communication technologies. In the second part of our work, we developed an extensive methodology to assess the risks involved within our cumulative smart grid model. While our threat catalog initially comprised a list of more than 500 threats, we were able to create a clustered catalog of no more than 31 threats that can be practically handled on top of the smart grid areas in our model. Due to the close cooperation with leading manufacturers and utilities, we believe that our work has a high practical impact on European utilities, as it can support them to conduct a risk analysis of their specific infrastructure.

In near future, we also plan to extend our risk catalog with respect to risk mitigation approaches and security controls, so that utilities can effectively mitigate identified risks with the help of our framework.

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APPENDIX

Table 1: Threat Assessment (Part 1). Notice, the threat category and an exemplary threat are given in the first two columns. Subsequent columns contain the quantitative and qualitative assessments results for (P)robability and (I)mpact on a scale from 1 to 5 for each threat and per domain.

Threat Category	Threat	Functional Buildings	E-Mobility incl. Infrastruct.	Household	Generation (Low Volt.)	Generation (High Volt.)
Authentication / Authorisation	*Defective or missing authentication or inappropriate handling of authentication data*	Relevant for all interfaces to the Smart Grid Gateway (Building Automation, Market/Internet und Secondary Substation) (P: 2; I: 2)	An attacker could impersonate the EMS and take control over all charge stations in an affected area (e.g., a street), which could lead to instabilities in the grid (P: 2; I: 3)	Relevant for Smart Grid Gateway and Smart Meter and all interfaces (configuration interface, Market, PLC to data concentrator and Secondary Substation) (P: 2; I: 2)	Exact scope and functionality of Smart Grid Gateway is not clear to date - how will the authentication towards the Automation Front-end and the Smart Grid Gateway be handled? (P: 1-3; I: 2-3)	Exact scope and functionality of Smart Grid Gateway is not clear to date - how will the authentication towards the Automation Front-end and the Smart Grid Gateway be handled? (P: 1-3; I: 3-4)
Cryptography / Confidentiality	*Disclosure of sensitive data*	Building automation data are sensitive since they may give away information about productivity or working hours (P: 2; I: 2)	Confidential load data could be eavesdropped on through the connection to the E-Mobility Management System or Smart Grid Gateway (P: 2-3; I: 2)	Metering data is confidential since it affects privacy and habits of the customers; impact of accidental disclosure depends on the scope of data and the number of households affected (P: 2; I: 3)	Output data of small producers is confidential since they may allow conclusions to be drawn on consumer behavior; high probability since no protection measures currently in place (P: 4; I: 3)	Hardly relevant since outout data are not confidential; low motivation (P: 1; I: 1)
Integrity / Availability	*Tampering with devices*	Hardly relevant due to physical access control; Smart Grid Gateway could be physically part of the Building Automation system; building operator has no motivation to compromise his own load management (P: 1; I: 1)	Tampering with EV, charge station or E-Mobility Management System; a malicious user can easily access relevant components; impact depends on whether private or public charge station is targeted (P: 3; I: 2-3)	Customers have direct access to the components; main motivation is fraud, but more severe attacks might as well be possible (e.g. issuing control commands) (P: 4; I: 3)	Relatively exposed (in a household); the amount of energy supplied may be a subject to fraud; depends on the use of anomaly detection techniques and plausibility checks (P: 4; I: 2)	Basic level of physical protection; low probability due to professional operator (P: 1; I: 4)
Missing / Inadequate Security Controls	*Defective or missing security controls in networks*	Communication via the network in the building; Smart Grid Gateway communicates via insecure networks (Internet), which opens up the possibility of distributed attacks on the Smart Grid Gateway (P: 1; I: 4)	Use of protocols that lack security features (e.g. IEC 61334 via PLC)could lead to eavesdropping on confidential load data; negative consequences for manufacturer / operator of the charge station, although the utility may also be affected (P: 2; I: 2)	Communication over insecure networks (Internet, PLC) (P: 3; I: 3)	Especially relevant for Internet connection to Secondary Substation Node (P: 2; I: 2)	Especially relevant for communication over the telecontrol WAN, currently IEC 60870-5-104 without encryption (P: 2; I: 3)
Internal / External Interfaces	*Illegal logical interfaces*	Illegal communication channels between the Gateway and interfaces (Market/Internet, Secondary Substation, Building Automation) could be established and exploited in an attack (P: 2; I: 3)	Illegal communicating with EV, charge station or E-Mobility Management System could lead to disclosure of confidential load data (P: 2; I: 3)	Illegal communication channels between the Smart Grid Gateway and ist interfaces (Market/Internet, Secondary Substation, Smart Meter) could be establish and exploited in an attack (P: 2; I: 3)	Due to physical exponation an attacker could interact with the system directly, thus revealing new interfaces that could be exploited (P: 3; I: 2)	Basic level of physical protection; access to telecontrol WAN may be feasible through faulty operation or targeted attacks (P: 2; I: 3)
Maintenance / System Status	*Operation of unregistered or insecure components or components with overly broad range of functions*	The Gateway could have a wide range of capabilities and functions, thus increasing the attack surface via the interfaces (Building Automation, Market/Internet, Secondary Substation) (P: 2; I: 2)	Possible disruption of the E-Mobility Management System or Smart Grid Gateway if connected to a non-standard or manipulated charge station ; local impact only (P: 1; I: 1)	Smart Grid Gateway or Smart Meter could have a too wide range of capabilities and functions, thus increasing the attack surface via the interfaces (Smart Metering, Market, Secondary Substation) (P: 2; I: 2)	Rather low probability since the components are dedicated to a very specific use; however, backdoors constitute a realistic threat scenario especially in replicated devices (P: 3; I: 2)	Rather low probability since the components are dedicated to a very specific use; however, backdoors constitute a realistic threat scenario (P: 2; I: 3)

Table 2: Threat Assessment (Part 2). Notice, the threat category and an exemplary threat are given in the first two columns. Subsequent columns contain the quantitative and qualitative assessments results for (P)robability and (I)mpact on a scale from 1 to 5 for each threat and per domain.

Threat Category	Threat	Testpoints	Transmission (High/Med. Voltage)	Transmission (Med./Low Voltage)	Grid Operation	Metering
Authentication / authorisation	*Defective or missing authentication or inappropriate handling of authentication data*	No authentication between Automation Front-end and Testpoint, although the Front-end authenticates towards the Primary Subst. Node (PSN); a spoofing attack could lead to false data being sent to the PSN; low impact (suboptimal supply) (P: 2-3, I: 1)	Due to the relatively low number of Primary Substation Nodes accounts or parameters can be configured and tested manually, therefore the probability is lower than in lower parts of the architecture model (P: 1-2, I: 4)	Especially relevant for remote maintenance access points; Secondary Substation Node and Concentrator can be easily accessed mostly, which gives a high probability; possibly regional impacts in case of unauthorized access (P: 4; I: 3)	Access rights management on SCADA systems implemented on an individual basis at utilities, standard IT technologies are employed; "identity spoofing" of calls to EMS; main threat is exploitation of insecure remote access solutions (P: 2, I: 4)	The connection between AMI headend and Smart Meters is encrypted by utilizing strong cryptographic primitives (ECDSA, AES); authentication and authorization is realized through certificates; thus, a high security standard is expected (P: 1, I: 2)
Cryptography / Confidentiality	*Disclosure of sensitive data*	Does not apply since test data (voltage, frequency) is not confidential	Current supply data and control commands are probably not confidential; consumption data are aggregated, therefore low impact (P: 2, I: 1)	Processing of confidential supply/consumpt. data in Concentrator and Secondary Substation Node; medium probability due to little (physical) protection (P: 3, I: 3)	For load estimation, consumption and energy production data is anonymized; power grid plans and control data is required to be protected accordingly (P: 1-2, I: 4)	Relevant since confidential power consumption data is processed and stored (P: 1, I: 3)
Integrity / Availability	*Tampering with devices*	Hardly relevant due to physical access control mechanisms in place; manipulation via the communication interface could be feasible (e.g. changing the configuration on SD card); low impact (P: 2, I: 1)	Tampering hardly relevant due to high voltage, but this may not hold for malicious insiders; currently strong impact (outage), but timely mitigation can be expected (P: 2, I:3)	Tampering possible especially with Concentrator; rather high probability due to little (physical) protection measures; regional impact (P: 3-4, I: 3)	Relevant if direct manipulation by insiders; remote manipulation over telecontrol WAN possible; forged process data may cause malfunction of DMS and subsequently lead to grid instability (P: 2, I: 4)	Low relevance due to physical protection measures (P: 1, I: 3)
Missing / Inadequate Security Controls	*Defective or missing security controls in networks*	Connected to Primary Substation Node via telecontrol WAN with IEC 60870-5-104 (unencrypted); low impact (suboptimal supply) (P: 2-3, I: 1)	Especially relevant for the communication via the telecontrol WAN; probability is low since security controls in place are more efficient than for the components in the lower parts of the architecture model (P: 1, I: 1-2)	Especially relevant for Internet/PLC connection to Middleware and Smart Grid Gateway (P: 2-3, I: 3)	Relevant for some interfaces (telecontrol WAN, EMS link); link to PSN secured with IPSec; telecontrol WAN link to Secondary Subst. Node could include forged data causing grid instability; (P: 2, I: 4)	Especially relevant for the interfaces to the outside world (i.e. connection to concentrators) (P: 1, I: 2)
Internal / External Interfaces	*Illegal logical interfaces*	Relevant for unauthorized access via telecontrol WAN; a DoS-attack on the Primary Substation Node could lead to generation plants going offline, resulting in voltage drops (P: 2, I: 2-3)	Relevant for access via telecontrol WAN (P: 2, I: 4)	Relevant for access via telecontrol WAN (P: 2, I: 4)	Relevant due to unauthorized access over external interfaces: telecontrol-WAN (Automation Headend), Webservice (EMS), Remote Access (SCADA) depending on deployed technologies (P: 2, I: 4)	Due to illicit logical interface (e.g. due to a successful attack) a connection from the metering system over the middleware to the grid operation system is feasible (P: 1, I: 3)
Maintenance / System Status	*Operation of unregistered or insecure components or components with overly broad range of functions*	Unregistered components hardly relevant (physical access control); an overly broad range of functions possible despite on-site maintenance (mostly no remote maintenance); low impact (P: 1-2, I: 1)	Unregistered components hardly relevant due to physical access control; an overly broad range of functions possible; low probability due to highly specialized components (compared to home area) (P: 1, I: 2-3)	Due to easy accessibility of the substations unregistered components could be installed; regional impacts (P: 3-4, I: 3-4)	Unregistered components are of low relevance due to physical access protection; unused but active system functionalities are relevant, especially considering remote access or support interfaces for manufacturers (P: 2-3, I: 4)	Unused but active system functionalities in the AMI headend lead to an increased attack surface (P: 2, I: 2)

Thermal Storage in a Heat Pump Heated Living Room Floor for Urban District Power Balancing

Effects on Thermal Comfort, Energy Loss and Costs for Residents

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Abstract: For the Dutch smart grid demonstration project Meppelenergie, the effects of controlled thermal energy storage within the floor heating structure of a living room by a heat pump are investigated. Storage possibilities are constrained by room operative and floor temperatures. Simulations indicate limitations for floor heating storage due to absorption of solar energy within the house. To balance power for district renewable energy supply, substantial energy can be stored into the floor without violating comfort limits. Heat loss to the outside due to floor heating storage is small in case of low energy houses and can be financially compensated. This may result in a proposition for residents which is equivalent to heating without thermal storage for power balancing purposes.

1 INTRODUCTION

For the smart grid demonstration project Meppelenergie, funded by the Dutch program Switch2Smartgrids, we develop smart grid control for the energy system of the new Meppel district Nieuwveense landen (AgentschapNL, N.D.).

The Meppel energy concept consists of a biogas CHP (Combined Heat and Power engine), heat pumps and underground thermal storage. The CHP is the main electric and thermal heat generator. The heat is used for a district heating system, supplying part of the houses in the district with domestic hot water and space heating. The electricity is used to drive heat pumps placed at houses with no connection to the district heating. The heat pumps supply these houses with domestic hot water and space heating. The heat source for the heat pumps is an underground aquifer which consists of a warm and cold well. During the heating season, the warm well provides heat for the heat pumps, during the cooling season, the cold well provides cooling energy for the houses.

Using heat pumps together with underground aquifers is increasingly applied in the Netherlands for commercial buildings, e.g. hospitals, office parks and malls (Rijkswaterstaat, 2013). Within housing projects, underground aquifers are mainly used for apartment buildings. Houses often use closed systems such as underground heat exchangers (CBS, 2011) and as an example (Witte et al., 2006).

For the Meppel district heating, there are large water stores to store thermal energy from the CHP, which is beneficial for the heat grid control. The houses with a heat pump have a domestic hot water storage but not for space heating. However, some storage capacity can be provided by thermal storage within the inert concrete floor heating system, which we will name Floor Heating Thermal Energy Storage (FHTES) throughout the paper. The application and economics of such a storage system within smart grid electricity control is investigated in (Toersche et al., 2012) and (Nykamp et al., 2012) which demonstrates that investments for strengthening the electricity grid can be avoided by applying FHTES for demand side control. However, FHTES has immediate effects on thermal comfort of

residents and also on energy loss of the building and therefore costs for the residents, which are not investigated yet. The problem statement for this paper is therefore: what are the effects on thermal comfort if energy is stored in the floor heating system, what is the energy loss and what are the related financial consequences?

Contribution of this paper is to develop mathematical relations and to demonstrate the relation between FHTES, thermal comfort, energy loss and energy costs. These insights and relations are to be used for developing algorithms to control district heating and heat pumps.

Outline of this paper: Chapter 2 describes related works on Thermal Activated Building Systems (TABS), control and performance. Chapter 3 gives theoretical backgrounds on modelling and thermal comfort. Chapter 4 describes a case study, followed by results and discussion in chapter 5. Conclusions are drawn in chapter 6. The appendix contains a list of abbreviations and the applied thermal network model.

2 RELATED WORK

In this section we discuss related work on TABS and power balancing by FHTES.

FHTES is investigated for different applications. One of the applications is cooling offices by thermal activation of floors during night hours (Fellin and Sommer, 2003), (Lehmann et al., 2007), (Pavlov and Olesen, 2011), (Rijksen et al., 2010) and (Saelens et al., 2011). Another application is lowering peak heating power for residential buildings (Airaksinen and Vuolle, 2013). More close to our application is a study on measured performance of heating and cooling systems using TABS in apartments (Alvi and Qureshi).

Besides effects on thermal comfort, FHTES also influences energy loss of the building and therefore energy costs paid by the residents. In (Scheepens, 2013) the ecocost approach was applied to investigate a novel house heating/cooling system with individual room temperature control for the Meppel project. In (Tahersima et al., 2011) the contribution of a control strategy for power balancing and FHTES is investigated. Thermal tolerance is introduced as a measure for effects on thermal comfort due to FHTES. In (Verhelst et al., 2012) optimal heat pump control in case of floor heating in relation with varying electricity prices is investigated. Thermal discomfort is introduced as a measure for effects on thermal comfort. Instead of using thermal tolerance or thermal discomfort, we propose in this paper to develop measures from governing standards on thermal comfort, as outlined in section 3.2.

Most of the mathematical work within the cited papers is applicable for general use. However, effects on thermal comfort, energy loss and energy costs are not investigated yet in a way corresponding with thermal comfort standards. Therefore we investigate how thermal comfort is influenced by FHTES and from this we deduce constraints and guidelines for control algorithms.

3 MODELLING APPROACH

In this section we define a simulation model and constraints from theory on thermal comfort.

3.1 Thermal Network Model

The thermal network approach is a convenient way to demonstrate the relation between FHTES, energy demand and effects on thermal comfort. Another reason to adopt this approach is to use the model equations for model predictive control within the TRIANA smart grid control method (Molderink, 2011), which is a part of future work. Accuracy of thermal networks is demonstrated in (Liu et al., 2011) and (Bacher and Madsen, 2011).

The applied thermal network for the living room of typical Dutch low energy house as defined by (AgentschapNL, 2013) and model equations are shown in the appendix. The concrete floor, the zone including internal separation walls, inner and outer parts of envelope walls and ceiling are modelled as temperature nodes with a thermal capacitance. Solar gains are defined at the outer wall node and the zone node by window transmittance. Heat loss due to ventilation and infiltration is defined at the zone node, as well as appliances and people gains. Heating input is defined at the floor node.

Weather data from Hoogeveen (close to Meppel) of ambient temperature and global transmittance, i.e. total solar radiation on the horizontal plane is used as input data within the model. Solar radiation on building planes is calculated using correlations by (Erbs, 1982) and equations by (Duffie, 1980). Transmitted radiation through the windows is for 25% absorbed by the floor and 75% by the zone structure. The house orientation is ideal for passive solar gains and there are no obstacles which could cast shadows on the house surfaces. In practise, this may not always be the case, especially not in mid-

winter when the sun is quite low above the horizon.

The simulation model includes Proportional Integral (PI) control of the heating/cooling input to the floor with the error between the zone temperature and its set point as controlled variable.

3.2 Theory on Thermal Comfort

The thermal network model of the living room is defined in such a way that it is possible to calculate the operative temperature of the zone. The operative temperature is defined in (ISO, 2005) and (ASHRAE, 2010) and is the most important comfort parameter to evaluate the influence of radiation from surfaces and air convection on experienced human thermal comfort. For relatively low air velocities applicable for home situations, the operative temperature of a zone is calculated from (ASHRAE, 2010):

$$T_{op} = \frac{T_{air} + T_{rad}}{2} \quad (1)$$

In which T_{air} is the zone air temperature and T_{rad} is the mean radiation temperature of all surfaces surrounding a person. It is impractical to calculate T_{rad} for each person as this also depends on the place where the person is situated in a room. Hence an average for a zone is proposed based on (ASHRAE, 2009).

$$T_{rad}^{4} \cdot \sum_{i=1}^{6} A_i = \sum_{i=1}^{6} A_i \cdot T_i^{4} \quad (2)$$

The living room zone is surrounded by 6 surface areas A_i with surface temperature T_i. Guidelines for the operative temperatures are defined in ISO 7730 and are related to the outdoor temperature in case adaptivity to outdoor conditions is taken into account:

- If $T_{outdoor} < 10°C$ then $20°C < T_{op} < 24°C$
- If $T_{outdoor} > 15°C$ then $22°C < T_{op} < 26°C$

A heated or cooled floor has an effect on the mean radiant temperature and on the operative temperature. But according to ISO 7730, a warm or cold floor also directly influences the thermal comfort of people. Limits can be calculated from the percentage dissatisfied equation given in ISO 7730 which yields: $19{,}2°C < T_f < 28°C$.

According to ISO 7730, another constraint is on dynamic changes of the operative temperature. Periodic peak-to-bottom variations should be limited to 1°C which is combined with a maximum rate of change of less than 2°C/hour.

Limits on radiant asymmetry pointed out in ISO 7730 are quite large and therefore not relevant for floor heating systems.

For home applications, it is worth to note the following:

1. ISO standard 7730 is developed and validated mainly for people working in offices and schools. People may evaluate thermal comfort different in a home situation, while people are more at rest while being at home. Besides that older aged people tend for higher operative temperatures than younger people. This causes differences in energy demand between households, which is important to take into account for the energy system configuration.
2. The minimum allowable floor temperature may not be reached during the heating season, as the floor heating will have to compromise heat loss of the house. So the minimum floor temperature is the floor temperature which is necessary to maintain a comfortable operative temperature of the zone.
3. The minimum allowable floor temperature limits cooling capacity of the floor cooling system during the summer season.

4 CASE DESCRIPTION

In this section we describe relevant details for the living room model and define scenarios for the case study.

Model parameters, i.e. specific mass of the concrete floor, ceiling and walls are derived from Dutch building details (Bouwformatie, 2013), (BUVA, 2013) and (VIEGA, 2009), which are currently applied for low energy houses in the Netherlands. The floor is a hollow channel concrete type. On top of the floor, the floor heating tubes are laid on a grid mat filled up with a concrete casting. Specific density of the total floor is typically 514 kg/m^2. The ceiling has the same structure as the floor. The envelope wall consists of a concrete inner wall, insulation material, air gap and brick outer wall.

To calculate electricity demand for the heat pump, a constant COP of 4,5 is assumed at all times.

Weather data of February 2012 from station Hoogeveen is used. Simulation results are shown for the 2nd week which runs from hour 168 to 336, i.e. midnight of the 1st until the 7th day.

The following control scenarios are investigated:

1. Control 1: Constant temperature set point of 20°C.

2. Control 2: Varying temperature set point: 19,5°C at night, 20,5°C at day. Control 2 is scheduled in such a way that operative temperatures are within thermal comfort limits during daytime hours and total energy demand is comparable to control 1.
3. Control 3: Same as scenario 2 but with additional short term storage for district power balancing.

Besides these control scenarios, the following energy price schemes are investigated:

1. Conventional: conventional power grid with lower night time energy rates.
2. Alternative: district power grid based on renewable PV-generation. Lower rates apply during hours with sunshine and higher rates during hours without sunshine.

5 DISCUSSION OF RESULTS

Simulated heating input for control 1 is shown in Figure 1 together with the global transmission, $G_{t,h}$ and the operative temperature of the living room. The influence of solar absorption by the interior of the living room can be observed as hours of less or even no required heating input. Besides this positive effect, this however reduces the possibilities for FHTES by the heat pump, as is deduced from the operative temperature. As explained in section 3.2, operative temperature variation should be less than 1°C, so the allowable range for this case is 20-21°C. On the 1st day, 21,3°C is reached due to solar absorption. As this is just outside the allowable range and energy can be saved by using the absorbed solar energy, possibilities to store energy by the heat pump are limited. It is also observed that as solar energy decreases the remainder of the week, longer periods of heating energy are required and operative temperatures are more stable, enabling more possibilities for FHTES by a heat pump.

To study heat loss, control 3 is introduced, which is basically the same as control 2 but with small additional two hour storage periods taking place at the indicated circles in Figure 3. As is observed from Figure 2, the heating input of control 3 is shifted in time compared to control 2. A simple way to accomplish this in a smart grid is that the central controller asks the home controller to temporarily raise the temperature set point. The total stored energy in the floor during each shift is 1600 Wh. Observe from Figure 2 that the total energy demand for the whole week is almost not influenced by these storage periods. The additional energy loss is calculated at 479 Wh, i.e. 6% of the total charged energy (8.000 Wh). This is rather small because of (a) good insulation of the house and (b) stored heat is consumed by the interior and results in a period of less heating input, observe the larger drop in the heating input of control 3 after each storage period, compared to control 2.

The effects of the storage periods on the operative temperature are shown in Figure 3 (compare control 3 with 2). The last four peaks almost reach to 21°C, which is just within the allowable range. The operative temperature seems to increase quite fast, but still less than 0,5°C/h, well below the requirements set out in section 3.2.

The short term storage period which was just calculated is significant for district power balancing. For the living room, the average heating requirement during the investigated week is calculated at 475 W.

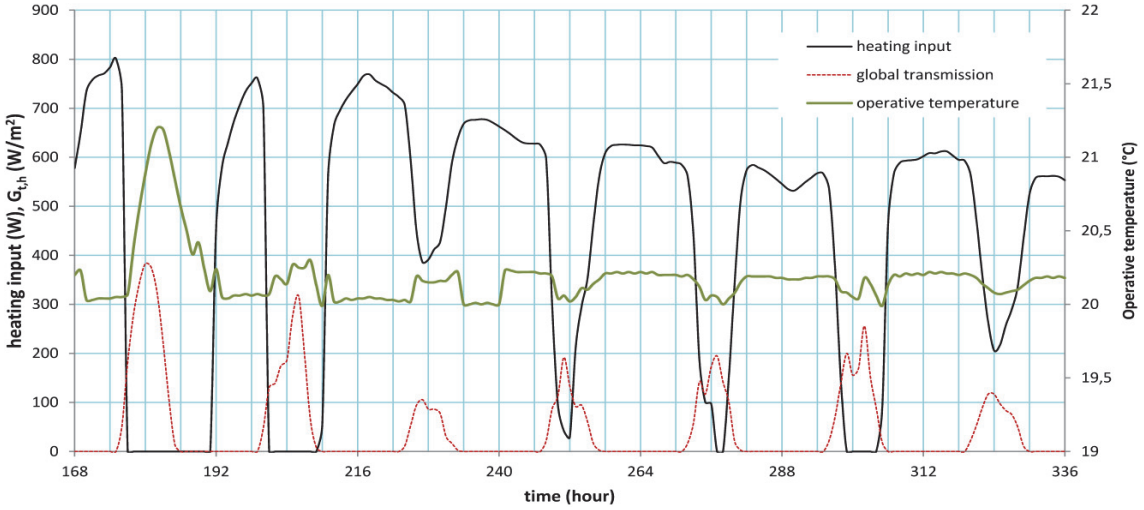


Figure 1: Floor heating input and operative temperature for control 1.

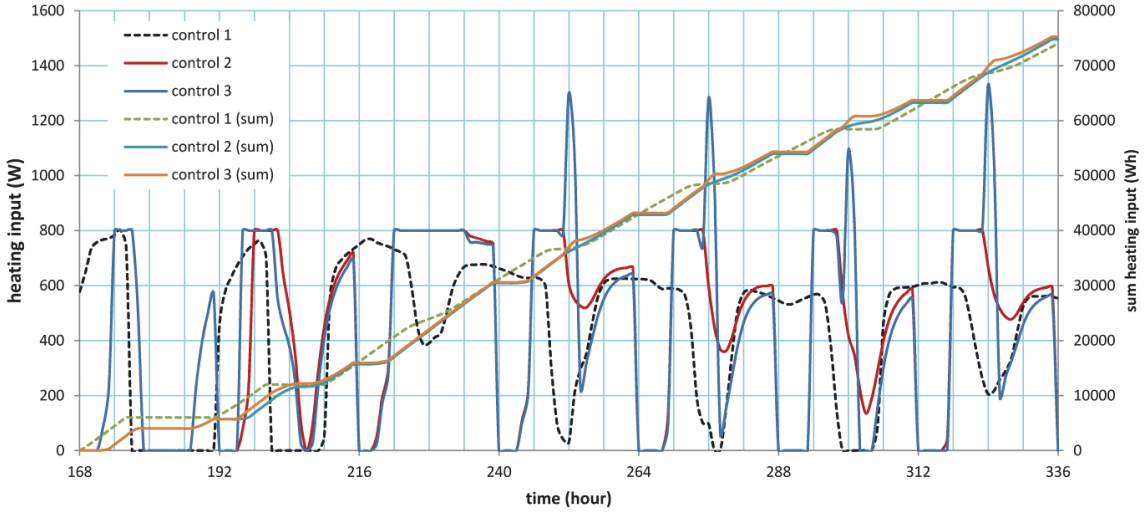


Figure 2: Heating input and sum of heating input to floor heating system.

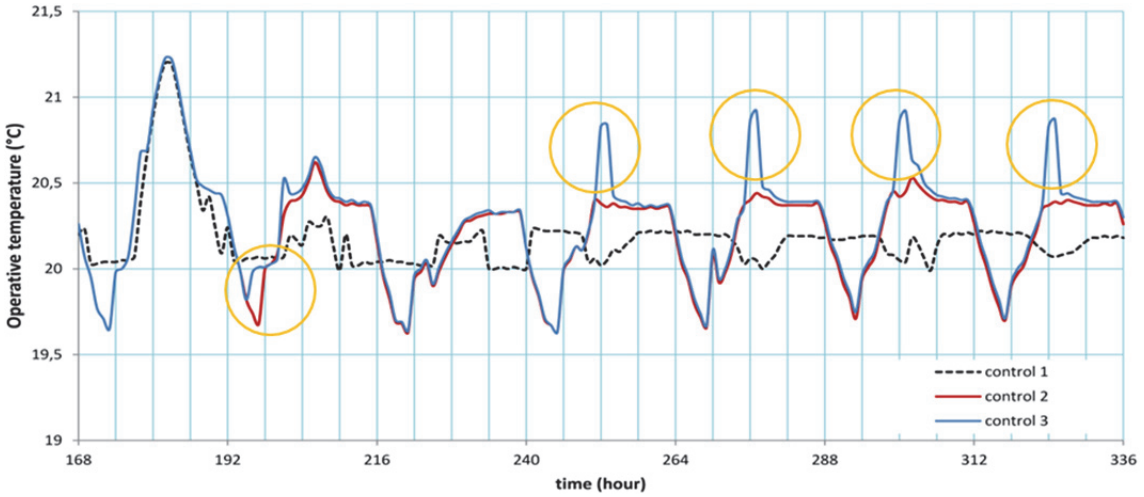


Figure 3: Operative temperatures.

With the heat pump COP assumed at 4,5 the CHP has to deliver on average 106 W electric energy to the living room. The short term storage period just investigated involved 800 W, i.e. 178 W electric energy. This is 168% of the average electric energy demand. Hence we conclude that floor heating systems can be used very well for short term periods of storage for district power balancing.

To study energy costs for the residents, the simulated energy input for the three control methods is translated into total required electric energy which is multiplied by energy price rates. A high rate of €0,30/kWh and low rate of €0,20/kWh including taxes and network costs are defined, i.e. close to actual Dutch consumer electricity rates.

Energy costs for the investigated week are referred to the reference case on the first line (i.e. 100%) in Table 1. As observed from Table 1 costs are higher for control 2 than for control 1 in case of a conventional power grid (compare both grey marked lines), because energy demand for control 2 is shifted towards daytime hours.

In case of PV-generation, control 1 has higher costs and control 2 has lower costs, as is observed from the 2nd and 4th line of Table 1.

Control 3 (5th line, Table 1) has the same basic temperature control as control 2 (lower night time temperature) but with some additional heat storage periods during day hours, typical for district power balancing in case of PV-generation. If on average the heat storage is offered for €0,21/kWh then the costs are comparable to the reference.

As a general rule for the storage rate, the standard rate for the applicable hour should be

reduced with the percentage energy loss (i.e. 6% in this case) caused by storage to offer a cost neutral proposition for the residents.

Table 1: Results energy cost comparison.

control	peak rate hours	energy costs (%)
1	07.00-23.00	100
1	18.00-24.00 0.00-09.00	112
2	07.00-23.00	119
2	18.00-24.00 0.00-09.00	100
3	18.00-24.00 0.00-09.00	100

6 CONCLUSIONS

By simulation the amount of Floor Heating Thermal Energy Storage (FHTES) by a renewable energy supply system, energy loss and cost strategies associated with FHTES is investigated. Resulting values are case specific, but the observed effects on energy demand and operative temperatures due to FHTES are valid for any building equipped with floor heating.

Our simulations show that the amount of energy that can be stored in a floor heating system depends on the house and floor heating structure, degree of insulation, weather and temperature settings by the residents.

From theory on thermal comfort, we find the following constraints for FHTES:

- allowable room operative temperature range: 20 to 24°C.
- periodic operative temperature variation: less than 1°C peak to bottom.
- operative temperature rate of change: less than 2°C/hour.
- allowable floor surface temperature range: 19 to 28°C.

In our simulations we compare three types of temperature control. A constant day/night temperature set point (control 1) shows that heating demand mostly occurs at night hours. A lower set point during night hours (control 2) shifts heating demand towards day hours. For district power balancing, control 2 has the advantage that the heat pump can be used more flexible during the night for generating domestic hot water. If additional to control 2, short storage periods during daytime hours are introduced (control 3), we find that operative temperatures remain within allowable comfort limits. We conclude from this that a house with a floor heating system provides substantial storage capacity which can be used to maintain power balance within a district energy supply system.

Energy loss due to FHTES appears to be small, at least for low energy houses. However, a fair energy cost policy should take this loss into account, e.g. by offering a discount energy storage rate to residents. In this way FHTES can facilitate district power balancing while maintaining acceptable levels of thermal comfort and energy costs for residents.

Our future work will be dedicated to further research on district power balancing and algorithms for smart grid control in which we apply knowledge presented in this paper.

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APPENDIX

This appendix contains the applied thermal network model and state equations for the temperature nodes. The used symbols and subscripts are listed in Table 2.

Table 2: Symbols and subscripts.

Nomenclature	
T	Temperature
R	thermal resistance
E	electric energy
q	thermal energy
HP	heat pump
Subscripts	
z	zone
f	floor
c	ceiling
z2	zone on first floor above living room
cs	creeping space
wi	interior wall of envelope wall
wo	exterior wall of envelope wall
rad	radiation
cv	convection
a	ambient or outdoor

Thermal network model equations

$$
\begin{aligned}
C_z \frac{dT_z}{dt} &= \frac{T_c - T_z}{R_{zc}} + \frac{T_a - T_z}{R_{win}} + \frac{T_{wi} - T_z}{R_{zw}} + \frac{T_f - T_z}{R_{zf}} + q_{gain,z} \\
C_f \frac{dT_f}{dt} &= \frac{T_z - T_f}{R_{zf}} + \frac{T_{cs} - T_f}{R_{fcs}} + \frac{T_c - T_f}{R_{fc}} + q_{gain,f} \\
C_{wi} \frac{dT_{wi}}{dt} &= \frac{T_z - T_{wi}}{R_{zwi}} + \frac{T_{wo} - T_{wi}}{R_{wi\text{-}wo}} \\
C_c \frac{dT_c}{dt} &= \frac{T_z - T_c}{R_{zc}} + \frac{T_{z2} - T_c}{R_{cz2}} + \frac{T_f - T_c}{R_{fc}} \\
C_{wo} \frac{dT_{wo}}{dt} &= \frac{T_{wi} - T_{wo}}{R_{wi\text{-}wo}} + \frac{T_a - T_{wo}}{R_{wo\text{-}cv}} + \frac{T_{sky} - T_{wo}}{R_{wo\text{-}rad}} + q_{gain,wo}
\end{aligned}
\qquad (3)
$$

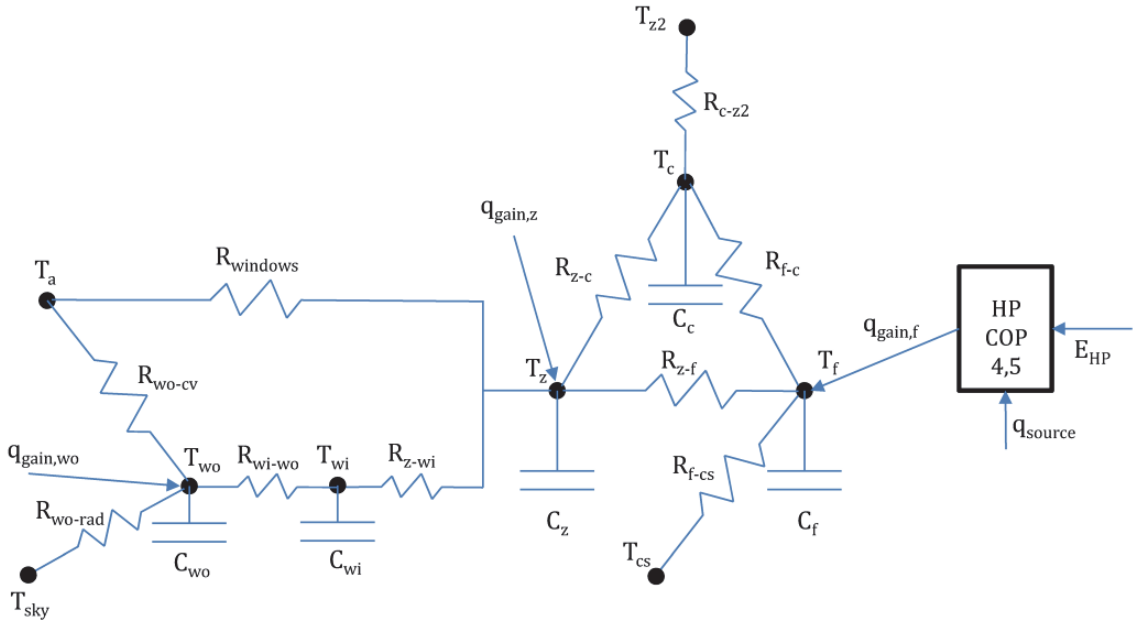


Figure 4: Thermal network model of low energy house living room.

SHORT PAPERS

Dynamic Modelling and Implementation of VSC-HVDC System
The Grid Connected Large Offshore Wind Power Plant Application

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Keywords: VSC-HVDC, Power System Analysis, Wind Farm Integration, DC Transmission System, Power System Modelling.

Abstract: This research contribution, investigates and analyse the operational characteristics of a voltage source converter (VSC), High-Voltage Direct Current (HVDC) transmission system. The main objective of this research endeavor is to evaluate the implementation of a HVDC transmission system for integrating offshore wind energy with the grid. Dynamic model of the system is developed in the Simulink environment. Stability analysis has been performed through three case studies namely the two active grid interconnection, active and passive grid interconnection and the offshore wind farm interconnection with the grid. Results are analysed and compared according to E.ON grid code requirements for offshore grid connection.

NOMENCLATURE

$\underline{i}, \underline{u}$	complex current, voltages
p, q	active power, reactive power
l, c, r	inductance, capacitance, resistance
P_m	modulation index
K, T	gain constant, time constant
ω	angular speed
Subscripts	
r, i	real, imaginary component
d, q	direct, quadrature axis component

Sign Convention: load oriented; consumed active and inductive reactive power are considered positive.

1 INTRODUCTION

Wind energy is one of the leading and foremost sources of energy in reducing the greenhouse-gas emission. According to the European Wind Energy Association, 9,616MW of wind energy was installed in the European Union during 2011, among which 8,750MW was onshore and 866MW offshore(Wilkes, 2010).

According to wind distribution theory, roughness class at sea level is lower than at ground. Lower roughness class means less obstacles and low wind speed variation. This predict that wind farm at offshore could have higher capacity as compare to onshore site. For short distance offshore site from land, HVAC transmission system is suitable as, it is least expensive, evolve and conventional technology for grid integration. However, at longer transmission distance due to cable capacitance, reactive losses increases significantly. Typically, HVAC transmission length is limited to 120km for offshore connection. HVDC system has some advantages over HVAC but it has higher development cost(Hulle and Gardner, 2010).

Nowadays, transmission and distribution system operators are giving significant consideration to HVDC transmission system. Past researches has established an idea that in comparison to HVAC for longer distance, HVDC transmission system is a suitable solution for transferring a large amount of energy, but beside that it is also very important to ensure that HVDC system should fulfills the grid compliances and perform similar as conventional transmission system.

General grid code defines the operational limits

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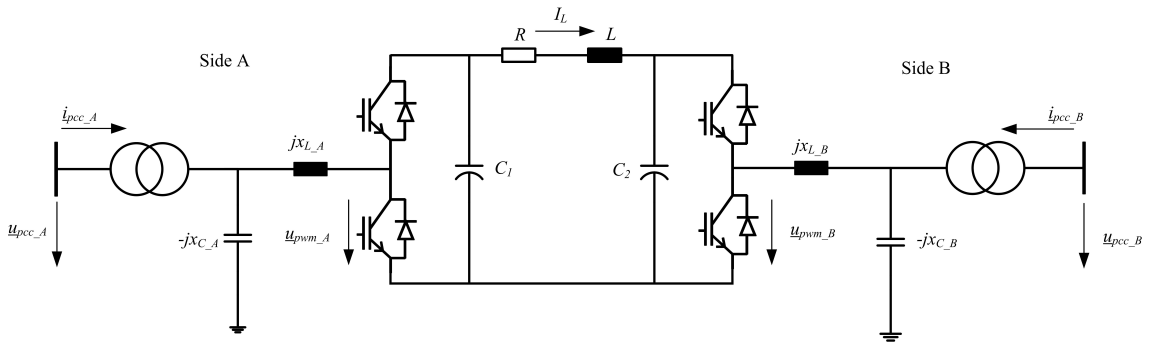


Figure 1: Point-to-Point Voltage-Source-Converter High Voltage Direct Current Transmission System Configuration.

and characteristic that a system must exhibit at point of common coupling (PCC). These limits are defines in term of voltage levels, frequency deviation and duration limits, reactive power capability, fault condition, and active power control. The E.ON grid code compliances for offshore wind farm integration with the grid summarized as follows(E.ON, 2008)(E.ON, 2006).

1. *Voltage Stability*: The nominal voltage (U_n) level of the grid is 155kV and continuous operational voltage range is 140-170kV. Wind generators should not be disconnected if voltage decreases $0.8U_n$ up to 3s, and voltage increase $1.2U_n$ up to 200ms.
2. *Active Power Control and Frequency Limits*: If frequency at PCC bus drop to 46.5Hz or rise above 53.5Hz then all wind turbines must be disconnected within 300ms. If grid frequency is in the range of 46.5-47.5Hz or 51.5-53.5Hz then turbines are only allowed to disconnect after 10s. After fault recovery in order to stabilize the voltage level, increase in active power per minute is permissible at maximum rate of 10% of P_n. If grid frequency exists within the range of 50.1Hz to 51.5Hz, active power must be decrease at the rate of 98% per Hz and 25% per second.
3. *Reactive Power Control*: Within the voltage range of +/-$0.05U_n$, and at power generation from maximum to $0.2P_n$, wind turbines must be capable of supplying reactive power up to $0.4P_n$ in overexcited and -$0.3P_n$ in under-excited condition. At PCC bus power factor must be control within the range of 0.925 lagging to 0.95 leading.
4. *Fault-Ride-Through Capability*: During fault, wind turbines must inject addition reactive current into PCC bus in order to support the voltage level. Voltage support must be provided when voltage drop is equal or greater than 5% of generator rated voltages. Voltage support control system should be activated within 20ms after fault detection. The amount of addition reactive power injection is depend on nominal voltage and rated current of the wind generator. Wind turbine must not be disconnected if voltage drops to $0.15U_n$ for 600ms.

Although, Voltage Source Converter (VSC) transmission system is new as compared to Line Commutator Converter (LCC) but it provides some advantages such as, option to control the active and reactive power flow independently, low harmonics, black or passive start, low or no reactive power requirement at no-load and bi-directional power flow.

In VSC, principle of a converter control systems is based on (1). Power flow between converter and network is controlled by varying voltage magnitude and phase angle.

$$\begin{aligned} P &= \frac{U_{pcc}U_{pwm}\sin\delta}{\omega l} \\ Q &= \frac{1}{\omega l}\left\{U_{pwm}^2 - U_{pcc}U_{pwm}\cos\delta\right\} \end{aligned} \tag{1}$$

2 VSC-HVDC SYSTEM MODELLING

The architecture of the VSC-HVDC transmission system developed is shown in Fig. 1. In this configuration, two points (defined as PCC bus) are connected via two VSC system and DC cables. PCC bus could be a connection point of a grid, island network (passive load), or wind farm. Bi-direction power among these two buses flows according to VSC control mode.

System is divided into three sections for modelling; VSC (converter/inverter), DC transmission line, and AC network. PWM-Converter is connected with the grid through coupling reactance. Coupling reactance stabilize the AC current, reduce the fault current, helps to reduce the harmonic current content

and enables the control of power flows from the voltage source converter. Typically, AC filter and converter reactor transform the non-sinusoidal output of converter into sinusoidal output.

The transformer is an ordinary single phase or three-phase power transformer, with a tap changer. The secondary voltage (filter bus) is control with the tap changer to achieve the maximum active and reactive power from the converter (both consumption and generation). In order to maximize the power transfer, low frequency zero-sequence voltage generated by the converter, is block by un-grounding the transformer secondary winding(Wang et al., 2009). Moreover, ability of VSC system to support the grid stability depends on three factors:

- *Rated Current of IGBTs*: According to (3), DC power is equal to AC active power. Since, maximum current flow is limited by IGBTs, therefore at rate power, MVA capability decreases if AC voltage drops.
- *DC Voltage Level*: Maximum AC voltage generated by VSC depends upon maximum DC voltage. Also, the amount of reactive power flow is proportional to the voltage difference of PCC and converter bus voltage. The reactive power capability of a converter is low if the difference between DC level and grid voltage is low.
- *Rated DC Current*: Maximum active power flow depends on the current carrying capacity of DC cable.

2.1 Voltage Source Converter (VSC) Model

In Simulink for RMS simulation, converter is model using DC voltage controlled AC voltage source and output signal is depend on modulation index. Complex AC voltage generated by the converter is calculated using (2). For simplicity, it is assume that there are no losses in the converter thus, power balancing equation is completed using (3). Converter can act as rectifier or inverter depending upon operation mode and set-points.

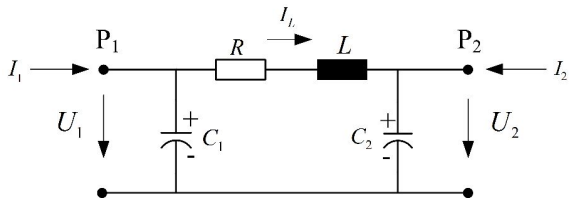


Figure 2: Equivalent Model of DC Cable.

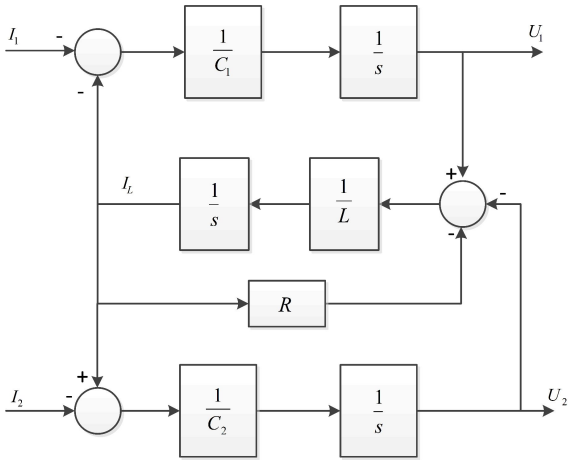


Figure 3: Simulink Control Diagram of DC Cable.

$$\begin{aligned} U_r &= K_0 P_{mr} U_{dc} \\ U_i &= K_0 P_{mi} U_{dc} \end{aligned} \tag{2}$$

$$P_{ac} = \Re\left(\underline{u}_{ac} \cdot \underline{i}^*_{ac}\right) = U_{dc} I_{dc} = P_{dc} \tag{3}$$

2.2 DC Transmission Line

DC cable is modelled as a π-link as shown in Fig. 2. Cable capacitance is divided into two parts and added with capacitance of the converter capacitance. In DC transmission only active power flows, therefore, line inductance is small enough to neglect, but it is included in model to complete the differential equation(Bao et al., 2011). Control system diagram of the transmission system is shown in Fig. 3.

2.3 AC Network System

AC network is consist of transformer, capacitor bank and series reactance. The system is represented as LCL network (inductance-capacitance-inductance). Characteristically, this configuration act as low pass T-filer as shown in Fig. 4. Transformer impedance and voltages are referred to the filter bus side. Using (4) and (5), we can represent AC system in *dq0* -coordinate system.

$$u^{\angle u_{pcc}}_{pwm\_d} = u^{\angle u_{pcc}}_{pcc\_d} + \omega l_T i^{\angle u_{pcc}}_{pcc\_q} + \omega l_L \left(i^{\angle u_{pcc}}_{pcc\_q} - \omega c u^{\angle u_{pcc}}_{pcc\_d} \right) \tag{4}$$

$$u^{\angle u_{pcc}}_{pwm\_q} = u^{\angle u_{pcc}}_{pcc\_q} - \omega l_T i^{\angle u_{pcc}}_{pcc\_d} - \omega l_L \left(i^{\angle u_{pcc}}_{pcc\_d} + \omega c u^{\angle u_{pcc}}_{pcc\_q} \right) \tag{5}$$

3 HVDC CONVERTER CONTROL SYSTEM

Control system has five operational modes i.e. passive network control, active power control (P), reactive power control (Q), DC voltage control (U_{dc}), and AC voltage control (U_{ac}). The flow diagram of HVDC control system is shown in Fig. 5. Control modes are defined according to the operational requirement(Yuan and Wang, 2012).

1. $U_{dc} - Q$: In this mode, DC-voltage and reactive power set-points are given. Usually, this mode is defined at the grid side converter to integrate passive load with active grid.
2. $U_{ac} - P$: In this mode, AC-voltage magnitude and active power set-points are given. This mode is set to integrate two active grids.
3. $P - Q$: This mode specifies active and reactive power set-points. Through, this mode PQ characteristic of a system is determined.
4. $U_{ac} - U_{dc}$: This mode specifies AC and DC voltage set-points.
5. *Passive Network Control*: In this mode, converter operates as a slack node (magnitude and phase control). Set at passive network or wind farm side converter control.

3.1 Active Power Control

In this mode, active power flow is control at PCC bus at desire value. An adaptive closed-loop proportional-plus-integral control system is developed for active power control. In voltage oriented reference system, for the condition $u_{pcc\_d} = 1.0p.u$, the active current reference can be obtained using control configuration shown in Fig. 7. Active power flow from AC to DC network raises the DC voltage. If there is large imbalance in power at both side then DC voltage will exceed the maximum operating voltage limit of cable. Furthermore, when transferring large power over a long distance, DC voltage difference between sending end and receiving end will be high due to line resistive losses.

Therefore, it is needed to limit the power flow according to maximum permissible DC voltage. Dynamic saturation limits shown in Fig. 6, are applied at the output of proportional-plus-integral controller.

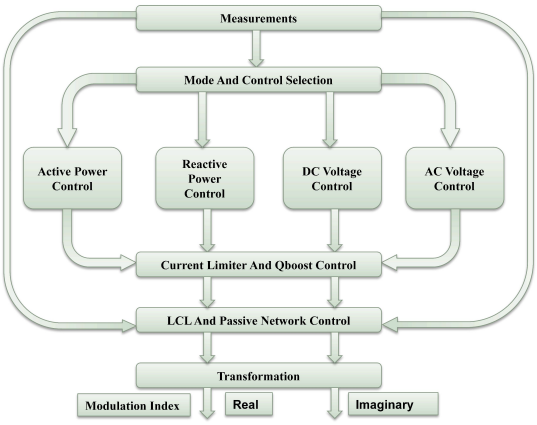


Figure 5: Voltage Source Converter Control Architecture.

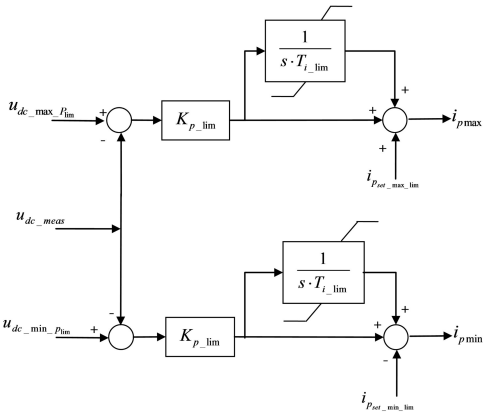


Figure 6: Dynamic Limits for Active Power Control.

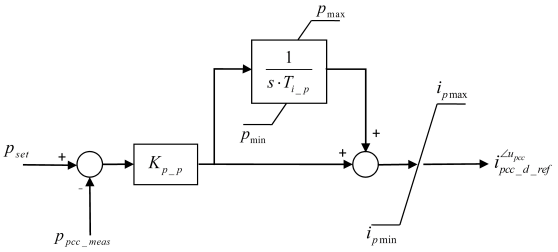


Figure 7: Proportional Plus Integral Controller for Active Power Control.

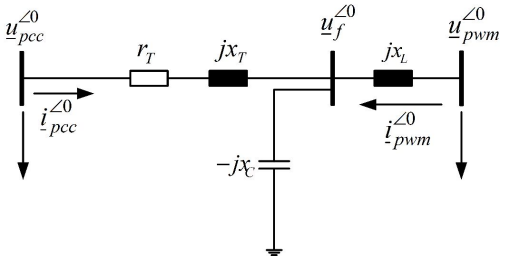


Figure 4: Phasor Representation of Transformer Impedance, Series Reactance and Filter Capacitor as LCL Network.

3.2 Reactive Power Control

In this mode, reactive power flow is control at PCC bus at desire value. In voltage oriented reference system, reactive power can be controlled by reactive current reference using (6). PI control configuration is calculated using (7).

$$q_{set} = i_m \sin\delta = -i_{pcc\_q\_ref}^{\angle u_{pcc}} \tag{6}$$

Reactive power demand depends on the PCC bus voltage. Often, it is defined in grid code to have a power factor within the range of 0.925 overexcited and 0.95 in under-excited operation. Thus, according to *PQ* characteristic maximum permissible reactive power flow is approx. 55% of rated power.

$$i_{pcc\_q\_ref}^{\angle pcc} = \left\{ K_{p\_q} \left(1 + \frac{1}{s \cdot T_{i\_q}} \right) \right\} \cdot (-q_{set} + q_{meas}) \tag{7}$$

3.3 DC Voltage Control

In this mode, converter control the DC voltage at desire value. Active AC and DC power transmitted over a DC cable using voltage source converter is calculated using (8) and (9).

$$P_{ac} = U_d I_d + U_q I_q \tag{8}$$

$$P_{dc} = U_{dc} I_{dc} \tag{9}$$

In balance rotating, synchronous frame in voltage oriented system, *dq0* voltages are constant. Such that U_q and U_0 are zero and U_d is rated voltage. Imbalance in AC and DC power leads to a change in DC voltage level across DC capacitors. Voltage across the capacitors is calculated using (10).

$$C \frac{\partial U_{dc}}{\partial t} = \frac{1}{U_{dc}} \{P_{ac} - P_{dc}\} \tag{10}$$

To maintain the constant DC level at rated voltage, system must fulfill condition (11).

$$\begin{aligned} P_{ac} &= P_{dc} \\ U_d I_d &= U_{dc} I_{dc} \end{aligned} \tag{11}$$

From (11), it is obvious that DC voltage can be controlled through the d-component of reference current. The PI control system implementation for DC voltage control is shown in Fig. 8. Maximum and minimum permissible voltage levels are 120% and 90% of rated DC cable voltage, respectively.

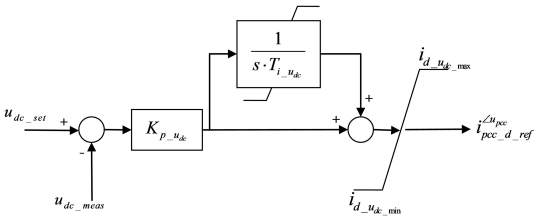


Figure 8: Proportional Plus Integral Control for DC Voltage Control.

3.4 AC Voltage Control

In this mode, AC voltage of PCC bus is control at desire value. It is obvious from (1) that reactive power flow can be control by controlling voltage difference between converter and PCC bus. Thus, voltage drop across transformer and line reactance together can be calculated using (12). In *dq0* balance voltage oriented synchronous frame, reactive power is controlled by q-component of the reference current, consequently controlling AC voltage level.

Close loop PI control system is implemented to control the AC voltage. In addition to that, washout filter is also incorporated to block the high frequency noise in input signals. The control diagram of AC voltage control is shown in Fig. 9.

$$\begin{aligned} \Delta u &= u_{pcc}^{\angle 0} - u_{pwm}^{\angle 0} \\ &\approx (r \cdot i_d - x \cdot i_q) + j(x \cdot i_d + r \cdot i_q) \\ &\approx -x \cdot i_{q\_ref}^{\angle u_{pcc}} + jx \cdot i_{d\_ref}^{\angle u_{pcc}} \end{aligned} \tag{12}$$

3.5 Passive Network Control

Passive network control is designed for operating wind farm and consumer load. In this mode, PCC bus acts as an active node i.e. voltage magnitude of converter bus is adapted according to load impedance, such that voltage level at PCC bus controlled to 1.0p.u. Passive network control equations is derived using (13).

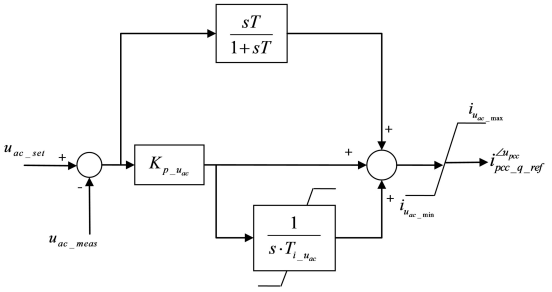


Figure 9: AC Voltage Control of Voltage Source Converter with Washout Filter.

$$u_{pwm\_d}^{\angle u_{pcc}} = u_{pcc\_d}^{\angle u_{pcc}} + x_T \cdot i_{pcc\_q}^{\angle u_{pcc}} + x_L \cdot i_{pwm\_q}^{\angle u_{pcc}}$$
$$u_{pwm\_q}^{\angle u_{pcc}} = -x_T \cdot i_{pcc\_d}^{\angle u_{pcc}} - x_L \cdot i_{pwm\_q}^{\angle u_{pcc}} \quad (13)$$

Voltage stability depends upon the demand of reactive power. The droop Characteristics for voltage set point is implemented to generate or absorb the reactive power. A droop characteristic for the voltage controller is demonstrated in Fig. 10. Since, reactive power flows from higher voltage level to lower voltage level, therefore, set-point of voltage should be increased, when the demand for the reactive power increase. Droop control system is useful for supplying power to inductive load or wind farm with DFIG(Zhang and Lennart, 2011).

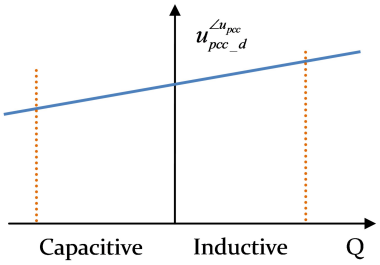


Figure 10: Droop Characteristic of Passive Network Control.

The voltage reference value is calculated using (14):

$$u_{pcc\_d}^{\angle u_{pcc}} = u_{pcc\_d\_set}^{\angle u_{pcc}} + K \cdot q \quad (14)$$

4 DYNAMIC PERFORMANCE ANALYSIS

Dynamic response of HVDC system is evaluated using three case studies. Analysis are performed to evaluate the system ability to remain stable due to small disturbance during operation. Since, VSC-HVDC transmission will be used as an alternative of the convention AC transmission system, therefore, it is important to assess the performance of the system compatibility with the existing system. And, it is required to perform the operational capability tests such as, ability to transfer large power at long distance while maintaining voltage stability, independent active and reactive power control capability, ability to integrate weak grid, ability to supply power to island or passive network, and ability to integrate wind farm. For all case studies, approx. 100km transmission length is considered.

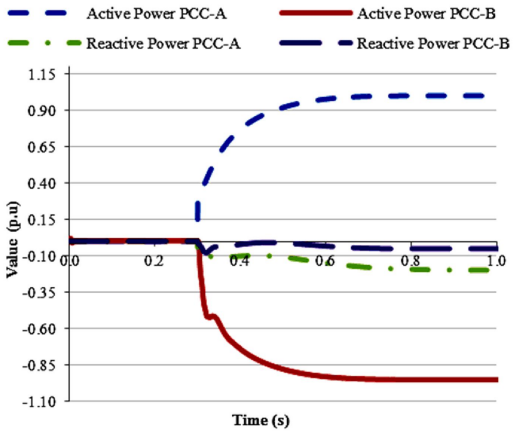


Figure 11: Power Flow Response of a HVDC System Interconnecting Two Active Grid.

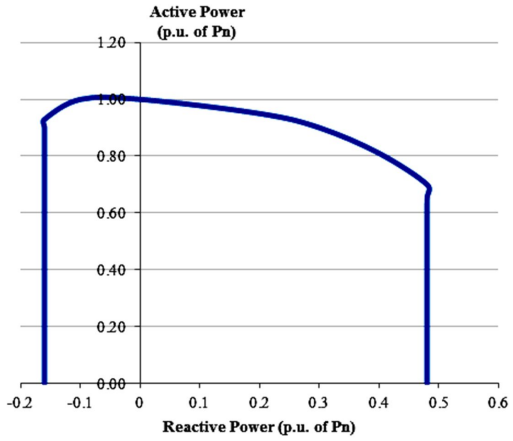


Figure 12: P-Q Diagram of 'Side-A' Converter with 100km Transmission Line.

4.1 Interconnection of Two Active Grids

In this study, transmission system describes in Fig. 1. is connected with two active grids each at both sides. Capacity of converter is approx. 200MW. 'Side-A' converter is set in $P-Q$ mode and 'Side-B' converter is set in $U_{dc}-Q$ mode. Initially, $P-Q$ set-points are zero, therefore, no power flows. Step change in power demand from zero to full load at 0.3s is applied by changing $P-Q$ set-points at 'Side-A' converter, which lead power to flow from side A to B. Due to sudden in-feed of active power into transmission system, DC voltage rises up to 1.16p.u. Increase in DC voltage level is proportional to the active power available to 'Side-B' converter to supply into network.

Power and voltage response of the network are shown in Fig. 11. and Fig. 13. respectively. It is to be notice that at set active power at 'Side-A', in order to stabilize the voltage level at PCC bus, 20% of P_n re-

active power injection is required. This is achieved by setting the reactive power set-point to $-0.2p.u.$ This demonstrates VSC control scheme capability to control active and reactive power independently.

Losses and voltage drop over the DC transmission line depend only on the resistance of the cable. At given cable parameters, voltage drops over the cable according to simulation results are approx. $0.04U_{dc\_rtd}$.

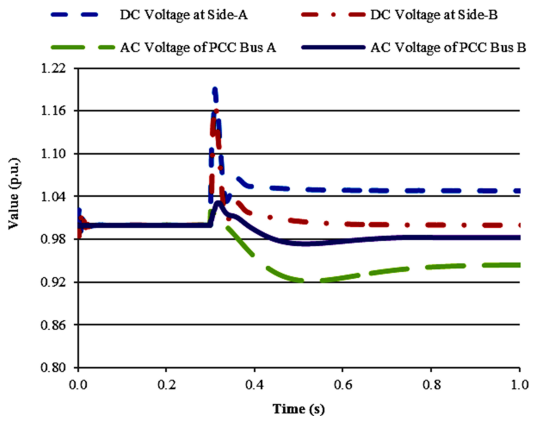


Figure 13: DC and AC Voltage Response Interconnecting Two Active Grid.

PQ diagram provides information about the range and limits of operating point of the system for stable operation. Fig. 12. shows the *PQ* characteristic of 'Side-B' converter, connected to the capacitor bank of $0.15P_n$ capacity.

Voltage strength of the network also depends on the short circuit capacity of the grid. A high short circuit capacity means, network is strong and stiff i.e. switching on/off a load, or shunt capacitors/reactors will not affect the voltage magnitude, significantly.

The effect of grid strength is directly reflected by the grid frequency. Strength of the network is defined by a short circuit ratio (SCR) i.e. it is the ratio of grid short circuit power to the converter rated power(Egea-Alvarez et al., 2012).

Table 1: Strength of Network.

Network Strength	SCR
High	> 5
Moderate	$3-5$
Low	$2-3$
Very Low	< 2

$$SCR = \frac{S''_{k\_grid}}{P_{r\_con}} \tag{15}$$

The comparison of VSC-HVDC system ability to maintain the system frequency at nominal value with both strong and weak network connection can be visualized from Fig. 14 and Fig. 15. At lower SCR, change in grid frequency during transition period is approx. 0.7Hz, which lead grid frequency drop to 49.3Hz at 'Side-A' and rise to 50.7Hz at 'Side-B'. In addition, weak grid has high internal impedance as compare to strong grid, thus it cause the higher voltage drop at PCC bus. Therefore, in order to stabilize the bus voltage 20% of P_n at 'Side-A' and 5% of P_n at 'Side-B' capacitive reactive power injection is required.

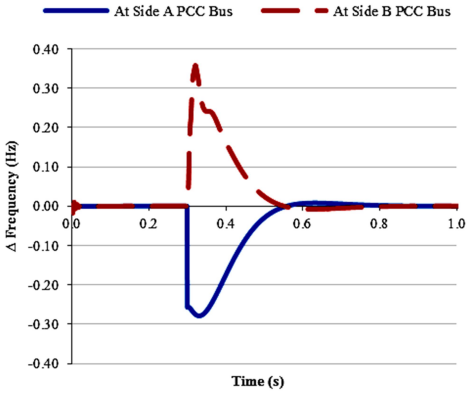


Figure 14: Effect of change in grid frequency at both sides PCC bus on changing load demand at SCR ratio of 5.0.

4.2 Interconnection of Passive Network

In this case study, analysis is made to evaluate the performance of developed control system for black start and to supply energy to passive network. For simulation, network configuration is same as shown in Fig. 1. Here, converter at load side 'Side-A' is set into passive mode and grid side converter 'Side-B' is set into $U_{dc} - U_{ac}$ mode.

Load side converter act as an active source to the load. The passive control system tries to maintain the PCC bus voltage at 1.0p.u, and voltage magnitude and phase angle at the converter bus adopt itself, accordingly. The response of basic operation of consumer connected to the grid through HVDC system is shown in Fig. 16. Consumer load of 0.7p.u active power and 0.1p.u inductive reactive power is set for simulation purpose.

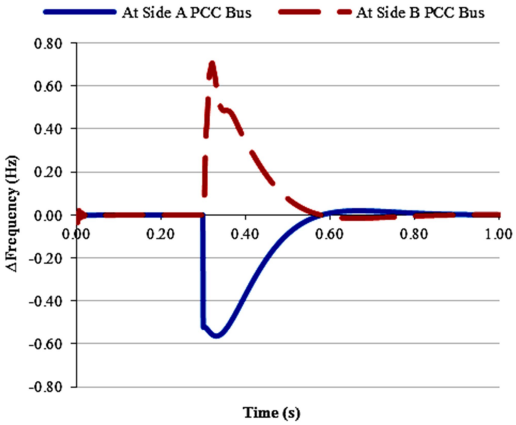


Figure 15: Grid frequency variation at both sides PCC bus at 2.5 SCR.

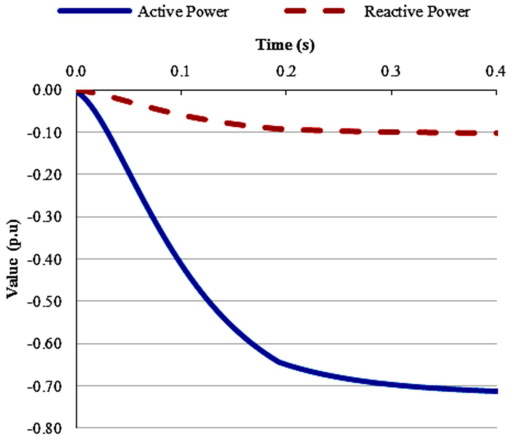


Figure 16: Active and reactive power at PCC bus of 'Side-A' connected with passive load.

AC signal generated by VSC is dependent on DC voltage. Sufficient DC voltage is required to generate the desired AC magnitude and phase angle to fulfill the demand. Converter model generates 1.0p.u AC magnitude at 1.0p.u DC voltage level at modulation index ($P_m = 1$). At the given parameter, voltage drop across the transmission line is 5% of U_{dc}. In order to deliver the rated power, it is required to compensate the voltage drop and the power losses into the transmission system. This is done by adjusting the set point for DC voltage control at the grid side converter to higher level. Fig. 17. shows the voltage response at passive load PCC bus.

In Table. 2, capability of VSC-HVDC system to operate at different power factor is shown. As explained previously, that the passive network control system tries to maintain the PCC bus voltage at the load side to 1.0p.u. The effect of capacitive and inductive load can be seen from converter bus voltage.

It is to be seen that at u_{pcc}, nominal voltage remains 1.0p.u at all power factor and converter control system adapt its voltage to generate or consume reactive power. Now, if we observe the simulation results at 0.9 capacitive power factor, converter bus voltages (u_{pwm}) reduce to 0.87p.u. And, at 0.9 inductive power factor, u_{pwm} increases to 1.2p.u. Moreover, DC voltage across the capacitor at 'Side-B' is rise to its maximum permissible voltage. Theoretically, voltage collapse phenomena occur, when bus voltage does not remain within the following limits;

$$0.8 \leq u_n \leq 1.2$$

Since, internal bus voltages are within the above design criteria. Thus, it can be concluded that the system is stable for 0.9 leading to 0.9 lagging power factor.

Table 2: Simulation Results of 'Side-A' System at Different Capacitive and Inductive Power Factors.

				Passive Load		DC Voltage Across Capacitors	
	Power Factor	u_{pcc}	u_{pwm}	Active Power	Reactive Power	Side-A	Side-B
Capacitive	**0.90**	**1.00**	**0.87**	**1.00**	**0.48**	**1.00**	**1.05**
	0.925	**1.00**	**0.89**	**1.00**	**0.41**	**1.00**	**1.05**
	0.95	**1.00**	**0.93**	**1.00**	**0.33**	**1.00**	**1.05**
	0.98	**1.00**	**0.97**	**1.00**	**0.20**	**1.00**	**1.05**
	1.00	**1.00**	**1.05**	**1.00**	**0.00**	**1.05**	**1.10**
Inductive	**0.98**	**1.00**	**1.12**	**1.00**	**0.20**	**1.07**	**1.12**
	0.95	**1.00**	**1.17**	**1.00**	**0.33**	**1.11**	**1.16**
	0.925	**1.00**	**1.19**	**1.00**	**0.41**	**1.14**	**1.18**
	0.90	**1.00**	**1.20**	**1.00**	**0.48**	**1.15**	**1.20**

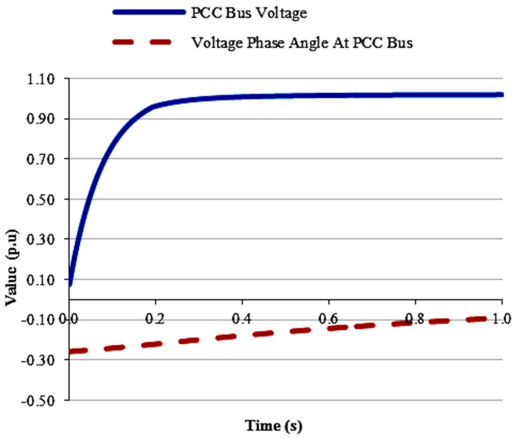


Figure 17: Response of AC voltage and voltage phase angle at PCC bus connect to passive load

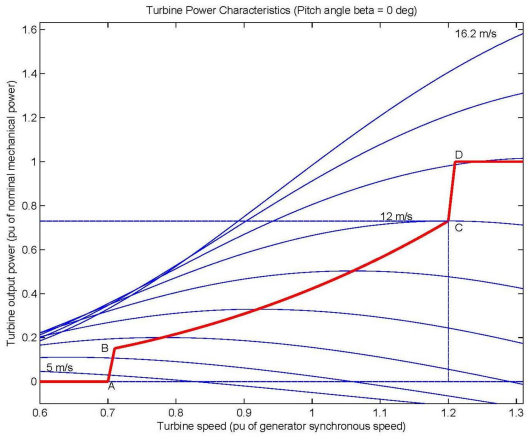


Figure 18: Doubly-Fed-Induction generator torque speed characteristic

4.3 Interconnection of Wind Farm

In this case study, system response connecting wind farm with the grid over long distance is analysed. MATLAB standard DFIG model is used for simulation purpose. The behavior of wind turbine output power with respect to turbine speed and wind velocity is shown in Fig. 18. At 'Side-A' in Fig. 1. an equivalent model of wind farm array is connected with the overall capacity is 45MWatt. To simulate the model, converter connected with wind farm is set into passive control mode and grid side converter is set into the $U_{dc} - U_{ac}$ control mode.

The response of wind farm power in-feed into the grid via HVDC transmission system can be observe from Fig. 20. It can be notice that power generation increases due to change in wind speed from 3m/s to 14m/s. As a result, active power received from wind

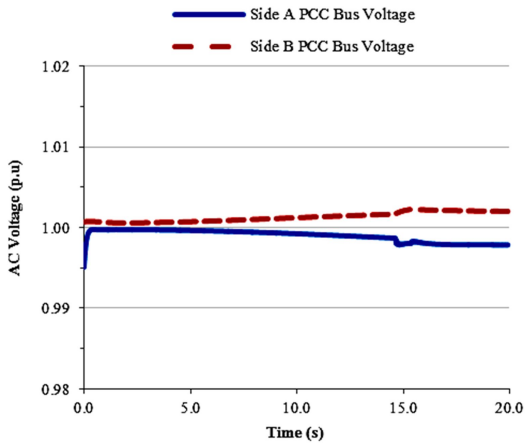


Figure 19: Dynamic AC voltage response due to wind energy injection into the grid

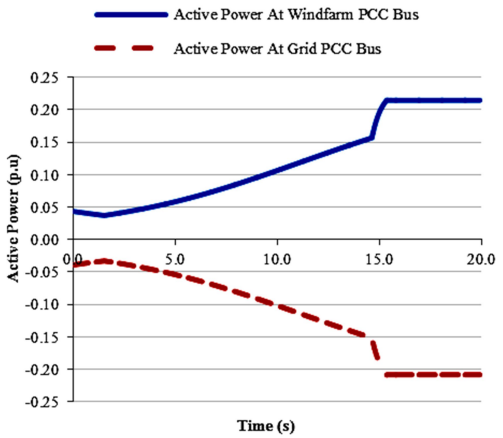


Figure 20: Wind farm active power generation and in-feed into the grid

farm is transferred to grid with minimum losses, and HVDC system provides the stable operation. Fig. 19 demonstrate the ability of VSC-HVDC system to fulfil the DFIG reactive power demand and control system is able to maintain the voltage level within the design limits.

Despite the higher investment cost of HVDC transmission system as compare to AC transmission system for interfacing wind turbines with the grid(Bresesti et al., 2007), HVDC system provide benefit of reducing the impact of varying wind generation and gives ability to control the reactive power, consequently, supports the grid voltage.

5 CONCLUSION AND RECOMMENDATION

The aim of the work resulting in this research is to develop the VSC-HVDC control system and study the feasibility of using it as an alternative of conventional HVAC system. 'Case-A' study concluded that with independent control of the active and reactive power, it is possible to transfer large power between strong and weak grid and achieved improve voltage and frequency stability. Results have shown that the reactive power generation capability of VSC-HVDC system increases by increasing capacitor bank capacity and, ability to operate at full active power at maximum over-excited condition is increased by decreasing the transmission length. The design system is capable of operating at 0.9 under and over excited power factors. The simulation results of 'Case-B' show that the change in power factor at load side does not affect the voltage stability at grid side system. Also,

leading and lagging reactive power generation capability of converter can be improved by incorporating transformer tap control into converter control system. Results from 'Case-C' study conclude that the developed control system is capable of integrating wind farm with the grid over long distance and fulfil reactive power demand of wind turbine without addition compensation.

In addition, VSC-HVDC system is model for simulation of small signal disturbance. The developed control system can be extended for critical case investigation such as fault-ride-through capability and multi-terminal HVDC system. This research outcome is useful for pre-designing electrical power system, power system modelling and simulation and to study the impact of wind energy on system dynamics.

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PMU for Detection of Short-circuit Point in the Transmission Line

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Keywords: SmartGrid, Phasor Measurement Units, Short-circuit Point, Transmission Lines.

Abstract: One of the challenges facing energy systems is failure of overhead and cable transmission lines. Short circuits pose a particular danger. The improvement of the quality of installation, and reliability of insulators and conducting materials decreases the probability of short circuits but does not eliminate it. Short circuits result in disconnection of certain companies and even regions. The suggested method is based on the fact that the short circuit current at the source end of the line depends on the distance to the point of short circuit. The paper considers the following issues: theoretical possibility of detecting the point of fault on the basis of time when the short circuit response arrives at the source and load ends of the line; development of an algorithm for primary data processing, development of a structural scheme of additional devices which are not envisaged within phasor measurement units.

1 INTRODUCTION

Electric power industry is one of the most dynamic sectors which employs the advances of fundamental and applied sciences. At this very stage special attention is paid to the global system of universal time. Even two decades ago the universal time was the province of special organizations dealing with space, industry, defence, astrophysics, etc. The adoption of the Global positioning system has made it possible to receive the standard time signals at an individual substation and use this precise time for solving a wide range of problems. Based on these technologies it has become possible to develop and adopt intelligent electric systems, Smart Grids, and phasor measurement units (PMU).

A serious problem facing energy systems is failure of overhead and cable transmission lines. Short circuits represent a particular danger. The probability of short circuits decreases but does not disappear with an increase in the quality of installation, reliability of insulators and conducting materials. Short circuits lead to disconnection of individual consumers and the entire regions. This imposes high requirements on reliability and fast operation of relay protection. However, if a short circuit has occurred and relay protection has successfully operated there remains the task to promptly and where possible accurately detect coordinates of the short circuit. This, in the end allows us to quickly restore the transmission line and place it into operation which in turn will minimize economic losses.

There can be two types of research in the electric power industry: active and passive experiments. An active experiment can be exemplified by probing the faulty transmission line with the help of short pulses of current and assessing the response time. This time depends on the distance between the source end of the line and a short circuit point. A disadvantage of active experiments is the necessity to apply special equipment and the time to get prepared to the experiment.

There is a great variety of methods for detection of overhead and cable line fault locations. Let us enumerate them in brief.

The pulse method is based on measuring time intervals between the moment of transmitting a probe pulse of alternating current and the moment of receiving a reflected pulse from the fault location. To make measurements by the method of oscillation discharge the voltage supplied to the faulted cable conductor is gradually raised to the voltage of cable fault. The loop method is based on measuring resistances by the direct current bridge. The capacitance method suggests measuring capacitance of a broken conductor by measuring bridges. The acoustic method supposes creation of a spark discharge at the fault location and listening to sound vibrations that occur above the fault point. There is

also the induction method and others.

Passive experiment however makes it possible to use modern high speed digital technologies, and obtain data (instant values of current and voltage, voltage and current phases) directly from the signals associated with the processes that occur in transmission lines after a short circuit, i.e. in real time. One of the possible solutions to this problem is related to the dependence of currents at the source end of a line on the distance to the short circuit point (Gilany, 2005, Hajjar, 2004, Ferreira, 2012, Chengjiang Wang, 2011, Provoost 2005, Suslov 2012). However, there are reasons that decrease the accuracy of the fault point detection, namely: variations in the effective values of voltage at the transmission line connection point, as well as the dependence of current amplitude on voltage phase at the time of short circuit. The authors suggest the use of time factors related to the final velocity (v_F) of power (electric signal) transmission along the transmission line. It is obvious that there will be a response (echo) spreading in both directions along the line, that will have the form of a front of increasing or declining voltage or current and the time of the response arrival at the source end or load end of the line can be recorded with a high accuracy.

The paper focuses on the following issues:

- Consideration of the theoretical possibility of determining the fault place on the basis of time when responses come to the source end and load end of the line;
- Determination of the possibility of using the available infrastructure of PMU to determine the above time instants and transfer the data to the processing center;
- Development of an algorithm for primary data processing;

Development of a block diagram of additional devices which are not envisaged within PMU.

2 THE MAIN PRINCIPLES OF THE APPROACH

We will consider the idea of the suggested method on the example of a transmission line without branches with one-way supply.

Figure 1 shows the calculation scheme for the determination of the short circuit place, taking into consideration the time of signal arrival at the source and load ends of the line.

Let the short circuit occur at time t_{sc} *at* point K (Fig.1) and a transient process start. For the sake of simplification we make the following assumptions:

- voltage at point K drops to zero;
- length of the considered line is much shorter than the length of the incident current wave λ (λ≈5000 km at the frequency of 50 Hz).

We can also assume that the instant values of current and voltage in the steady state are constant along the whole line.

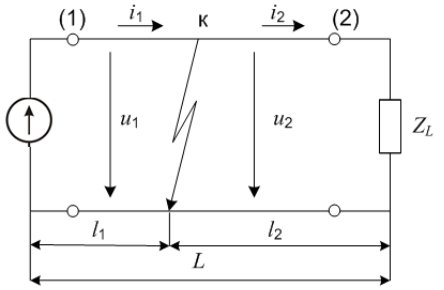


Figure 1: Design scheme of a short circuit in a line.

In Figure 1: L-length of the line; l_1, l_2 – distances from the short circuit point to the source and load ends of the line, respectively; i_1, i_2, u_1, u_2 – current and voltage of the first and second sections of the line, respectively.

Figure 2 presents a model of the line with lumped parameters for the calculation of transient process in the line with distributed parameters.

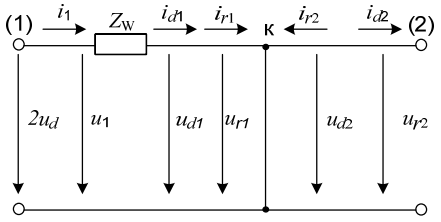


Figure 2: Model of the line for calculation of transient process in the line

In Figure 2: Z_w- wave impedance of the line; i_{d1} - incident current wave of the first section, i.e. from the source end to the short circuit point; i_{r1} – reflected current wave of the first section; u_{d1}– incident voltage wave of the first section; u_{r1} – reflected voltage wave of the first section; i_{d2} - incident current wave of the second section, i.e. from the short circuit point to the load end of the line; i_{r2} – reflected current wave of the second section; u_{d2} – incident voltage wave of the second section; u_{r2} – reflected voltage wave of the second section.

It is easy to see from the model that at time t_{sc} :

$$i_{r1} = i_{d1} \text{ and } u_{r1} = -u_{d1}$$

Thus, a positive current wave front and a negative voltage wave front travel at velocity v_F in the direction from point K to the source end of the line. The fronts can be detected with the aid of current and voltage sensors. Time t_1 of their arrival at the source end of the line can be recorded with high accuracy thanks to the clock showing the time synchronized with the universal time.

At the second section of the line there is also a transient process. At time t_{sc} current i_2 and voltage u_2 at the beginning of the second section vanish which means that

$$i_{d2} + i_{r2} = 0\ ,\ i_{r2} = -i_{d2}$$

$$u_{d2} + u_{r2} = 0\ ,\ u_{r2} = -u_{d2}$$

Hence, from point K negative fronts of current and voltage travel to the load end of the line. Time t_2, when these fronts arrive at the load end of the line can be recorded with the aid of current and voltage sensors as well as with high precision clock.

Let us show that knowing t_1 and t_2, we can detect the place of short circuit. To this end we will consider a geometric model of the short-circuited transmission line. The technique of identifying the short circuit place is explained in Figure 3.

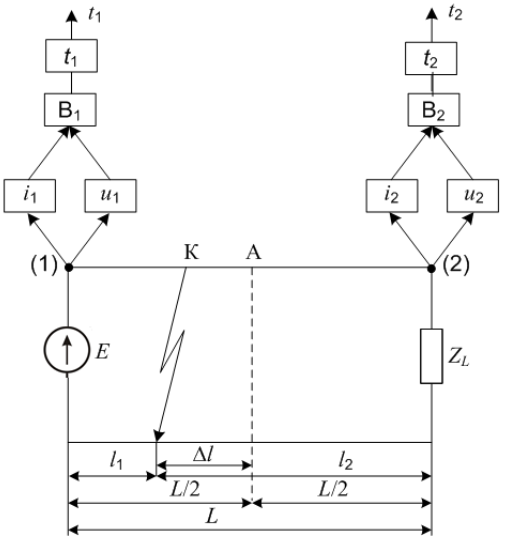


Figure 3: A scheme of devising an algorithm for determining the place of point K.

In Figure 3: (1), (2) are the sites at which the chronometers (t) and primary current (i) and voltage (u) sensors are installed; A – geometric center of the line; B – modules for processing the data from current and voltage sensors; Δl – distance from the center of Line A to the short circuit point K.

Using this scheme we determine Δt_1 - the time of wave propagation from the short circuit point to the source end of the line:

$$\Delta t_1 = \frac{l_1}{V_\phi}$$

In the same way we find Δt_2 - the time of wave propagation from the short circuit point to the load end of the line:

$$\Delta t_2 = \frac{l_2}{V_\phi}$$

Express time t_1 of the signal (response) arrival at the source end of the line through the short circuit time:

$$t_1 = t_{sc} + \Delta t_1$$

Similarly find time t_2 of the response arrival at the load end of the line:

$$t_2 = t_{sc} + \Delta t_2$$

Determine the difference between the time of response arrival at the source end of the line and the time of response arrival at its load end:

$$t_1 - t_2 = \Delta t_1 - \Delta t_2 = \frac{l_1}{V_\phi} - \frac{l_2}{V_\phi} = -\frac{2\Delta l}{V_\phi}$$

and finally determine Δl

$$\Delta l = -\frac{(t_1 - t_2)\, V_\phi}{2} \qquad (1)$$

Knowing Δl, we find l_1 and l_2 by the equations

$$l_1 = \frac{l}{2} - \Delta l, \qquad (2)$$

$$l_2 = \frac{l}{2} - \Delta l \qquad (3)$$

If point K is closer to the source end of the line (to the left of point A), then $\Delta l > 0$. If point K is closer to the load end of the line, then $\Delta l < 0$.

When the time aspect is taken into consideration the issue of accurate determination of the time instants t_1 and t_2 is particularly important.

We suggest using the available infrastructure of phasor measurement units (Fig. 4).

Phasor Measurement Units (PMU) make it possible to take phasor measurements of currents and voltages at the given points of the power system. Phasor measurement implies simultaneous measurement of both the effective value and the phase of current and voltage. These parameters allow us to calculate current values of transmitted power, voltage drops in the sections of the transmission line, power loss in the transmission line, etc. In fact, the measurement of effective values and phases of current and voltage is not a new

problem. However, such measurements, although possible, have not become widespread, since the control of the system under dynamic operating conditions requires that the data be definitely connected with the universal time. For instance, in order to determine losses in the line we should simultaneously measure active power at the source and load ends of the line precisely at the same time.

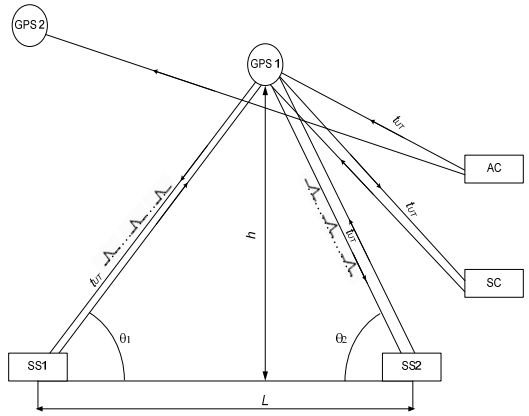


Figure 4: PMU infrastructure. (where SS1- feeding substation; SS2- receiving substation; *L*– length of the line; AC- atomic clock; GPS1, GPS2 – satellites sending time signals; SC – control center; SS1, SS2 – network substations; t_{UT} – time pulse of the atomic clock; h – height of the satellite above the Earth in the area, where the substations are located; Q_1, Q_2 – angles at which the satellite is seen from SS1 and SS2, respectively.

The time measurement resolution of PMU is not sufficient to accurately determine the time of the event. Therefore, at the measurement points we should form our own time (count) pulses with a short time interval of, for example, 10^{-9} seconds, using additional devices.

Consider the use of the PMU and additional devices for accurate determination of time t_1 and t_2. These pulses are formed by the pulse generators installed in modules B_1 and B_2, and received at the input of the pulse counters located in modules t. The pulses are generated with the same frequency. At the outputs of modules t we obtain t_1 and t_2 , respectively, in the following form:

$$t_1 = t_{gps} + ndt, \quad (4)$$

$$t_2 = t_{gps} + mdt, \quad (5)$$

where t_{gps} – a synchronizing pulse from GPS satellite, that contains complete information about the universal time, namely: year, month, day, hour, minute, second, milliseconds;

n, m – number of count pulses from the arrival of t_{gps} to the moment, when the response to the short circuit is received at the source end and load end of the line, respectively.

We determine the difference between the time the responses arrive at the source end of the transmission line and the time they arrive at its load end, using expressions (4) and (5):

$$t_1 - t_2 = (n - m)dt$$

Knowing t_1 and t_2, we find Δl, l_1, l_2 according to expressions (1), (2), (3).

3 CONCLUSIONS

The proposed method is very promising, since it mainly uses PMU devices, and the costs related to the development and use of additional devices are insufficient.

This method allows to determine the coordinates of the damage in real time. The error is not more than 50 meters. This figure will be adjusted to the experiments conducted.

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Towards Energy-aware Optimisation of Business Processes

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Abstract: Time dependent energy tariffs are a matter of concern to managers in organisations, who need to rethink how to allocate resources to business processes so that they take into account energy costs. However, due to the time-dependent costs, the resource optimisation problem needs to be redesigned. In this paper we formalise the energy-aware resource allocation problem, including time-dependent variable costs; and present a case study in which an auction mechanism is used to find a solution. Our results show how the choice of cost (energy, monetary, or duration) affects the schedules obtained.

1 INTRODUCTION

Increasingly, energy prices are changing from flat rates to time-dependent tariffs, which presents companies with the problem of smoothing and shifting peaks from expensive to cheaper hours. Dealing with time-dependent energy costs has been mainly studied in the context of household management (Gottwalt et al., 2011), and business process management has been mostly neglected. An exception is the proposal of Hoesch-Klohe et al. (2010) in which resources are annotated with CO_2 consumption details, which are known to the process manager that aggregates the energy costs.

This paper considers allocation and optimisation of resources in business processes while taking into account energy costs. Business processes pose particular challenges to optimisation because, unlike household energy usage, they are structured (e.g. a process may involve an extended sequence of steps), and may include structural uncertainty (e.g. the business process may include embedded decisions, so the exact tasks to be performed will not be known with certainty ahead of time).

The key contribution of the work is the problem formalisation, which includes the optimisation of resources taking into account time-dependent energy costs. With the formalisation of the problem, we aim to provide a new optimisation problem to the research arena, the solution of which will provide new tools for business managers to support energy-aware decision-making.

We also provide an auction-based resource-allocation mechanism to illustrate with a case study the possible outcomes of the energy-aware optimisation process. However, the focus of the paper is not the technological part (auction-based resource allocation), but to provide a first approach to formalising the problem of energy-aware optimisation of business processes.

This paper is organised as follows. First we start by reviewing related work in Section 2. Next, in Section 3 we provide the formalisation of the energy-aware resource optimisation problem. In Section 4 a case study is provided, and we end in Section 5 with some discussion and ideas for further research.

2 RELATED WORK

Research on green business process management is described by Nowak et al. (2011) , who identify the required changes for business processes to be environmentally aware. Focusing on energy, Ardagna et al. (2008) propose a framework that includes a control layer in which the energy consumption is optimized according to execution times. In subsequent

work, Cappiello et al. (2010) describe a tool for validating the desired energy consumption. All of these approaches are based on web services and a task is assigned to at most one service. By contrast, our work allocates a given task to bundles of services (i.e. resources).

The timeline-based scheduling work of Chien et al. (2010) is similar to our work in that they have a collection of business process instances, each of which has resource requirements. A key difference between their work and ours lies in the fact that they are able to drop business process instances. Furthermore, we deal with time-dependent costs of resources, which they do not.

Time-variable cost functions have been recently considered by the constraint community (Simonis and Hadzic, 2010), but the solution proposed can only be applied in centralised environments and is not applicable to our business process model. More generally, traditional research on the job shop problem and workflow resourcing considers a one-to-one mapping of tasks to machines, whereas we allow a task to require multiple resources. Other differences include our allowance for uncertainty in the workflow (through the presence of XOR nodes), and our use of abstract tasks.

3 PROBLEM FORMULATION

We address energy optimisation issues in the context of resource allocation for business processes. The main inputs of our problem are the tasks to be performed and their sequencing dependencies, the resources available, constraints on the time and resource availability, and the cost function that characterizes the optimisation target.

3.1 Tasks

Formally we define a set of all the task instances involved in a given workload $T = \{t_1 \dots t_m\}$. Each task has an associated duration that is not fixed, but depends on the resources used. We then define a business process instance B as being a graph $B = (V, E)$ where the vertices are one of the following: a task t_i, one of a set of XOR nodes $X = \{x_1, \dots, x_k\}$, or either the distinguished start node s or end node e. Formally $V = T \cup X \cup \{s, e\}$. As usual, E is a set of pairs of vertices (v, v') where $v, v' \in V$. Each XOR node x_i has an associated set of options: $option(x_i) = \{B^1_{x_i}, \dots, B^{k_i}_{x_i}\}$ where each of the elements of the set $B^j_{x_i}$ is a graph, as defined above. In other words, we have a top-level graph B which may have some nodes that are themselves place-holders for one of a set of sub-graphs. We require that the tree of graphs is finite—the leaf graphs are those with no XOR nodes ($X = \{\}$).

The interpretation of XOR nodes is that eventually at run time each x_i is replaced by one of its subgraphs $B' \in option(x_i)$. This replacement is repeated until there are no XOR nodes remaining. Since there is a choice of $B' \in option(x_i)$ for each x_i, this process is non-deterministic. It results in a "decided" graph which has $X = \{\}$, i.e. no XOR nodes.

This run-time recursive replacement of each XOR node with one of its alternative subgraphs models the "don't know" non-determinism of workflow execution, where there may be different sub-workflows for performing a complex job, but the one that will be used for any workflow instance will be decided at run time (due to resource availability or other situational factors that we do not attempt to model).

We use $v \rightsquigarrow v'$ to denote that there is a path from v to v', defined in the usual way[1], and use $v_1 \rightsquigarrow v_2 \rightsquigarrow v_3$ as shorthand for $v_1 \rightsquigarrow v_2 \wedge v_2 \rightsquigarrow v_3$.

We require the graph (V, E) to be well-formed, which we define to mean that there are no arcs to the start node ($\neg\exists v.(v, s) \in E$); there are no arcs from the end node ($\neg\exists v.(e, v) \in E$); there are no cycles ($\neg\exists v \in V.v \rightsquigarrow v$); and for any node $v \in V$ (apart from the start and end nodes), there is a path from s to v and from v to e ($\forall v \in (V \setminus \{s, e\})\ .\ s \rightsquigarrow v \rightsquigarrow e$).

3.2 Resources

Each task requires *resources* in order to be carried out. We define a set of known resource types $RT = \{r_1, \dots, r_n\}$. We use multisets to represent the set of available resources, *AvailRS*, and the resources that are allocated to each task in a process schedule. A multiset over RT (a "resource multiset") is defined by a characteristic function $R : RT \to \mathbb{N}$ indicating how many copies of each element of RT appear in the multiset[2]. For convenience we will write multisets using standard set notation[3], but with the possibility of ele-

[1] $v \rightsquigarrow v' \equiv (v, v') \in E \vee (\exists v''.(v, v'') \in E \wedge v'' \rightsquigarrow v')$

[2] This definition of multisets does not allow for real-valued quantities of resources to be represented, but this is not a limitation: we could easily extend the notation to use real numbers, or assume that the unit of measurement is sufficiently fine grained that natural numbers are not a limitation, for instance, measuring coal in units of grams.

[3] We use standard definitions of multiset relations and functions (Syropoulos, 2001): $R_1 \subseteq R_2 = \forall r \in RT.R_1(r) \leq R_2(r)$. We distinguish between a maximum-based set union ($\cup$) and an accumulating union ($\uplus$): $R_1 \cup R_2 = g$ where $\forall r \in RT.g(r) = \max(R_1(r), R_2(r))$ and $R_1 \uplus R_2 = g$ where $\forall r \in RT.g(r) = R_1(r) + R_2(r)$.

ments appearing multiple times. We will also use the abbreviation a^n to represent n copies of an element, e.g. $\{a^2, b\} = \{a, a, b\}$.

Each resource type has associated monetary and energy costs. As discussed earlier, a key requirement is that these costs may vary over time. Formally we define the monetary cost $cost(\tau_1, \tau_2, r_i)$ and energy cost $energy(\tau_1, \tau_2, r_i)$ as being functions from a time interval $[\tau_1, \tau_2]$ (i.e. $\tau_1 \leq t \leq \tau_2$, where $\tau_1 < \tau_2$, $\tau_1, \tau_2 \in \mathbb{N}$) and a resource type $r_i \in RT$ to a cost (a real number), representing the *total* cost of *one* unit of resource type r_i over the given time interval.

We also define time-dependent monetary and energy *set-up* costs, $setup\_cost(r, t_1, \tau_1, t_2, \tau_2)$ and $setup\_energy(r, t_1, \tau_1, t_2, \tau_2)$, representing additional costs (or cost savings) that apply when a resource of type r is used for a task t_1 starting at time τ_1 and the next task for the resource is t_2 starting at τ_2 (not necessarily immediately after the end of t_1). A resource type r may also have a minimum set-up time that must be allowed between its use for a task t_1 starting at τ_1 and its next task t_2, denoted $setup\_time(r, t_1, \tau_1, t_2)$. Unlike the set-up cost and set-up energy cost, we assume that this does not depend on t_2's starting time.

Note that, because our representation doesn't distinguish between different instances of a given resource type, set-up costs and times can only be non-zero for resource types where there is a single instance available, i.e. $AvailRS(r) = 1$. We use RT[1] to denote those resource types for which exactly one instance is available.

Finally, we generalise the set-up costs and times to also apply to XOR nodes: $setup\_cost(r, t_i, start_i, x_j, start_j)$ is defined as the *maximal* cost over those tasks in the subgraphs of the XOR node that are *initial* for r. Given a set of subgraphs, a task is initial for r if it is possible for it to be the first task using r to be executed in one of the subgraphs, i.e. if we only consider tasks that use r, it is an initial task. We define $setup\_cost(r, x_j, start_j, t_i, start_i)$ in an analogous way (in terms of tasks in x_j that are *final* for r), and extend this to define the set-up cost between two XOR nodes in terms of a maximum over the tasks that are final for r in the set of options for the first XOR node and those that are initial for r in the set of options for the second XOR node.

We link tasks and resources by defining $need(t_i)$ which denotes the resources that task t_i requires. In order to model "don't care" nondeterminism, where there are multiple ways of achieving a task, and we are happy to have the choice be dictated by the needs of other processes, we define $need(t_i)$ as a *set of alternative requirements*. Furthermore, for each alternative resource requirement, we also specify the duration of the task when those resources are allocated to it. Formally, $need(t_i) = \{(R_1, d_1^i) \ldots (R_{k_i}, d_{k_i}^i)\}$, where each R_i is a multiset and each d_j^i is a natural number denoting the duration of task t_i if the jth resource multiset is used.

3.3 Schedules

A *schedule* S for a business process assigns to each task a starting and ending time (respecting the sequencing constraints) and resources (such that the available resources are not exceeded at any point in time). Formally, a *schedule* S is a set of task records:

$$\begin{aligned} S = &\{s_1, \ldots, s_m\} \cup \{s'_1, \ldots, s'_k\} \\ &\cup \{(start_s, end_s, \{\}, s), (start_e, end_e, \{\}, e)\} \end{aligned} \quad (1)$$

There are two types of task records: s_i which correspond to tasks, and s'_j which correspond to XOR nodes. A task record s_i is a tuple $s_i = (start_i, end_i, RS_i, t_i)$ where $start_i$ is the start time of the task's performance, end_i is the completion time, RS_i is a multiset of resources assigned to the task, and t_i is the task. For convenience we include task records for the start and end nodes. These are treated as tasks that take no time to perform (so $start_s = end_s$ and $start_e = end_e$) and have no resource requirements (so $RS_s = RS_e = \{\}$). An XOR node record is a tuple $s'_j = (start_j, end_j, S_j, x_j)$ where $start_j$ and end_j are respectively the start and end times, x_j is the XOR node identifier, and S_j is a *set of sub-schedules*, i.e. a schedule for each sub-graph in $option(x_j)$. We require that $start_j$ must be the smallest of the starting times of a schedule in S_j, and similarly end_j must be the largest finishing time of a schedule in S_j.

Schedules are subject to various constraints related to tasks, set-up times, and resources. First, the task records in a schedule must satisfy a number of constraints: (i) each task t_i has a single corresponding task record s_i; (ii) each XOR node x_j has a single corresponding XOR node record s'_j; (iii) each task t_i is allocated the resources specified by one of the resource multisets in $need(t_i)$, and takes the corresponding specified length of time to be executed[4]; and (iv) the task start and end times must satisfy the constraint that $(t_i, t_j) \in E \Rightarrow end_i \leq start_j$.

Second, the above constraints on the schedule need to be extended to respect set-up times: where a (singleton) resource of type r is used by t_i and then by t_j, the schedule must satisfy the stronger constraint $end_i + setup\_time(r, t_i, start_i, t_j) \leq start_j$. Note

[4]Formally, for some $(R_j, d_j^i) \in need(t_i)$: $R_i = R_j$, and $end_i - start_i = d_j^i$.

that t_i and t_j may not be constrained to occur in sequence. We therefore define this additional feasibility constraint using a singleton resource schedule S^r which, given schedule S and singleton resource type r, is a list of the task records for those tasks (both s_i and s'_j) that use resource r, sorted by starting time. The additional feasibility condition is then: $\forall r \in RT^1 \forall (t_i,t_j) \in S^r \;.\; end_i + setup\_time(r,t_i,start_i,t_j) \leq start_j$ where $(t_i,t_j) \in S^r$ denotes the selection of adjacent elements in the list, i.e. $S^r = \langle \ldots,t_i,t_j,\ldots \rangle$.

Third, having defined the constraints that ensure a schedule is feasible with respect to time (including set-up times), we now define the feasibility of a schedule with respect to the available resources (*AvailRS*). We begin by defining functions that accumulate the resources used by a schedule S at time τ:

$$res(\tau,(start_i,end_i,RS_i,t_i)) = \begin{cases} RS_i & \text{if } start_i \leq \tau \leq end_i \\ \{\} & \text{otherwise} \end{cases}$$

$$res(\tau,(start_j,end_j,S_j,x_j)) = \bigcup_{s \in S_j} res(\tau,s)$$

$$Res(\tau,S) = \biguplus_{s \in S} res(\tau,s)$$

The first function (*res*) takes a time τ and a task record s_i or s'_j and returns the resources required for the task at time τ, which will, for s_i, be either RS_i if the task is being performed at time τ, or the empty set; and for x_j is simply the maximum of the resources required at time τ over the sub-schedules in S_j (we need to use the maximum since we do not know which option will be selected). The second function (*Res*) takes a time τ and an entire schedule, and collects the resource requirements for a given time τ across all the tasks. Finally, a schedule S is feasible with respect to the available resources *AvailRS* if and only if $\forall \tau \; start_s \leq \tau \leq end_e \;.\; Res(\tau,S) \subseteq AvailRS$.

3.4 Optimisation Costs

Finally, we need to define the *cost* of a given (feasible) schedule. In fact there are three costs that we consider: the energy cost, the monetary cost, and the time. The energy cost of a schedule is defined as follows[5]:

$$Cost_e(S) = \sum_{s \in S} Cost_e(s) + \sum_{r \in RT^1} \sum_{(t_i,t_j) \in S^r} setup\_energy(r,t_i,start_i,t_j,start_j)$$

$$Cost_e(s_i) = \sum_{r \in RT} RS_i(r) \times energy(start_i,end_i,r_j)$$

[5]For convenience we overload $Cost_e$ to operate on both schedule and task records.

$$Cost_e((start_j,end_j,S_j,x_j)) = \max_{S \in S_j} Cost_e(S)$$

Finally, the time cost is simply the makespan:

$$Cost_t(S) = end_e - start_s$$

In other words, the cost of a schedule is the sum of the costs for each of the task entries s_i and the XOR entries s'_j (first term) and the sum of the set-up costs (second term). Note that because the set-up cost is defined over both task and XOR nodes, and S^r includes both types of nodes, the second term includes the set-up costs between tasks and XOR nodes. To compute the cost of an individual task record, we compute for each resource type the cost of a single unit of that resource type across the given time interval, and multiply by the number of resource type units $RS_i(r)$ allocated. For XOR records, we take the maximum across the options. Similarly, we define the monetary cost, and finally, the time cost is simply the makespan: $Cost_t(S) = end_e - start_s$

3.5 Problem Statement

Given a workload represented by graph B, the problem we are tackling is to find a feasible schedule S which minimises the three cost functions ($Cost_€$, $Cost_e$ and $Cost_t$). This is a multi-criteria optimisation problem in which we cannot assign *a priori* a greater importance to any given criterion, and so we are looking not for a single "optimal" solution, but for a set of Pareto points.

4 CASE STUDY

In this section we address the problem by means of an auction mechanism, with the aim of illustrating the different solution outcomes that arise when each of the energy, monetary cost, and makespan (i.e. time cost) are given precedence.

4.1 Auction Implementation

Auctions have been widely used for task and resource allocation among different entities with the particularity that the price of the resource allocation is decided when clearing the market (Chevaleyre et al., 2006). When auctioneers demand tasks to be performed by bidders (resource agents), the mechanism is known as a reverse auction. The protocol followed in such auctions includes the main following steps:

1. The auctioneer sends a request for proposal, in which the tasks to be performed are specified.

2. The bidders answer with some offers.
3. The auctioneer decides the set of winner bids.
4. The auctioneer acknowledges the winner bidders.
5. The bidders commit the time to perform the tasks.
6. After the tasks have been performed, bidders send the auctioneer a "done" message that enacts the last step.
7. The auctioneer pays for the activity performed by the resources.

To apply an auction mechanism to our problem there are several choices to be made when designing the auction.

First, there is the choice of when the allocation of resources to tasks is performed. Resources can be scheduled in advance or following a dynamic approach, interleaving scheduling and execution of tasks. The latter approach improves the specifications of the tasks to be performed, since the uncertainty about which branch of the XOR node will be followed is cleared before resources are allocated. Due to the fact that we operate on business process instances and during the execution of the business process we may not have a sufficient amount of time to perform the scheduling, we are interested in solutions where we conduct scheduling ahead of time and booking of resources is done in advance. This approach requires us to consider overlapping resource allocation across tasks that belong to separate exclusive-or paths of the business process graph.

Second, we can perform a single auction with all of the tasks involved in a business process, or we can proceed with a sequential process, auctioning a task at a time. The latter case is useful if we can obtain a more precise picture of the requirements and constraints of a task once the preceding tasks have been allocated, as in the work of Collins and Gini (2009). However, the presence of XOR and parallel (AND) branches introduces uncertainty on which tasks should be allocated first. Thus we follow the first approach: scheduling all of the tasks in a single auction.

Third, given the set of tasks to be performed, bidders can provide bids on bundles of tasks so that the resulting mechanism is a combinatorial auction. Moreover, bidding on bundles enables the resource to express that the assignment of two (or more) consecutive tasks can improve cost, for example, to reduce the transport cost of moving some resource to a given place where the tasks should be performed (set-up costs).

Fourth, there is a single winner determination problem (WDP) to be solved. The solution of the WDP includes the allocation of both start time and

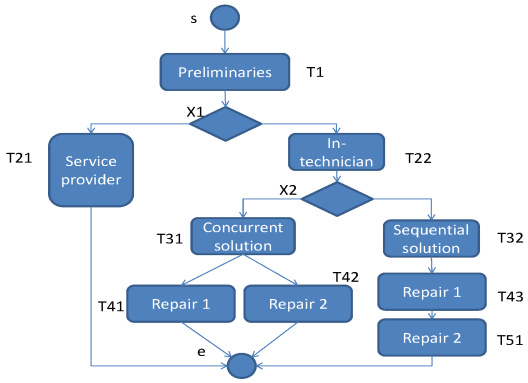


Figure 1: Business process example.

resources, for each of the tasks of a business process, taking into account the constraints specified in the problem formulation. Moreover, and thanks to the explicit definition of resource bundle alternatives associated to each task ($need(t_i)$), the winner determination algorithm decides upon a single bundle for a task based on the bids provided. From this point of view, the auction model is a combinatorial auction, since the auctioneer needs to get all of the resources of an alternative ($R_j \in need(t_i)$), or none of them. Therefore our auction model is two-fold combinatorial: bidders bid for bundles of tasks and auctioneers assign tasks to bundles of resources. This auction model is related to combinatorial exchanges (Parkes et al., 2001).

Steps four to six of the protocol involve resource acceptance and deployment after the allocation has been cleared. We are dealing with a single auction where no other request, outside this auction, is being managed by any resource agents. Thus we do not expect any rejection on behalf of agents. Failures during the tasks' execution are out of the scope of this paper (see the work of Ramchurn et al. (2009) for preventive issues).

We assume that the final step—the payment mechanism—is incentive compatible, so all of the resource agents provide truthful bids (i.e. they do not cheat when bidding).

4.2 Results

In this section we provide an auction-based solution for scheduling resources to the instances of the business process given in Figure 1. There are two XOR nodes X1 and X2. X1 decides whether the branch containing T21 or the branch containing T22 will be executed. X2 decides whether the branch containing T31 or the branch containing T32 will be executed. Note that tasks T41 and T42 can be executed concurrently (i.e. there is an AND split and join).

For each task, the bundles of resources (or single

Table 1: Resources required by each task.

Task	(Resources, Duration)
T1	({R1}, 1)
T21	({R2,R1}, 5), ({R2,R3}, 5)
T22	({R1},1), ({R4},1)
T31	({R1},1), ({R4},1)
T32	({R1},1), ({R4},1)
T41	({R3},2), ({R4},2)
T42	({R3},3), ({R4},3)
T43	({R1},2), ({R4},2)
T51	({R3},1), ({R4},1)

Table 2: Resource costs. Energy is expressed in kWh; money in euros; duration in hours.

Id	kWh	€	Duration
R1	1	160	(T1,1), (T21,4), (T22,3), (T31,2) (T32,1), (T43,1)
R2	10	200	(T21,4)
R3	5	90	(T21,4), (T41,3), (T42,4), (T51,1)
R4	3	50	(T22,1), (T31,1), (T32,2), (T41,3), (T42,3), (T43,4), (T51,2)

resources) that are capable of performing the task and the expected duration to complete the task (from the auctioneer's perspective) are given in Table 1. For example, task T21 can be performed by two different bundles of resources, $\{R2, R1\}$ or $\{R2, R3\}$. The resource costs (energy costs and monetary costs) are provided in Table 2. Note that the expected duration of tasks from an auctioneer's perspective may or may not correspond to the actual ability of the resource agents (i.e. the resource agents may provide a different duration as a part of their bids and this information is internal to a resource agent). For example, the common information indicates that T21 takes 5 hours regardless of which resource bundle is taken, but the resources themselves indicate that the task actually only takes 4 hours.

We assume that day-ahead hourly prices (i.e. energy costs in kW per hour) are available (see Figure 2). This is similar to the work of Gottwalt et al. (2011). Additionally, we also assume that the resource allocation process starts at 8am.

All the tasks from all of the business process instances are allocated in a single auction. For the business process given in Figure 1, there are 9 tasks for

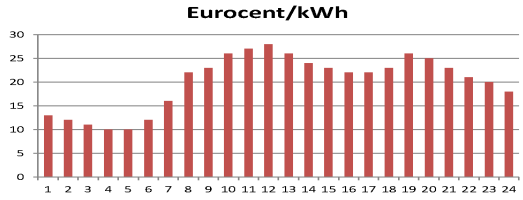


Figure 2: Day-ahead hourly tariffs.

which resources need to be allocated. They are T1, T21, T22, T31, T32, T41, T42, T43, T51. For each task, a time window is generated according to the duration estimated by the auctioneer (see Table 1) with a slack time of 2 hours. For example, since the schedule begins at 8am and T1 takes 1 hour, the request (T1, [8,11]) is sent to R1.

It should be noted that each agent may receive several requests. Agents process the requests and generate a single bid, which includes the set-up times. We have considered set-up costs in R4 (between T32 and T43, and between T43 and T51) and R3 (between T43 and T51). In all of the cases, the set-up cost consists of an extra monetary, energy and time unit cost.

Once the auctioneer collects all of the bids, the winner is determined. For determining the winner of the auction we consider three different scenarios. These three scenarios consider three attributes: the energy cost, the monetary cost and the makespan. However, the relative importance of these attributes differs in each of the scenarios.

Energy wins: the bid with the cheapest energy cost is selected. In case of a tie between energy costs, the one with the cheapest monetary cost will be preferred. Again if there is a tie, the makespan will be considered.

Money wins: the bid with the cheapest monetary cost is selected. In case of ties (the same monetary costs), energy costs will be considered for comparison. If there is a tie in energy costs, makespan will be considered.

Makespan wins: the bid with the shortest makespan is selected. In case of a tie, the cheapest energy cost is considered. If there is a tie between energy costs, the cheapest monetary cost is considered. We consider the makespan with the starting time that is closest to the earliest starting time of the activities scheduled for a given day (i.e. 8am in our case).

We note that six different scenarios can be considered for a combination of three attributes. In this paper we compare three scenarios, and we believe these scenarios are sufficient to show the consequences of using energy costs in resource allocation in business processes.

The resultant resource allocations at the end of the auction process for each of the scenarios are shown in Figure 3. Note that a resource agent can have overlapping bookings, because of the XOR nodes. The overbooking of an agent is represented as different horizontal bars in Figure 3. For example, R1 has three bookings (R1.1, R1.2 and R1.3). Note that the booking R1.1 overlaps with the other two. However, these bookings are for the tasks in XOR nodes, so these would not result in a conflicting situation at run-time,

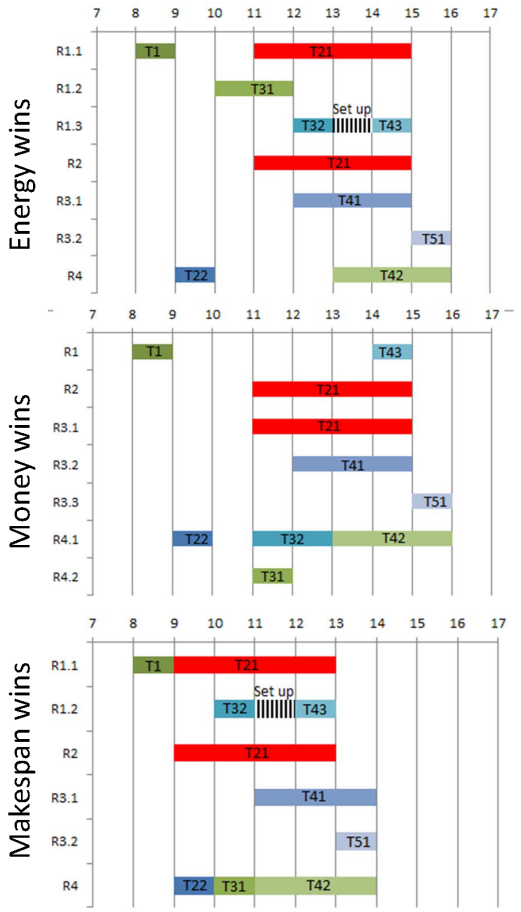


Figure 3: Resource assignment. Top: Energy wins scenario. Centre: Money wins scenario. Bottom: Makespan wins scenario.

since only one of the options of the XOR node would actually be required to be executed, i.e. if task T21 is performed, then the other tasks that R1 is allocated to (T31, T32, and T43) will not be performed.

If we look at T21, we see how the bundles are allocated differently in each of the scenarios. In the energy priority scenario (top of Figure 3) T21 is assigned to R1 and R2 (at time 11), in the monetary priority scenario T21 is assigned to R2 and R3 (also at time 11), and in the makespan scenario T21 is assigned to R1 and R3 again, but at time 9. In the figure, it is possible to observe how parallel branches (tasks T41 and T42) do not need to be executed at the same time. Finally, note that set-up costs have only been considered in the energy and makespan scenarios, when sequencing tasks T32 and T43 in R1.

To quantify the results obtained, we have measured the worst (max) and best (min) cost on each scenario. We have a range of possible costs for each scenario because of the uncertainty associated with XOR nodes: we don't know in advance which branch will be taken. The results obtained are shown in Table 3. If we compare the worst case energy costs between scenarios 1 and 2, the energy cost in scenario 2 is 33% more than scenario 1 (11.58 vs. 15.38). The monetary cost in scenario 1 is 33.3% more than in scenario 2 (1760 vs. 1320). In the best case monetary cost scenario, the difference in monetary cost between scenarios 1 and 2 increases to 39% (780 vs. 560). However, in this case scenario 1 has a lower makespan than scenario 2. Money and energy are moving in different scales (hundreds versus tens). However, with our experiments we are showing how the resource selection changes the energy costs. In other scenarios, energy could be more expensive.

Table 3: Comparison of three scenarios ($Cost_e$ and $Cost_€$ are in Euros, whereas $Cost_t$ is in hours).

	Scenario 1 Energy	Scenario 2 Money	Scenario 3 Makespan
Max $Cost_e$	11.58	15.38	12.28
Min $Cost_e$	2.84	3.97	3.02
Max $Cost_€$	1760.00	1320.00	1760.00
Min $Cost_€$	780.00	560.00	780.00
Max $Cost_t$	8.00	8.00	6.00
Min $Cost_t$	7.00	8.00	5.00

In the makespan scenario (scenario 3), the monetary cost is the same as in scenario 1, however, the energy cost increases by 6% both in the best and worst case scenarios when compared to scenario 1. It should be noted that resources are more idle in scenario 1 than scenario 2 (worst case make span of 8 vs. 6).

The results presented in Table 3 show three what-if scenarios modelled, which can be valuable for decision makers (e.g. managers of the business processes). They can use this information to consider trade-offs between alternatives. For example, a manager currently employing the makespan strategy (scenario 3), can now consider the trade-off in moving towards a scenario where energy costs are minimised (i.e. scenario 1).

5 DISCUSSION AND FUTURE WORK

This paper presents an approach that considers energy as one of the attributes for optimising resource allocations in business processes. Towards that end, this paper presents the problem formalisation and discusses an auction mechanism that can be employed. One of the key contributions of this paper is the consideration of time-dependent energy costs as a part of scheduling and resource allocation, which has not been pre-

viously considered by work on BPM.

We used an auction mechanism to illustrate a possible instantiation of the problem formalisation and different outcomes, depending on the cost focus: energy, price and makespan. They have been analyzed using three what-if scenarios, to show how business managers can consider the consequences of considering energy during the resource allocation process.

Considering energy as a key component in scheduling and resourcing business process executions offers interesting challenges. For example, for an organisation to adhere to the ISO norms of being energy efficient and also consuming green energy (ISO, 2011), an organisation may choose to negotiate a deal with the energy provider based on the energy signature (or energy consumption shape curve) for a particular day. Energy providers can offer special rates for those companies that adhere to their expected energy shape (i.e. energy usage at different hours of the day).

This leads to other interesting scenarios such as companies offering auctions on excess surplus energy to those that need some additional energy, similar to the dynamic coalition formation scenario considered for the construction of virtual power plants (Mihailescu et al., 2011). One approach to address this problem is to enable Workflow Management Systems (Ehrler et al., 2005) in charge of business process resource allocations to coordinate their activities with Energy Management Systems (EnMS) that are in charge of company energy policy (Roche et al., 2010). An EnMS can facilitate choosing external resources that closely align with the energy objective functions of a given organisation.

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Intelligent Dynamic Load Management Based on Solar Panel Monitoring

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Abstract: The Smart Grid will largely increase the amount of measurement data that needs to be processed on distribution grid level in order to fulfill the promised smart behavior. Many modern information systems are capable of handling the produced data amounts quite well. However they are usually highly specialized systems that are costly to change or limited to very basic analytical tasks. We aim to overcome these limitations by utilizing an optimized event processing based framework that can easily be customized to a certain application scenario. In the paper we outline our approach by applying it to one of our motivational scenarios from the area of intelligent dynamic load management.

1 INTRODUCTION AND PROBLEM STATEMENT

Smart Grids promise to improve the efficiency, reliability and sustainability of today's power grids by utilizing communication and information technology. To this end, detailed information on supply, transmission and consumption is made accessible, which leads to a massive increase in measurement data to process in particular at the distribution grid level. This holds most notably for dynamic load management (DLM) approaches, cf., e.g., (Koch et al., 2009; Dam et al., 2008).

Dynamic load management is a special form of demand-side management that refers to the ability to influence load curves dynamically as a reaction to an operational state, such as transformer overloading or the measured level of energy production of a photovoltaic unit (PV). DLM will become particularly important in the future due to the proliferation of stochastic and distributed renewable energy sources such as solar panels and wind turbines (Molderink et al., 2010): The high fluctuation in energy production leads to higher grid volatility, which jeopardizes the stability and security of power supply. DLM can be used to balance fluctuations by complementing long-term storage units, such as pumped-storage hydropower plants, cf., e.g., (Koch et al., 2009). To implement DLM in a smart grid, it is necessary to introduce highly flexible monitoring and information systems that are able to monitor and rapidly process the huge amounts of data from advanced metering infrastructure (AMI) and external sources. To provide the necessary decision making capability to automatically trigger load shifting, complex relations in the produced data must be analysed. Many modern information systems are capable of handling these data volumes quite well. Yet, there is usually a trade off between two aspects:

- the capability to monitor and process big data amounts in near real time, and
- the amount of flexibility in performing complex analytical tasks.

One approaches that allows for a partial reconciliation of these two aspects is complex event processing (CEP). It allows for monitoring and rapidly analysing Big Data streams. Yet, to ensure scalability, the conventional CEP processing model requires the incoming event streams to be pre-partitioned. The static pre-partitioning limits the flexibility of the approach in analysing complex relationships in the data, since data streams can only be related to each other if they share the same partition. This can pose a problem for DLM solutions that rely on highly dynamic and complex patterns for grid state estimation. To overcome this problem, we propose an extension of the conventional CEP framework which we call *dynamic complex event processing* (DCEP) framework. It adds a

situation specific *dynamic partition* to the static CEP partitions. We outline the proposed DCEP framework by applying it to one of the use cases identified in the EUROSTARS project DYNE[1]. Here, we consider the issue of increased voltage variations along branches of the distribution grid, which stem from the stochastic infeed of decentralized PVs. The voltage variations can be balanced with DLM if intraday PV production forecasts can be provided. Since they depend on fast changing weather conditions such as moving clouds, these patterns must be analysed to estimate the grid state, and we show that they usually break with any static partitioning of sensor measurement streams.

The paper is structured as follows: Section 2 briefly outlines similar approaches to dealing with big data in DLM applications. Section 3 describes the reference use case that is used as a running example in the remainder of the paper. The processing model of the DCEP framework is described in detail in section 4. The paper ends with conclusions and an outline of future work.

2 APPROACHES TO HANDLING BIG SMART GRID DATA

The highly dynamical nature of the power grid, the proliferation of distributed generation (DG), and the massive amounts of measurement data available in a smart grid pose considerable challenges to DLM processing. This holds in particular for DLM applications that aim at avoiding switching off DG units when the frequency or voltage deviation in the grid exceeds the allowable threshold, cf., e.g., (Lu and Hammerstrom, 2006). To meet these challenges, DLM algorithms often use *demand* prediction to estimate future grid states. Yet, accuracy of estimations is limited, since short-term forecasting of PV *production* curves is usually omitted due to the stochastic nature of the infeed. Many DLM models employ differential equations and optimization functions that require significant time to be solved numerically. As a consequence, grid state estimations can be updated only in intervals of several minutes (insetad of several seconds), and the according load management operations operate at a similar level of detail. E.g., (Koch et al., 2010) employ a Model Predictive Control strategy to operate controllable thermal household appliances for minimizing the "balance error" of a group of end customers at distribution grid level. In this case, a 15-minute update cycle leaves enough time to pre-calculate the estimated grid state. As another example, (Ringwood et al., 2001) use neural networks for peak demand prediction, but the level of detail acquired omits other cardinal points of the load curves such as valleys, which are necessary for short timescale dynamic load management.

In order to allow near-real-time DLM operations that operate at a higher level of detail, the accuracy of grid state estimation must be increased. This can be done by complementing the above mentioned demand forecast approaches with short time scale production forecasts, and we address this challenge in our reference use case, cf. section 3. To achieve this goal, the computing performance of DLM solutions must be increased. As of today, only few approaches exist that address the problem, and they mostly do not directly address DLM. E.g., (Yin et al., 2011) propose a scalable and reliable middleware layer for real time data management in smart grids. The proposed software is tailored to smart grid requirements and thereby eliminates overheads of other data middleware such as latencies and unpredictable performance stemming from e.g. the use of generalized APIs. Yet, the software has not been tested with DLM applications. Another approach is given by (Huang and Nieplocha, 2008) who propose a parallelization approach with high performance computing (HPC). Unlike these solutions, the proposed DCEP approach does not rely on costly HPC hardware. We increase the computing efficiency by separating simple pattern matching tasks (that can operate rapidly on Big Data using conventional CEP) from dynamically changing complex analysis tasks that only required a small portion of the overall data stream for their deductions.

3 USE CASE SCENARIO

The introduction of decentralized energy production causes increased variability of the voltage level along distribution lines at the lowest grid layer, and, as a result, the voltage level sometimes exceeds the maximum allowable threshold (Vovos et al., 2007), cf. Figure 1.

This problem can be solved by switching off generators when the threshold is met, by increasing the capacity of power lines, or by installing distribution grid transformers that are switchable on load. Our reference use case addresses the latter scenario: here, DLM peak shaving can be used to avoid unnecessary switching operations of the adjustable transformer, switching being costly and reducing equipment life span.

Figure 1A) illustrates the problem of increased

[1] www.project-dyne.eu

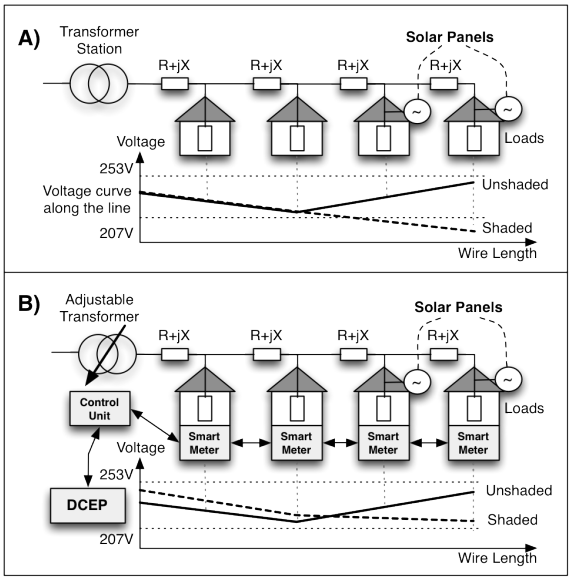


Figure 1: Increased variability of voltage levels caused by PV infeed, A) with conventional transformers, B) with adjustable transformers.

variability of the voltage level when conventional transformers are used. In rural areas, distribution power lines are often connected to the grid by only one feeder. If additional decentralized PV units are connected to such power lines, the voltage level progression along a line depends not only on the power consumption of the households, but also on the PVs' power production. The figure shows the voltage level progression along a power line in times of high power consumption. The continuous line depicts the voltage curve when the PVs production is average. In order to account for the additional PV infeed, the transformer's level of infeed is lower than normal, and chosen so that the resulting (continuous) voltage curve is well within the tolerance band of 230 ± 23V. In contrast, the dotted line depicts the voltage curve when PVs production is low, e.g., at nighttime or when PVs are shaded by fog or passing clouds. In this case, PVs do not add to the voltage level. Since the infeed level is low and can not be changed, the dotted curve falls below the lower threshold of 207V. Choosing a higher infeed level does not solve the problem, since the continuous voltage curve would exceed the upper threshold of 253V.

Figure1B) illustrates the situation when adjustable transformers are used. Here, the infeed level can be changed on load. Whenever PV production is low, smart metering devices at the households measure a drop in the voltage level, and report it to the autonomous management unit of the adjustable transformer, which steps up the infeed level. The dotted line shows that the resulting voltage curve stays

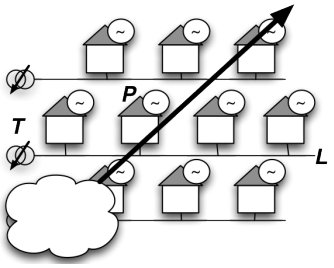


Figure 2: Use case scenario.

within the tolerance band.

DLM can be used to in order to avoid unnecessary switching operations that are, e.g., caused by fast travelling clouds, cf. Figure 2. As a cloud passes over a PV P installed along the power line L, it temporariliy casts a shadow on P and causes the transformer T to switch the infeed level up and then down againg in fast succession. Whenever the time span in question is less than than 30 minutes, DLM is well suited to temporarily shift or reduce consumer loads on household level, e.g., by delaying the charging of electric vehicles or by temporarily interrupting the operation of heat pumps, cf., e.g., (Koch et al., 2009).

Yet, the intervals between switching operations are often much smaller, and DLM algorithms must react quickly. To provide the required rapid reaction time, DLM algorithms must include short-term demand and production forecasts. Our use case focuses on predicting sudden drops in PV production that are caused by traveling clouds in areas of high PV density. Here, smart meter readings of neighbouring PVs can be used to estimate a cloud's trajectory, which in turn can be used to predict the time and duration of shading of a given PV, cf. Figure 2.

Complex Event Processing (CEP) is a scalable method for analysing and combining Big Data streams from multiple sources to infer events or patterns that suggest more complicated circumstances. Its goal is to identify and track meaningful events and respond to them as quickly as possible. It hence provides the capability to process and analyze big data amounts in near real time, and this is a necessary requirement to implement the cloud tracking task described above. Unfortunately, CEP does not provide sufficient flexibility to indeed implement the task, since CEP requires the overall event stream to be partitioned in advance to ensure the scalability of the approach. The partitions can not be changed during processing, and complex patterns can only be recognized if they are composed of event streams of the same partition. As a consequence, cloud tracking can not be implemented with conventional CEP.

To see this, consider Figure 3, which sketches a sensor field consisting of PV units, partitioneded into

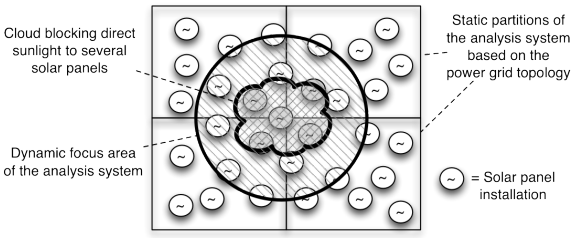


Figure 3: Fiexed partitions prevent cloud tracking.

four squares. A cloud that is traveling above the PV field may have an arbitrary trajectory that potentially crosses the boundaries of any predefined partition along its way. E.g., as shown in the figure, the cloud may occlude parts of all four partitions of the sensor field at a given point in time. In this case, the CEP platform can not recognize the cloud as one integral object, but instead recognizes four different objects, one in each of the four partitions. This would not a problem per se, if the trajectories of the four "cloud parts" could be calculated to estimate their future movements. Unfortunately, this is not the case: when trying to derive an object's trajectory, a tracking algorithm must consider changes of sensor readings in the object's neighbourhood. This is not always possible, since the neighbourhood of a cloud part overlaps with another partition, preventing the algorithm from analyzing its movement.

4 PROCESSING MODEL AND PROTOTYPE ARCHITECTURE

In order to address the problem of prepartitioning in conventional CEP architectures, we extend it with the possibility of instantiating dynamically changing partitions. We refer to such a dynamic partition as a *focus area*, and the processing tasks performed within are referred to as *focused processing*. Our focused processing framework consists of three phases: The *situation indication phase* is based on normal CEP stream processing; the *focused processing initialization phase* determines the selection of data streams necessary for a given complex analysis task (e.g., cloud recognition and tracking); finally, the *focused processing phase* performs the the dynamically changing and computationally intensive analysis tasks in a separate processing environment that is decoupled from the normal CEP processing with its fixed pre-partitioning. The prototype architecture has been developed in a cooperation of the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) and the Finnish technology company

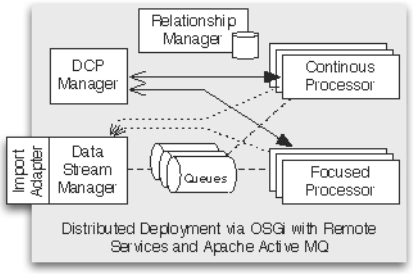


Figure 4: DCEP Architecture Overview.

BaseN[2] as part of the DYNE project. BaseN's real-time monitoring and stream processing platform provides built-in components for preprocessing the raw event stream data from PV measurements. The preprocessing includes semantic enrichment with context information such as measurement units and device parameters, as well as filters for statistical evaluation and data concentration. In particular, data quality issues such as noisy PV measurement data, varying latencies and packet loss observed in smart metering systems can already be partially dealt with in the preprocessing step.

The processing system architecture defines several loosely coupled components that can be deployed on multiple computers to allow for basic scalability (Figure 4). The main components are defined as follows: The *DCEP Manager* acts as an overseer of components that manages the life cycle of the specified use cases including the initial situation monitoring setup and the coordination of the focused processing. The *Continuous Processor* is configured by the DCEP Manager to continuously monitor for use case specific situation indicators in the incoming event data. The event data is provided by the *Data Stream Manager* which allows each component to subscribe itself to event streams provided by the BaseN Monitoring platform. A specialized adapter component mediates between the BaseN communication system and our DCEP system. If an indicator for a complex situation of interest is detected during normal CEP processing, the DCEP Manager is notified, which configures the *Focused Processor* component to initialize a new focused processing and to subscribe to the required data streams. Both processing components, the continuous and the focused processing, are intended to be instantiated multiple times on several computers to provide scalability. The resource provisioning of the infrastructure is handled by the BaseN Platform and is similar to a typical cloud infrastructure as a service offering. To support the processing tasks with additional domain specific knowledge, the *Relationship Manager* provides access to a specialized knowledge

[2]https://www.basen.net/

base specified by a RDF schema.

To illustrate the focused processing mechanism, we outline the processing flow for a cloud tracking use case in simplified form.

Identifying relevant event streams. For every use case, a processing model specific representation of the use case is provided: the so-called *use case template*. It refers to domain specific background knowledge that is available through the *relationship manager*. Since not all event streams are relevant for every use case, the knowledge contained in the use case template is used to query the relationship manager for relevant data streams. For each of the single event streams contained in the result set, the situation indication is initialized as a normal processing task by the DCEP Manager. In our example use case, relevant event stream sources are the PV sensors. The query is specified in SPARQL:

```
PREFIX :<http://www.w3.org/2000/01
        rdf-schema#>
PREFIX rdf:<http://www.w3.org/1999/
        02/22-rdf-syntax-ns#>
PREFIX sg:<http://project-dyne.eu/
        smartgrid#>
select distinct ?streamid where
{?streamid rdf:type sg:solarPanel}
```

Situation Indication Phase. The use case template provides a set of rules that defines an indication of the possible occurrence of a situation of interest. It is evaluated against each of the relevant individual event streams. In our example use case, a sudden production drop in a single PV sensor can serve as an indicator that it may be shaded by a cloud. The indication rule is specified in the event stream processing language used by the JBoss Drools Fusion engine[3]:

```
package eu.project-dyne;
import eu.project-dyne.Measurement;
declare Measurement
  @role(event)
end
rule "ProductionDrop"
dialect "mvel"
when
  Number($avg:doubleValue)
  from accumulate(
    Measurement($val:value, value>0)
    over window:time(1m)
    from entry-point
      "datastream_0",
    average($val))
  Number($avg<30)
then
  // trigger situation
end
```

Focused Processing Initialization Phase. Once a situation indication rule fires , the DCEP Manager is informed so it can determine an initial focus area for a focused processing instance. To do this, a SPARQL query to the Relationship Manager retrieves a set of single event stream identifiers to be monitored in the beginning of the focused processing stage. In the example, the focus area consists of all PV sensor event streams that are in the immediate neighbourhood of the event stream that triggered the indication rule, cf. Figure 3. The exact query would exceed the size of this paper. It is of a similar structure as the previous SPARQL query and uses the additional WGS84 Geo Positioning vocabulary[4]. To avoid reduntant instantiations of processes in the focused processing phase, the DCEP Manager checks if the retrieved focus area coincides with other focus areas of already instantiated focused processing tasks. If so, the process is aborted. Otherwise the DCEP Manager instantiates a new focused processing instance.

Focused Processing. An algorithm is specified that performs the actual focused processing. Since we consider highly dynamical problems that can not be solved with the conventional CEP pre-partitioning of the event stream, the focus area is expected to change dynamically over time during focused processing. To account for this fact, the algorithm is designed as an iterative process that allows for the adaptation of the focus area after each iteration step. Furthermore, it generates external notifications after each iteration steps and checks for termination criteria. In the example, the focused processing algorithm tries to determine the border of a cloud by looking at the measurement streams within the focus area. In case a coherent shape can not be found, the focused processing is terminated. Otherwise the generated shape is validated against background knowledge to distinguish it from other patterns such as fog or malfunction of PVs. If the shape's distance from the focus area border falls below a threshold, the focus are must be updated, i.e., moved and/or extended such that the identified shape has sufficient padding. The DCEP Manager is informed about the update and again checks for redundancies. Each processing iteration produces as its result the current shape of the cloud which is published within the DYNE system to be usable by other DLM components, such as a forecasting service that predicts the PV production curves.

[3]Ref to JBoss hp

[4]http://www.w3.org/2003/01/geo/wgs84_pos

5 CONCLUSIONS AND NEXT STEPS

The extension of the conventinal CEP architecture by decoupled dynamic partitions overcomes the problem of limited flexibility due to pre-partitioning. It thereby allows for applying the proposed DCEP approach to highly dynamic and high volume DLM scenarios. By seperating simple CEP pattern matching tasks from dynamically changing complex analysis tasks, we increase the computing efficiency of DLM processing.

In a next step, the prototypical realization of the DCEP architecture will be evaluated using several data sets of AMI data from a smart grid test field in northwestern Switzerland. The provided PV measurement data will be combined with simulated cloud movement data, based on empirically tested assumptions about the signal behaviour of the PV devices under the effect of cloud shading. Existing studies show that PV arrays under partially shaded conditions exhibit characteristic signal patterns, cf., e.g., (Vemuru et al., 2012). These signal characteristics can be used for cloud recognition when combined with background domain knowledge on typical cloud shapes, shape change, movement patterns and the geographic charactersitics of PV locations that influence the shading patterns. Other challenges that must be addressed in the generalized DCEP framework design such as the fuzzy matching of time lags between situations of interest will be addressed in future work, cf. also (Schaaf, 2013).

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Energy Aware Clouds Scheduling Using Anti-load Balancing Algorithm - EACAB

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Abstract: Cloud computing is a highly scalable and cost-effective infrastructure for running HPC, enterprise and Web applications. However rapid growth of the demand for computational power by scientific, business and web-applications has led to the creation of large-scale data centers consuming enormous amounts of electrical power. Hence, energy-efficient solutions are required to minimize their energy consumption. The objective of our approach is to reduce data center's total energy consumption by controlling cloud applications' overall resource usage while guarantying service level agreement. This article presents Energy aware clouds scheduling using anti-load balancing algorithm (EACAB). The proposed algorithm works by associating a credit value with each node. The credit of a node depends on its affinity to its jobs, its current workload and its communication behavior. Energy savings are achieved by continuous consolidation of VMs according to current utilization of resources, virtual network topologies established between VMs and thermal state of computing nodes. The experiment results show that the cloud application energy consumption and energy efficiency is being improved effectively.

1 INTRODUCTION

Up to now, the problem of efficiently allocating tasks in clusters has received considerable attention. Task scheduling algorithms have been proposed to optimize the placement of tasks with respect to performance-related criteria. Usually, those researches do not use migration to consolidate workload.

In recent years, many authors have studied the problem of power aware placement, finding theoretical solutions as well as practical ones(Lawson and Smirni, 2005)

In a similar field of research, performance of distributed systems, load-balancing techniques are often used in order to guaranty good performance. These techniques work by spreading load on all available servers, which is efficient from the performance point of view, but not from the energy point of view.

Typical performance measures include task response time, throughput and processor utilization. But when the goal is to reduce energy consumption, this type of algorithms can lead to have hosts largely under-loaded and therefore consuming energy unnecessarily.

In this context, this article proposes an energy-aware anti-load balancing algorithm. This run-time algorithm will migrate tasks while they are running, using on-the-fly migration technology.

Classical *anti-load balancing* algorithms based on migration techniques(Thiam and Da Costa, 2011) use mainly one single parameter: Threshold. Depending on a server load, if over a threshold, load is migrated on other servers or a new server is switched-on in order to keep a good quality of service. If under a threshold, load is migrated on other servers and the host is switched off.

Most researches on energy efficiency try to reduce energy consumption of servers, but they usually do not take into account the cost of cooling systems and related infrastructure. Thus it is important to set a minimum threshold to consolidate tasks, but also to avoid to load hosts heavily by concentrating too many tasks on the same host.

The main contribution of this work is to propose an efficient algorithm that migrate tasks to reduce energy-consumption while preserving performance and preventing hot spots. The algorithm, called EACAB, is based on results from the field of load balancing, especially on ALB (Thiam and Da Costa, 2011)

algorithm. We evaluate EACAB by simulation using Enersim.

The rest of the paper is organized as follows. Section 2 discusses related work, followed by the model in Section 3. The proposed migration algorithms are discussed in Section 4. An analysis of simulation results of the proposed algorithms is presented in Section 5.

2 RELATED WORK

In this section, we present energy consumption models and migration techniques.

2.1 About Energy Consumption

In the past few years, people start to realize that the energy consumption is a critical issue since energy demand of clusters have been steadily growing following the increasing number of data centers. Several strategies for energy saving in heterogeneous clusters have been proposed and studied. Recently, many energy-aware scheduling algorithms have been developed primarily using the dynamic voltage-frequency scaling (DVFS) capability which has been incorporated into recent commodity processors. However, these techniques are rarely compatible with optimizing both quality of service for tasks and energy consumption.

Chase et al. (Chase et al., 2001) illustrated a method of determining the aggregate system load and the minimal set of servers that can process a load. A similar idea leverages work in cluster load balancing to determine when to turn machines on or off to handle a given load (Pinheiro et al., 2001). A critical problem for these ideas is that in order to turn lightly loaded machines off or to assign workload to newly turned-on machines, the task need to be transferred from one machine to another. But almost all the operating systems used in the real clusters, e.g. Windows, Unix and Linux, cannot support such kind of operations. So in their research specific OS features have to be developed and applied, which in turn limits the practicability of their approaches. Research efforts are in great need to architect green data centers with better energy efficiency. The most prominent approach is the consolidation enabled by virtualization. Server virtualization technology has become known to improve utilization while reducing various aspects of consumption and offering the ability to ride the *green* trend while helping businesses save money. There are indeed a few high-performance computers designed with energy-saving in mind, such as BlueGene/L (Adiga et al., 2002), which uses a *system on a chip* to reduce energy consumption, and Green Destiny (Warren et al., 2002), which uses low-power Transmeta nodes. But their concern on energy saving is only confined to the design of hardware, with nothing to do with the strategies for power control at run-time, which also plays an important role. There is also a large effort in saving energy for desktop and mobile systems. In fact, most of the early researches in energy-aware computing were on these systems. At the system level, there has been work in trying to make the OS energy-aware by making energy the first class resource (Ellis, 1999). A number of good methods and ideas in these studies could be introduced to the energy saving schemes in cluster systems.

2.2 Job Scheduling

Migration allows tasks to be moved from their originally assigned hosts to another one, at runtime. Several virtualization software support virtual machine migration and switching off unused hosts to reduce energy consumption. Entropy(Hermenier et al., 2009), a Consolidation Manager for Clusters, is a resource manager for homogeneous clusters, which performs dynamic consolidation of resources based on constraint programming, using VM migration. (Beloglazov and Buyya, 2010) proposes a novel technique for dynamic consolidation of VMs based on adaptive utilization thresholds which reduces Service Level Agreements (SLA) violation. Also, vendors, like VMware with vSphere 4, includes a *Distributed Power Management* (DPM) that monitors virtual machines resource utilization within the cluster.

In (Srikantaiah et al., 2008) the proposed algorithm aims at finding a minimal energy allocation of workload to servers. In all these studies the objective is to minimize the energy consumption of the servers, while satisfying given performance-related bounds on the period. In (Pierson and Casanova, 2011), a model of cluster hosts that have DVFS capacities was used to calculate a bound on the optimal solution. Contrary to our work, those researches only minimize servers energy consumption while not taking into account the impact of hot spots on the cooling system. Proposed work considers the algorithm of load unbalancing to improve tasks management, taking into account the cost of migrations.

3 MODEL AND OBJECTIVES

In this section we consider a group of clusters that consists of H computing hosts, or hosts. We model each host with the unit: CPU cycles per time-unit. We also consider T services, or tasks, that run on the cluster. A task l is defined by its percentage of CPU need, l. The CPU need of a task is the CPU share it would use on a host that is dedicated to it. We will define multiple objective functions. They define optimization problems taking into account constraints that will result in efficient load unbalancing algorithms. We use an algorithm which is the opposite of load balancing because our main objective is to increase energy gain.

3.1 Model and Hypothesis

We consider an environment represented by a large-scale data center consisting of $H = \sum_{i=1}^{N} H_i$ heterogeneous physical hosts. Each cluster i has H_i hosts. There are N clusters. Each host is characterized by the CPU performance defined in Millions Instructions Per Second (MIPS). We consider T_i tasks, that run on the cluster i.

Thus, migration must take place under several constraints:

- Conservation of the execution context: It must be possible to stop the execution process of the task and restart it where it has stopped. We must be able to get the task execution context (MIPS, size, remaining size, state, memory, etc.), to transfer this state via the network, to reload and restart the task. The migration of virtual machines is used to obtain this result;
- Slowdown prevention : Job slowdown increases the execution time and therefore increases the energy consumed by hosts and impact users;
- Avoiding overloaded hosts to avoid heat points as it increases energy consumption of cooling. To measure the saturation of a cluster, we use the over-loaded threshold ε, which we call saturation. A cluster reaches saturation when its load is greater than ε.

The proposed algorithm provides solutions to these problems. The following steps are executed by the scheduler:

- Estimate the requested load (R_i) of the cluster i. This load depends on the number of task (T_i) executed by the cluster and their load ($l_{i,j,k}$ is the requested load of task k in cluster i on host j). $r_{i,j}$ is the aggregated load of all tasks on host j in cluster i.
  $R_i = \sum_{j=1}^{H_i}(r_{i,j}) \quad r_{i,j} = \sum_{k=1}^{T_i}(l_{i,j,k})$
  If task k is not running on host j in cluster i, then $l_{i,j,k}$=0.
- Computes load C_i and speed V_i of cluster i
  $C_i = \sum_{j=1}^{H_i}(c_{i,j})$
  $V_{i,j} = \sum_{j=1}^{H_i}(v_{i,j})$
  $c_{i,j}$ Actual load of host j in cluster i
  $v_{i,j}$ Maximum speed of host j in cluster i in Mips
- Job satisfaction S_i of cluster i (same for task satisfaction of host j in cluster i)
  $S_i = \frac{C_i}{R_i}$
- **constraints**
  $\forall j,k \quad l_{i,j,k} \in [0,1]$,
  $\forall i,j \quad r_{i,j} \in [0, S_i]$
  $\forall i \quad S_i \in]0,1]$
- **hypotheses**
  - Communication within a cluster and between other clusters are considered as negligible;
  - For each cluster there is at least one host and one task;
  - Migration cost is considered as the same in CloudSim. To migrate a VM, only RAM has to be copied to another node. The migration time depends on the size of RAM and the available network bandwidth. M migration delay = RAM / bandwidth + C (C = 10 sec). Bandwidth is considered as constant;
  - To minimize energy consumption the load of each host tries to verify : $\forall i,j \quad c_{i,j} \in \{0\} \cup [\gamma, 1]$
    γ is the underloaded threshold
    This equation means that each host are either switched off or with a load over γ;
  - Besides the under-load threshold we add another parameter ε corresponding to saturation and acting as a overload threshold. To verify that there is no over-loaded hosts :
    $\forall i,j \quad c_{i,j} \leq \varepsilon$

We will use the classical linear model of power consumption in function of load :
$\forall i,j \quad P_{i,j} = P^{i,j}_{min} + c_{i,j}(P^{i,j}_{max} - P^{i,j}_{min})$ Therefore the total power consumption of the system is: $P = \sum_{i=1}^{N}\sum_{j=1}^{H_i} P_{i,j}$ To obtain energy consumed during a time slice, instantaneous power has to be multiplied by time. Total energy is then obtained by summing

all the energy of those time slices. An objective is to minimize this energy.

3.2 Objectives

The main objective of our approach is to improve cloud's total energy efficiency by controlling cloud applications' overall energy consumption while ensuring cloud applications service level agreement. Therefore, our work must take place under several objectives :

- Ease of task Management : Managing jobs can be a tremendous task which requires many highly experienced IT experts. Providing an easily configurable system can significantly reduce the costs and ease the system management. One of our goals is to design a system which requires minimal human intervention to be configured. Moreover, once the system is deployed and configured, it becomes increasingly important to perform updates and/or add new servers. In such scenarios servers will be required to brought offline and added back later. Our goal is to design a system which is flexible enough to allow for dynamic addition and removal of servers. Finally, as system components can fail at any time, it is desirable for a system to heal in the event of failures without human intervention. Consequently, we aim at designing a system using self-healing mechanisms to enable high availability.
- Energy Efficiency: Over the past years, rising energy bills have resulted in energy efficiency to become a major design constraint for distributed systems providers. Given that traditional clouds are rarely fully utilized, significantly energy savings can be achieved during periods of low utilization by transitioning idle servers in a power saving state. However, as servers are rarely fully idle, first idle times need to be created. One of our goals is to propose task placements management algorithms which are capable of creating idle times, transitioning idle servers in a power saving state and waking them up once required (e.g. when load increases).
  - Avoiding overloaded hosts to avoid heat points as it increases energy consumption of cooling. To measure the saturation of a cluster, we use the over-loaded threshold ε, which we call saturation. A cluster reaches saturation when its load is greater than ε.

4 ENERGY AWARE CLOUDS SCHEDULING USING ANTI-LOAD BALANCING ALGORITHM (EACAB)

Selection policy selects appropriate tasks for migration. Location policy determines then suitable hosts to receive them. In other words, they locate complementary hosts to/from which they can send/receive tasks. Current version of our algorithm uses tasks load to take those decisions. In the following, we present an algorithm (EACAB) based on the merged principle of Comet(Jeon et al., 2010) and of anti-load balancing.

4.1 Credit based Anti-load Balancing Model

The algorithm proposed in this article aims at maximizing *Credit* which is a value used when calculating the energy-efficiency of the system behavior.

This Credits algorithm is an adaptation of the *The Comet Algorithm* (Chow and Kwok, 2002), a load balancing algorithm. Comet is based calculating credit for mobile agent. Each agent in Comet is trying to maximize its own credit by moving between hosts. An agent a_i uses the following formula:

$$C_i = -x_1 w_i + x_2 h_i - x_3 g_i$$

Where w_i : computation load of the host running agent a_i, h_i and g_i : communication load inside and outside agent a_i, and where x_1, x_2 and x_3 are positive float coefficients which constitute dependence assigned to each agent from its creation to estimate its affinity relative to their host. Thus an agent will move to a new host if it result in a lower host load, or if it reduces external communication or if it increases internal communication. This algorithm does not take int account migration cost.

In the same way, the proposed algorithm in this article works by associating a credit value with each host. The credit of a host depends on the host, its current workload, its communications behavior and history of task execution. When a host is under-loaded (load $<$ globally_defined_threshold), all its tasks are migrated to a comparatively more loaded host.

In dynamic load unbalancing schemes, the two most important policies are *selection policy* and *location policy*. Selection policy concerns the choice of the host to unload. Location policy chose the destination host of these moved tasks. An important characteristic of selection policy is to prevent the destination host to become overloaded. Also, migration costs must be compensated by the performance improvement.

Each host has its own *Credit*, which is a float value. The higher a host Credits, the higher its chance its tasks to stay at the same host. The credit of a host increases if:

- Its workload or the number of tasks in the host increases;
- Communication between its tasks and other hosts increases;
- Its load increases while staying between the under-loaded threshold γ and the over-loaded threshold ε.

On the contrary, the credit of a host decreases in the cases below:

- Its workload or its number of tasks decrease;
- It has just sent or received a message from the scheduler which indicates that the host will probably become empty in a short while.

The Credit of a host will be used in the selection policy: the host which credit is the lower is selected for tasks migration. The location policy identifies the remote host with the highest credit which is able to receive the tasks selected by the selection policy without being over-loaded. Figure 1 shows an example of migration. The percentage represents here the occupancy rate of each task on the host.

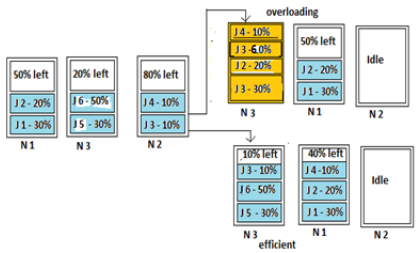


Figure 1: Different contexts for a migration.

4.2 Algorithm Description

In Comet mobile agents move between hosts according to their affinities (credit) to achieve load balancing. Here we work with tasks which migrate depending on the load of the host. We apply the Credit concept to the migration of tasks. EACAB algorithm is based on the technique of calculating credit ($\sigma_{i,j}$) of each host (j in cluster i) by the same method of Comet(Jeon et al., 2010). In EACAB, the formula is then:

$$\sigma_{i,j} = c_{i,j} - r_{i,j}t_{i,j} + \varepsilon - \gamma$$

Were $c_{i,j}$ is the actual load of host j in cluster i, $r_{i,j}$ is its requested computation load, $t_{i,j}$ is its task satisfaction, and γ and ε are respectively under-load and over-load threshold.

EACAB provides task scheduling strategy, which dynamically migrate tasks among computing hosts, transferring tasks from underloaded hostssec4 to loaded but not overloaded hosts. It balances load of computing hosts as far as possible in order to reduce program running time.

The decision making algorithm behaves globally as follows:

- If $\sigma_{i,j} < 0$, the host j of cluster i is over-loaded or under-loaded.
- If $c_{i,j} > \varepsilon$, the host j of cluster i is over-loaded
- If $c_{i,j} < \gamma$, the host j of cluster i is under-loaded

This algorithm is described in Algorithm 1. For the sake of simplicity, corner cases such as all nodes over-loaded are not included. Selection policies take into account credits and migration cost. The selected host (node j' in cluster i') is the one with the minimun $\sigma_{i',j'}$ weighed by the migration cost between the current position of the job and the potential host. If $\tau_{i,j,i',j'}$ is the migration cost between the node j in cluster i and the node j' in cluster i', the selected host is the one that minimize : $\sigma_{i',j'} \cdot \frac{\tau_{i,j,i',j'}}{Max_{i'',j''}(\tau_{i,j,i'',j''})}$

4.3 Analysis of the Algorithm

This migration algorithm's goal is to minimize the energy. It is composed of two parts. In the first part, it checks for each host i if the load is below the threshold. If this is the case, it locates the host j that will receive all tasks of host i. The second part manages hotspots. To reduce the load of an overloaded host, it begins to migrate the slowest task. Selection policy will choose the task that will stay the longest on the host. Policy of localization will then identify the host that will receive the task without exceeding its capacities (ie. its load after migration will still be under ε). So this host will be the new destination of the task.

5 EXPERIMENTS AND RESULTS

In order to evaluate the gains of EACAB compared to classical algorithms, we implemented this algorithm in EnerSim. This simulator is based on GridSim(Calheiros et al., 2011), where we added power consumption (extended from CloudSim(Buyya and Murshed, 2002) implementation) and virtual machine (mainly their migration). It is a java event driven simulator of grids, cluster and Clouds. It provides information about execution times, but also about instan-

Algorithm 1: Energy aware clouds scheduling using anti-load balancing algorithm (EACAB).

Calculate $c_{i,j}$, $\sigma_{i,j}$ *// Load, credit of node j in cluster i*
Sort in ascending order hosts according to the value of their credit
for (M_{orig} in sorted host j in all cluster i) **do**
  Update $c_{i,j}$, $\sigma_{i,j}$ for remaining hosts
  Sort the remaining hosts (per load)
  if $(c_{i,j} < \gamma)$ **then**
    // In case M_{orig} is under-loaded
    for (M_{dest} in all host j' in all cluster i') **do**
      if $M_{orig} \neq M_{dest}$ and $(c_{i',j'} \geq \gamma)$ and $(c_{i,j} + c_{i',j'} < \varepsilon)$ **then**
        Add M_{dest} to potential destination set *Potential*
      end if
      Migrate all task from M_{orig} to the element with lower credits weighted by migration cost in *Potential*
    end for
  else
    // M_{orig} can be over-loaded
    while $(c_{i,j} > \varepsilon)$ **do**
      // In case M_{orig} is over-loaded
      Calculate $l_{i,j}^{min}$ *// load of the lightest task in M_{orig}*
      for (M_{dest} in all host j' in all cluster i' sorted by their credits) **do**
        if $((M_{orig} \neq M_{dest})$ and $(c_{i',j'} + l_{i,j}^{min}$ ¡ $\varepsilon)$ **then**
          Migrate task from M_{orig} to M_{dest}.
        end if
      end for
    end while
  end if
end for

taneous power consumption and energy consumption of tasks.

5.1 Simulation Environment

- Grid : 100 clusters of 100 hosts each. Each host speed is between 1GHz and 3.06GHz
- Jobs : 1000 randomly generated tasks
  - Duration between 10 and 40s
  - Requested load between 10% and 100%
- Host shutdown and wakeup energy are assumed to be zero as they are fast compared to the execution time of tasks.
- Hosts have two different power states for each core: Switched on and switched off. While switched on, power consumption is linear in function of load between P_{min} and P_{max}. Those values are different for each host and are respectively between 75 and 150W, and 200 and 250W.

In the following we compare EACAB with other algorithms.

- Dynamic First Fit: a dynamic *First Fit* where host are sorted according to their maximum power consumption.

5.2 Experimental Results

It is designed to be a centralized coud scheduler that emphasizes on cloud scheduler interoperation, and complemented by a dynamic resource discovery approach on centralized network.

In this subsection, we describe the simulation study performed to evaluate the performance of our algorithms in terms of energy minimization as well as the execution time and the number of migrations.

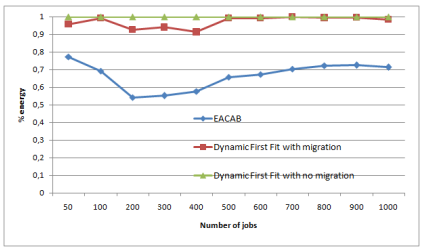


Figure 2: Energy of algorithms compared to dynamic first fit with unsorted hosts. Lower is better.

5.3 Algorithm Description

The first observation is that for two algorithms, EACAB consumes the least energy while Dynamic First Fit algorithm consumes the most energy (see figure 2), when the number of jobs $T > 350$. For a small number of tasks our algorithm leads to a significant energy consumption. Our EACAB algorithm performs even better. The second observation is that EACAB algorithm is able to reduce the energy consumption by 5 percent to 20 percent when job increases from 350 to 1000.

Figures 3 and 4 show respectively the maximum and median number of switched on host as a function of task number. When jobs increase then the number of nodes switched on also increase, leading to a higher power consumption. This is particularly true if there is no migration after the initial placement of tasks. Hence, the gain of our algorithm increases

Table 1: Makespane of algorithms compared to First Fit with sorted hosts.

	Number of Jobs									
Algorithm	100	200	300	400	500	600	700	800	900	1000
Dynamic first Fit	265.53	374.4	580.37	631.22	615.04	870.55	813.83	1006.31	853.68	1270.73
EACAB	230	225.81	321.95	399.45	495.09	589.84	565.48	872.3	738.43	815.65

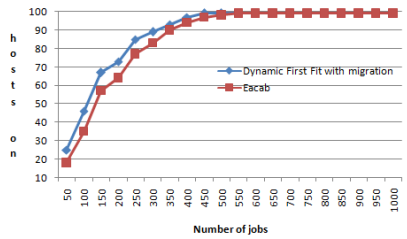


Figure 3: Maximum host switched on with EACAB.

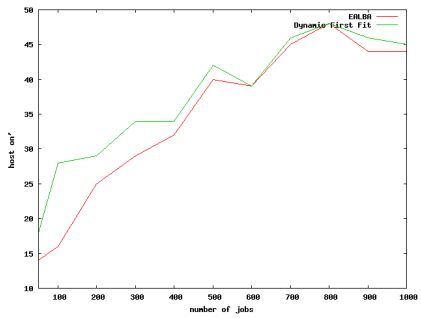


Figure 4: Median host switched on with EACAB.

power-wise with the number of tasks because migration is activated. Computing resources are fully used in both cases at the start of the experiment. In the case of the consolidation, less hosts are switched-on because we can adapt to the workload dynamism. The median has the same behavior but the maximum number of hosts is 50%. The observed gain increases with the number of tasks and becomes constant when hosts are saturated.

The good results of EACAB comes from the fact that with the increase of the number of tasks, it has more possibilities to migrate tasks. It can then better allocate tasks on computing resources, reducing the number of switched-on hosts.

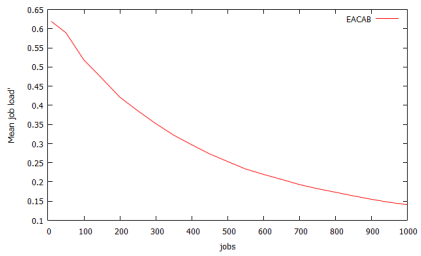


Figure 5: Job mean load with EACAB.

Due to the thresholds of EACAB, it would be possible to reduce further the number of switched on hosts but it would overload remaining hosts. Those hosts would become hot points and would have a negative impact on cooling. In order to prevent overloading, EACAB adjusts load as shown in Figure 5. If the number of tasks increases, it will reduce the mean actual load they will obtain.

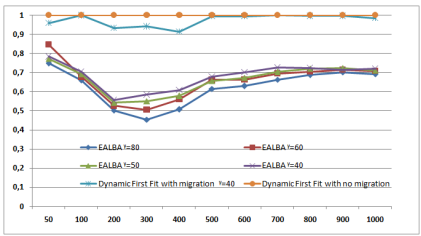


Figure 6: Variation of threshold vs energy gain with EACAB

Figure 6 shows that our algorithm is better than classical *Dynamic First Fit* regardless of the threshold when the number of tasks is important.

The choice of γ is still important. There is a energy consumption difference of 10% between the best and the worst value. The worst value is 10% more efficient than dynamic first fit, the best one is 20% more efficient.

For small number of tasks, energy consumption increases because of the many migrations. To choose this value it is omportant to consider the dynamisme of the tasks. As said previously, increasing γ, reduce energy consumption at the cost of consolidating more and more the tasks.

EACAB has the shortest execution time when the number of jobs increases. The result implicates that the scheduling algorithm such as EACAB can leverage interconnects with migrations to achieve high performance and energy efficiency. Table 1 shows that our algorithm produces faster scheduling regardless of the number of jobs.

6 CONCLUSION

In this paper, we presented and evaluated our energy-efficient migration algorithm for clouds. This algorithm is based on the principle of *Anti-load balancing*.

It provides energy-efficiency improvement compared to classical load unbalancing algorithms.

Our main problem was to optimize energy consumption given task performance constraints. Energy consumption is to be taken in a broad way as we try to prevent hot spots to reduce impact on cooling.

We have compared EACAB to classical solutions over a range of problem instances using simulation. EACAB parameters lead to a family of heuristics that perform well in terms of energy savings while still leading to good task performance.

EACAB consolidate tasks on a subset of the cluster hosts judiciously chosen depending on the characteristics and state of resources.

This algorithm has a low computational cost. It can then be employed in practical settings. Overall, the proposed EACAB algorithm can compute allocations effectively with an important energy gain. Experiments showed that with our algorithm we obtained a 20% gain over standard algorithms. However, it is important to investigate further how to improve the quality of service, but also the optimization algorithm.

Also current version of EACAB is centralized. We aim at distributing this algorithm, so that each cluster can exchange tasks, based on their respective credits. Future version of EACAB will also take int account other measures to compute Credit such as network communication patterns.

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Semantic Interoperability for Smart Grid
CIM Adoption Process

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Keywords: Smart Grid, Common Information Model (CIM), Semantic Interoperability, Distribution Management.

Abstract: This paper describes the experience obtained in the adoption process of the Common Information Model (CIM) as part of definition of a strategy for semantic interoperability for legacy information systems of *Comision Federal de Electricidad* (CFE by its acronym in Spanish). The strategy and the process described are supported by standards IEC 61968 and IEC 61970, as well as best practice in software development in the international context. Overall, the architecture for interoperability and the adoption process, will establish a solid infrastructure designed to meet Smart Grid requirements for management systems for the Electric Power System (EPS) in Mexico. Some results are discussed.

1 INTRODUCTION

The electric market deregulation in USA, Europe and several countries in the world, as well as emergent technologies required to establish the vision of Smart Grid have increased the need of the electric utilities to exchange information in a daily way, thus, overall they must ensure the reliability of the operation of interconnected electric systems.

Likewise, all electric utilities uses internally a great quantity of formats and technologies for systems and functions for manage the electric power system, considering data storage in several databases (hierarchical, relational, object oriented, geospatial) and files in custom formats, as well as operating systems of any kind and supplier, even though being incompatible among them.

In this way, it has become exponential the problem of develop and maintain updated a great quantity of data interfaces, many processes for exporting and importing information, as well as several requirements to transform the exchanged data, all of this coupled to a typical problematic: the information and function **duplicity**, that happens when two or more systems contain the same data or perform the same function; the data **inconsistency** is evident when two systems have different values for the same data; and the **incompatibility** that occurs when the information of two or more systems, it cannot be combined for technological causes, political, syntactical or semantic (Parra et al., 2012).

Smart Grid will be a great set of systems of interconnected systems (electric and computerized), thus being every time more evident the necessities of interoperability of the information systems in charge of monitoring, control and manage, overall, due to the advanced functions that are being defined, establish as a premise the capability of information exchange in agile and expeditious manner.

2 SEMANTIC INTEROPERABILITY

Interoperability refers to the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user (NIST, 2012).

According to the reference framework defined by the GridWise in (GWAC, 2008), the informative interoperability covers the content, the **semantics** and the data format or instruction flows (as are the accepted meaning of human beings and programming languages). It focuses into which information is exchanged and its **meaning.** It establishes the understanding of the contained concepts in the data structures of exchanged

messages, and integrates knowledge of the business related to the semantics or meaning in the work flow of a process. For the first time, the exchanged data are associated to the electric infrastructure of the enterprise and rules are established that ensure that the exchanged data meet the semantic definitions established in an Information Model, being general and independent of technological platforms, systems, brands or suppliers.

The Common Information Model (CIM) is a generic Model, open and standard that can be adopted by any enterprise. CIM is defined in a group of standards of the IEC, being the most important: IEC 61970-301 which defines the Model CIM Base for Transmission Power Systems for use in Energy Management Systems (EMS), IEC 61968-11 which defines the CIM extensions for Distribution Power Systems and IEC 62325-301 that establishes the extensions for the Electric Market or CME (CIM for Market Extensions). Figure 1 shows these three standards as UML packages in *Enterprise Architect*.

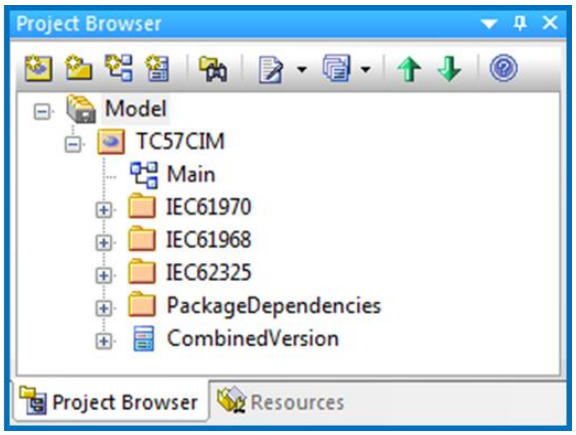


Figure 1: CIM packages in UML.

CIM have three primary uses: to facilitate the exchange of power system network data between organizations, to allow the exchange of data between applications within an organization, and to exchange market data between organizations. (EPRI, 2011).

2.1 CIM History

The CIM is a set of open standards for representing power system components originally developed by the Electric Power Research Institute (EPRI) in North America and now a series of standards under the International Electrotechnical Commission (IEC). (EPRI, 2011).

CIM was started in 1992 as part of the Control Centre API (CCAPI) of EPRI; from 1993 to 1996 it was developed with main target of allowing the use of compatible applications in order to protect the investment of the enterprises (E-R diagrams in MS-Visio were used and MS-Access as Database); in 1996 the CIM was transferred to the IEC, to the 57 Technical Committee (TC57) and 13 and 14 working groups (WG13 and WG14), the Transmission and Distribution areas were covered (UML was adopted as modeling language and it was kept in Rational Rose); in 2000 the first interoperability test was performed; in 2003 the CIM for Market Extensions (CME) development was initiated, followed by the models for Planning and Dynamics, currently the model for Weather and HDVC cables are in development; in 2005 the first version of IEC standard 61970-301 CIM Base was emitted and the CIM Users Group (CIMug) was established; in 2008 the CIM was formally adopted by the Union for the Coordination of the Transmission of Electricity (UCTE) in Europe; in 2009 the National Institute of Technology and Standards (NIST) identifies the CIM as two of the five key standards for the interoperability of the Smart Grid; in 2010 the European Network of Transmission System Operators for Electricity (ENTSO-e) migrates to CIM and sponsors the first CIM interoperability test in Europe; in 2011 in EDF interoperability tests were applied to parts IEC 61968-4 and IEC 61968-13 that define the Common Distribution Power System Model (CDPSM). Nowadays, CIM is maintained and distributed in UML with format of *Enterprise Architect* software tool.

In the Smart Grid context, in order to achieve the interoperability of the information systems in the electric utilities, several levels as well as schemes of reference have been defined, which allow to establish the strategy and enterprise architecture in order to achieve the vision. In (GWAC, 2008) a conceptual reference model is defined for the standard identification and necessary protocols in order to ensure the interoperability, the cyber security and define architectures for Smart Grid systems and subsystems; in (NIST, 2012), is defined a framework for architecture and standards for Smart Grid; in (Parra et al., 2012) is proposed an architecture for information systems of the electric utility in Mexico; and in (Espinosa and Rodriguez 2011) it is established the architecture of semantics interoperability for the Smart Distribution Power Network (SEDI by its acronym in Spanish) for CFE's Distribution Management Systems (DMS).

2.2 CIM Description

CIM is an Information Model that applies the paradigm "Object Oriented" of Software Engineering in order to represent the elements of the real world that are used for the infrastructure, management and operation of the electric systems of Transmission and Distribution, such as cables, lines, transformers, switches, protections, structures, poles, measurements, among others. The model is constituted by: Classes Packages, Object Classes, Attributes and Relations among Classes/Objects. The model defines the interfaces for systems integration and besides, it includes the connectivity of the electric system, thus facilitating the united exchange of data among systems and enterprises.

2.3 CIM Wrapper Description

A data interface that complies with CIM is known as "CIM Wrapper" and it must allow the reading/writing of messages or XML files, its information structure meets the syntactic, semantic and electric rules defined in CIM, thus ensuring that the receiver system of a CIM message will be able to read the content (syntactic) and will be able to interpret its meaning (semantic) in an identical way as to the transmitter, without the need to know the internal data structure of the source system and in an independent manner as to its technological platform, brand or supplier.

A "CIM Wrapper" is in charge of:

- Implementing the data access of the legacy system.
- Performs the data transformation according to the Concept Map and defined Semantic Model.
- Implementing functionality in order to exhibit information to other systems.
- Taking and interpreting the information from other systems for internal use.

3 CIM ADOPTION PROCESS

Due to its complexity and initial cost (in time and effort), the adoption of CIM in an electric utility it must be part of a long term integral strategy as part of the Vision and Technological Roadmap for Smart Grid. The systems that will be bound must be defined, as well as the more convenient adoption strategy. It is recommended that the initial scope is limited but challenging, meaning by this that the information that is to be transferred is not trivial, that it is coherent and that it considers or represents complete or integral concepts, thus giving a better experience to the development group that participates in the process.

A CIM adoption strategy, overall for integrating legacy systems, it is through the development of "CIM Wrappers", which must have perfectly defined its particular scopes. In Figure 2 it is shown the adoption process of CIM based in the development of "CIM Wrappers".

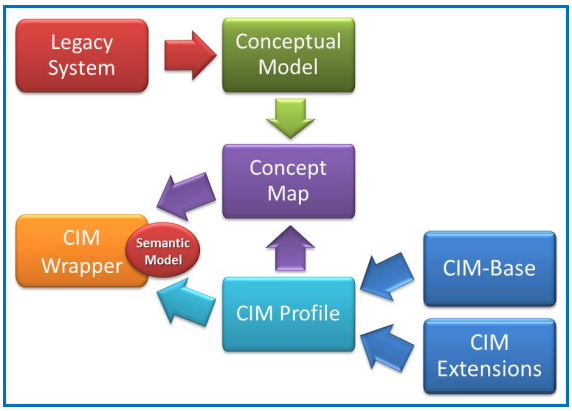


Figure 2: CIM Adoption Process based on "CIM Wrappers".

The first phase in the CIM adoption process, it has two parallel tasks: the creation of a **CIM Profile** and the development of a **Conceptual Model** of the Legacy System to integrate.

A **CIM Profile** is a subset of Classes, Attributes and Associations of **CIM Base Model** that represents the components of the real world selected for its use in the information systems. The **CIM Profile** is obtained by selecting only the concepts and its relations with other concepts that will be used in a scheme or architecture of semantic interoperability for an electric enterprise. For the concept selection and its relations it is used the software tool CIMtool (CIMtool, 2013) and the result must be obtained as Ontology in a format legible by computer, for example OWL or RDFS (Scheme) (Espinosa et al., 2011).

The **CIM Profile** can use native concepts of the CIM Base Model or the extended concepts during the **Concept Mapping.**

The **Conceptual Model** of a legacy system is a Model that formally represents the elements that compose it and the relations among them; according to the legacy system, this Model must be preferably created using the paradigm "Object Oriented" and UML, but in occasions, the relational model can be applied. This Model is the source of base information in order to know the meaning of the

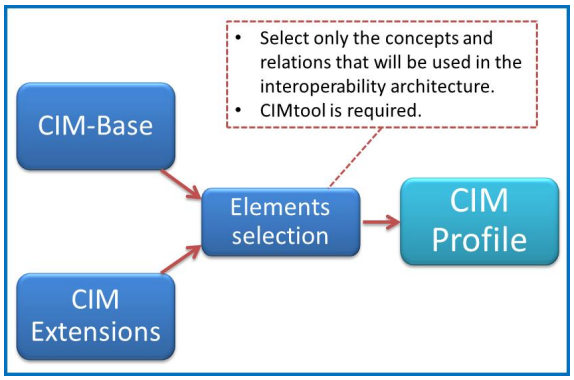


Figure 3: CIM Profile definition.

stored data and managed by the legacy system and it will allow performing the next stage.

The **Concept Map** refers to the relations among defined concepts in the **CIM Profile** and the stored concepts by the legacy systems, meaning by this that it describes the "translation rules" of the data to be exchanged. Figure 4 shows the process to define the **Concept Map**.

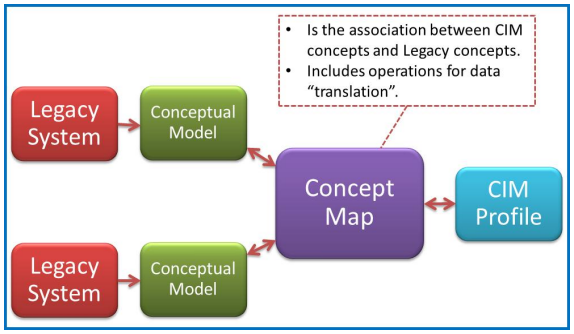


Figure 4: CIM Concept Map definition.

For example, the concept "Distribution Division" stored in the legacy systems in a table of a relational database, it can be translated in a direct way to "GeographicalRegion" of CIM, due to the fact that the CIM description establishes in a rigorous manner the definition of this Class and it corresponds to the "Division" hierarchy in the organizational structure of the enterprise. The concept "Distribution Zone" can be translated in a direct manner to the CIM concept "SubGeographicalRegion". Likewise, the relation among these two concepts of the enterprise adequately corresponds to the defined relation in CIM for this structure, due to the fact that a Division is composed by Zones and Zones must belong to a Division.

In the case that CIM does not consider a specific concept, it is required to define a CIM extension, without affecting the **CIM Base Model**, meaning by this that without altering Classes or Relations among them. For example, the attribute "Territorial extension" of a Zone, it could be mapped to an extension in CIM through a new Class inherited from "SubGeographicalRegion" which includes all the attributes that were not identified in the **CIM Base Model**.

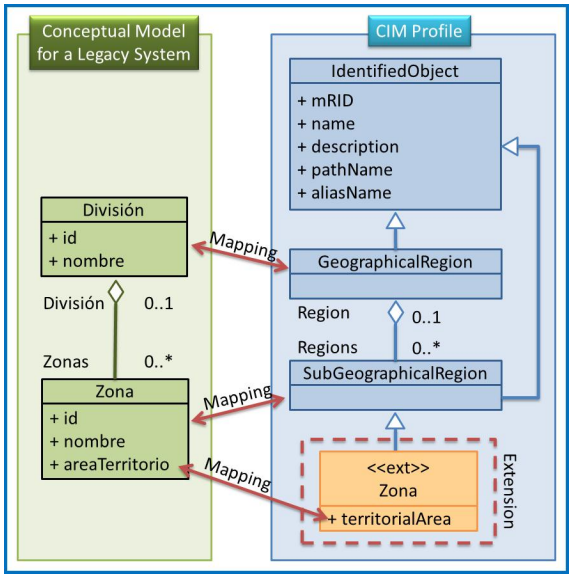


Figure 5: Example of Concepts Mapping between a legacy system and CIM.

Figure 5 graphically shows the way in which it must perform the **Concept Mapping** among the **Conceptual Model** of the legacy system and the concepts in the **CIM Profile** defined for the electric utility. It must stand out the fact that before deciding to include a CIM extension, all the resources must be exhausted in order to identify the concept in the native CIM Classes, because any extension will perfectly be managed by the internal systems that know the specific **CIM Profile**, but any entity, enterprise or system that comply with the **CIM Base Model** it cannot interpret the meaning of the extensions due to the fact that the specific extensions are not included in the standards emitted by the IEC.

Due to the relevance of the **Concept Map**, it is recommended to use a table that allows to establish the relations for the concepts translation among the legacy systems and CIM, in such a way that it serves as a tool of implementation of the meaning of information (in bidirectional way), as well as defining agreements among the development groups and maintenance of the information systems.

In case that the legacy system does not have a **Conceptual Model** and the description of the information that it contains, this table can be taken

to document the formal definition of each data to exchange. Likewise, if a specific data is duplicated among different systems, this table must establish the only source as origin of this data to keep consistency of the information and thus avoid a problem of duplicity to the interoperability context that is being implemented.

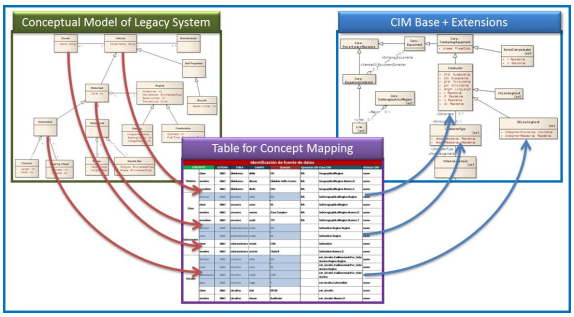


Figure 6: Table for Concept Mapping between legacy systems and CIM.

Due to the fact that CIM models the concepts that represent object of the real world of the electric utility, it is required to have the **Semantic Model** of data to share, thus it must have the explicit meaning of each data and value, as well as the relations among this data, this conceptual description must be exhaustive and rigorous with the purpose of facilitating the communication and the information exchange among different systems.

In CIM adoption process, the **Semantic Model** is obtained from the union of two artifacts, the **Concept Map** and the **CIM Profile** as shown in Figure 7.

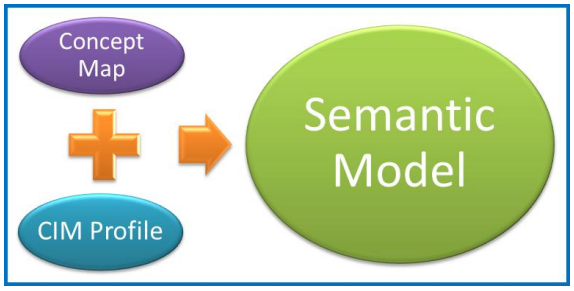


Figure 7: Definition of a Semantic Model – CIM based.

In summary, the development of a "CIM Wrapper" for a specific legacy system will use (or it will be based in) the **Semantic Model**.

3.1 Conceptual Model

The legacy system must expose the concepts that it stores or manages through its **Conceptual Model**, it must establish the meaning of each data to share and it must be the only source for these concepts in all the interoperability context and scheme scope. It must not define more than one information source for a same concept.

3.2 Concept Map

The **Concept Map** of legacy systems with the concepts in **CIM Profile** established in the mapping table, it will allows to perform the syntactic and semantic translation of transported data among information systems in both ways, from the legacy system to CIM, and from CIM to legacy systems.

3.3 CIM Profile

The **CIM Profile** will contain the common definition, strict and exhaustive, of the information to exchange among systems through CIM. It is based in the **CIM Base Model** and the concepts extensions (exclusive for a specific utility). It must be in a legible format for computer because the "CIM Wrapper" must completely implement it in Classes of some Object Oriented Programming (OOP) language for validation, reading and interpretation of the contained information in messages or files.

3.4 Completeness

The **Concept Mapping** can only use completely described concepts in the **Conceptual Model** of the legacy system and in the **CIM Profile** because in the case of accepting a non described concept, this could be ambiguous or without common interpretation of its meaning.

4 RESULTS

Next, some results obtained from applying the CIM adoption process to CFE legacy systems are described.

Figure 8 shows three views of a **CIM Instance** (real world data) with the organizational structure of the Distribution Subdirection of CFE. The left box shows a hierarchical tree that allows to navigate the components of a Division and its Distribution Zones. The right box shows the CIM segment that models these concepts and its relations. Finally, the below box shows in XML format the same data, where it is out stood that the "Distribution Division" is associated to the "GeographicalRegion" Class and "Distribution Zones" is associated to the

"SubGeographicalRegion" Class. In the example, the "Polanco" and "Tacuba" Zones are part of the "Valle de Mexico Downtown Division" (DVMC by its acronym in Spanish) and an only identifier (in red) is used to establish the association. This information comes from the Integral System for Distribution Management (SIAD by its acronym in Spanish).

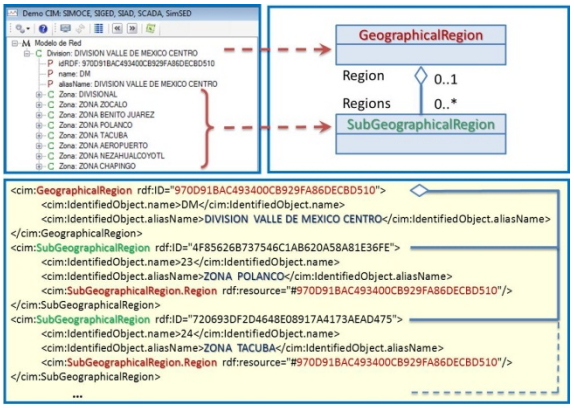


Figure 8: Different views of a CIM Instance for organizational structure in Distribution Subdirection.

Figure 9 shows that when navigating in the hierarchical tree, the **CIM Instance** allows to consult the electrical information of a Transformer of "Veronica" Substation, as well as connectivity topology and geospatial location, which comes from the GIS for Distribution Network and the electric details from the On-Line Simulator for Distribution Power Systems (Espinosa et al., 2010).

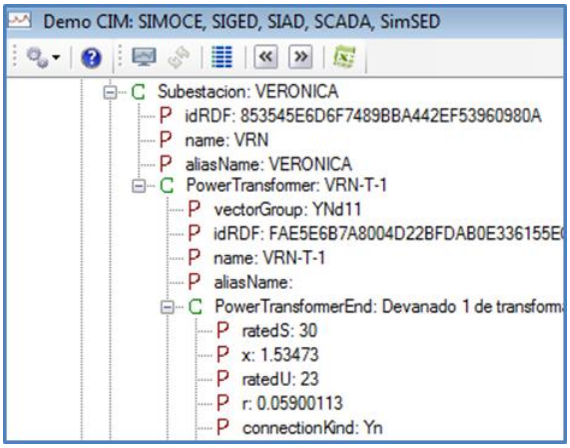


Figure 9: CIM Instance showing electrical parameters of the main power transformer in a Distribution Substation.

The application developed allows consulting multiple systems and sources of real information, without inconveniences for the user.

5 CONCLUSIONS

The adoption of CIM and an architecture of semantic interoperability are key elements that will allow the information exchange in a standard manner among systems, with the purpose of establishing advanced applications that take advantage of this capacity, such as Demand Response, Advanced Distribution Automation, Self-Healing, among others that are emerging and being defined in the international environment.

Some of the most important electric enterprises in the world are migrating their data interfaces to CIM as part of an integral vision of enterprise degree. Experience shows positive results in the majority of the cases because the common modeling by itself minimizes the inconsistency mistakes and duplicity of information.

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Exhaust Thermoelements Redundant Strategy to Improve Temperature Reading Reliability and Serviceability

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Keywords: System Reliability, Availability, Thermal Sensors, Gas Turbine, System Redundancy.

Abstract: Pollution linked to power generation is strictly connected to gas turbine control algorithms and efficiency performance. Parts life is affected by quality and type of combustion too. The control of the exhaust temperature is therefore a key parameter to indirectly monitor the effectiveness of the combustion in all the combustion chamber of an heavy duty gas turbine. Actually due to the high temperature and dynamics of the combustion chambers the performance measurement of the combustion is achieved through indirect pressure and temperature monitoring. Moreover, exhaust temperature monitoring may allow to avoid dangerous situations connected to flame loose in combustion chamber and subsequent gas leak towards gas turbine high temperature zone. A reliable readout configuration of such sensors may improve the system overall safety too. In this paper the authors discuss about the best thermoelements configurations in order to improve the reliability and serviceability performance in gas turbine in order to increase the system efficiency during power generation.

1 INTRODUCTION

In recent years researchers focussed part of the research efforts on power generation efficiency measurement due to the fact that traditional and renewable power sources have to be qualified not only in terms of power quality and stability but also in terms of overall system serviceability.

Therefore the efficiency of a power generation site has been enhanced through the vision that higher efficiency can be achieved through a life extension of power generators parts. Modular (mixed) generation sites where green power stations coexist aside with traditional generation structures based on gas turbine, for example, require outstanding reliability and availability figures to supply power baseline and power peak to the end users. Actually reliability plays an important role to grant a power plant capability and production over time while the availability figures are used to estimate the plant structure to arrange possible plant redundancies and maintenance. Some authors have extensively studied both reliability and availability of components up to complex equipment to evaluate the impact of aging on subsystem or system operating in a power generation plant (Hua and Yang, 2011); (Mugnaini et al., 2002); (Chowdhury and Koval, 2009); (Ceschini et al., 2002). Traditional approached exploit reliability block diagrams representations, fault tree analysis (FTA) and homogeneous Markov Modelling (MM) (Rao, 2005); (Birolini, 2010). Out of these studies it is pointed out that even small components failures like the ones which can take place at sensor levels like the ones used for lube oil temperature read out purposes or accelerometrics sensors in journal bearing vibration monitoring can lead to meaningful failure of huge parts of the production site, with the consequent impossibility to grant the nominal station power generation. Usually, such studies are performed taking into account constant failure and repair rates, because this allows an easier formulation and modelling of the problem.

Some efforts (Mugnaini et al., 2002); (Fort et al., 2013) have been done in order to improve the modelling of the components failure rates representation. For example dynamic changes of failure rates over time allows to be more adherent to real mission behaviour. Such researches proved that this approach is effective with promising results but its implementation on complex structure may require an extensive effort for data collection and synthesis.

Some of the parts that have an impact on system productivity reliability and safety are the thermoelements used in gas turbine exhaust for

temperature monitoring (Fort et al., 2013); (Catelani et al., 2000); (Catelani et al., 2007). Such sensors are widely exploited to monitor indirectly the behaviour of the combustion of the gas turbine and to check the temperature distribution on the high pressure wheel to extrapolate information on the gas turbine efficiency and on possible components thermal stress. Unfortunately designers somehow don't take into consideration the impact of the sensor number connected to the trip and control logics configuration in assigning to a specific gas turbine a certain number of thermoelements. This work aims in providing an analysis on how a selected number of different sensors configurations may present reliability and serviceability differences which can affect the overall system reliability and availability.

2 SYSTEM DESCRIPTION

The gas turbine exhaust temperature is monitored through a certain number of thermoelements (generally thermocouples) in order to provide indication on the combustion gas temperature distribution as well as on the combustion chamber and liner performance.

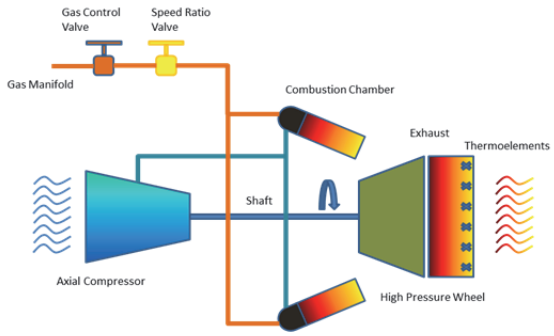


Figure 1: Simplified schematic of a gas turbine system transversal section.

In Figure 1 a simplified schematic of a gas turbine system transversal section is presented. It is possible to identify the main gas manifold which provides the system with the gas to be burned the combustion chambers which are roundly and symmetrically distributed around the gas turbine, a couple of gas valves named gas control valve which provides the main gas flow and the speed ration valve used to control the main wheel speed rotation respectively, the axial compressor which feeds with compressed air the combustion chamber, the high pressure wheel and the exhaust. Thermoelements for temperature monitoring are usually placed on the exhaust middle section on a radial geometry in order to grant the combustion chamber uniformity monitoring and complete mapping. Such sensors can be either thermocouples or negative temperature coefficient sensors dependently by the specific turbine designer.

The aim of such sensor is to monitor the temperature distribution of the exhaust and to support in the diagnosis of anomalous conditions like combustion malfunction in one of the chambers with alarm or trip (stop) signals. Of course in case of failure of one sensor it is barely unlikely to stop the whole machine comparing the cost versus the benefits of the operation. Nevertheless more than one failure can induce a machine trip but this has to be justified by a proper reliability/availability analysis.

The number of sensors that are generally present for temperature monitoring should take into account at least three factors: the reliability impact of the configuration according to the selected alarm/trip logic, the availability considerations and the overall system safety apportionment.

3 RELIABILITY AND AVAILABILITY MODELING

Reliability ($R(t)$) techniques exploit reliability block diagram modelling (RBD) (Mugnaini et al., 2002) while availability (A(t)) approaches relying on homogeneous Markov Modelling (flow state space) are preferred when dealing with constant failure and repair rates (Rao, 2005); (Birolini, 2010). With respect to reliability studies the presented paper will discuss about the figures of three different configurations taking into account six thermoelements, nominally identical, with a constant failure rate according to Table 1.

Table 1: Single thermoelement failure rate.

Failure Rate	[Failures/h]
λ	$0.1*10^{-6}$

The purpose is to evaluate which is the configuration that best fits a new product application on the reliability standpoint considering also the availability, serviceability and safety aspects.

The configurations that will be considered are a 2oo6 that means that at least two thermoelement over six have to be working to let the system accomplish its mission, the 4oo6 configuration where at least four element have to work and an hybrid configuration of 3oo6 plus two consecutive

failure. This latter in particular consider that in order to declare a system failure and therefore a system trip, 4 or more thermoelements should fail or two consecutive elements should fail. This additional condition takes into consideration that fact that in order to consider the system safety the temperature control over a large section of the exhaust should not be lost. The system RBD is represented in Figure 2 where on the upper part there are the odd thermoelements while in the lower part there are the even ones.

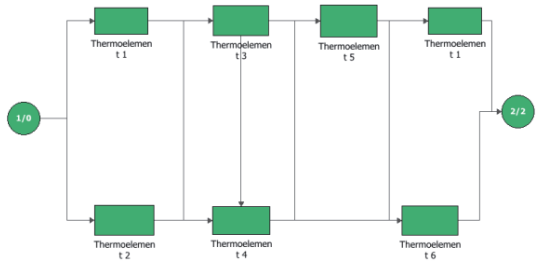


Figure 2: Reliability Block Diagram (RBD) of a 3oo6 +2 consecutive failures configuration.

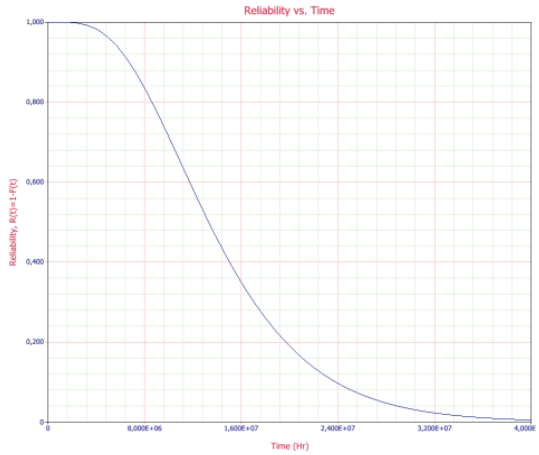


Figure 3: Reliability behaviour of a 2oo6 configuration with λ=0.1e-6 F/h and μ=0.

In Figure 3 there's the reliability behaviour over time of the 2oo6 configuration, while in Figure 4 and Figure 5 there are the reliability results of the 4oo6 and 3oo6 plus 2 consecutive failures respectively. It is possible to notice that as could be expected the 2oo6 configuration has the highest reliability degree but unfortunately such configuration does not allow to keep a satisfying exhaust temperature control. On the opposite site the behaviour of Figure 5 is very conservative because the reliability behaviour is not only far below the one of the other two configurations but also the slope on the first part of the curve is very high (negative slope) denoting a high change rate in the reliability of the system in the first part of its mission.

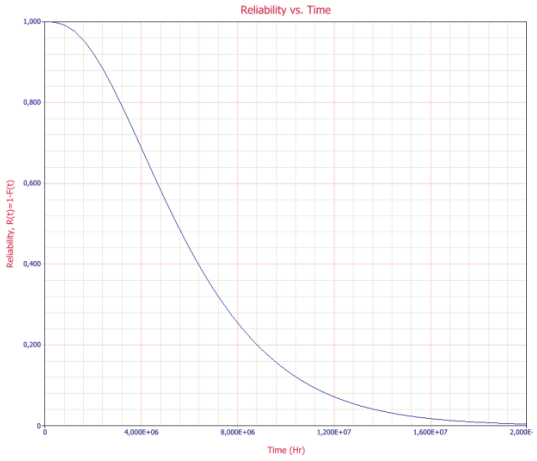


Figure 4: Reliability behaviour of a 4oo6 configuration with λ=0.1e-6 failures/h and μ=0.

Of course this is the effect of the combination of the safety requirement (2 consecutive thermoelements monitoring). Therefore, a good compromise among the three configurations could be represented by the 4oo6 placement where a reasonable reliability and system special covering can be granted at the same time.

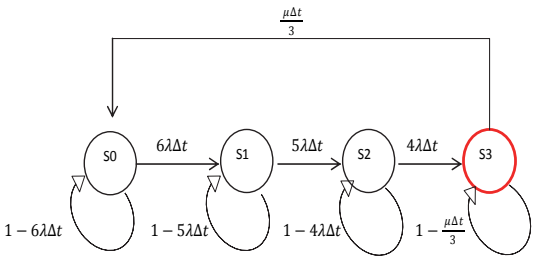


Figure 5: Reliability behaviour of a 3oo6 +2 consecutive failures configuration with λ=0.1e-6 failures/h and μ=0.

We introduce now the availability analysis through MM to evaluate such configurations enhancing the study with the availability considerations (Rao, 2005), (Birolini, 2010). It is common to find actual field situations where a system can be described or condensed as a block with certain properties in terms of failure rate (λ [failures/h]) and repair rate (μ [repairs/h]). For such systems it is possible then to build specific Markov models and solve them in terms of their availability, based on the following basics (but not limited) assumptions depending on the operability conditions assumed and on the number of states selected.

1. There are N observable states
2. There is an observable sequence $q_1,q_2,\ldots,q_T$
3. The failure and repair rates are constants over time (memory less condition) and the process is stationary
4. Each transition from one state to the other take place in defined Δt which is constant (sampling time)
5. In each Δt only one transition take place
6. Every Δt a transition should occur.
7. First order Markov assumption

For such modelling the authors decided to modify to the 2oo3 configuration adding the constraints of the three consecutive failed items to include safety monitoring aspects in such representation. Therefore we studied the three most promising configurations (4oo6, 3oo6+2consecutive and 2oo6+3 consecutive) from an availability perspective. We represented the state flow diagram as in Figure 6 where S_X is a specific transition state corresponding to a physical sensing arrangement behaviour while one state, the red one, represents the system failure condition. Each transition taking place every sampling time is associate with a probability through the failure and repair rates. The system dynamics can be expressed through (1):

$$\frac{dP(t)}{dt} = \begin{pmatrix} -6\lambda & 0 & 0 & \frac{\mu}{3} \\ 6\lambda & -5\lambda & 0 & 0 \\ 0 & 5\lambda & -4\lambda & 0 \\ 0 & 0 & 4\lambda & -\frac{\mu}{3} \end{pmatrix} P(t) \qquad (1)$$

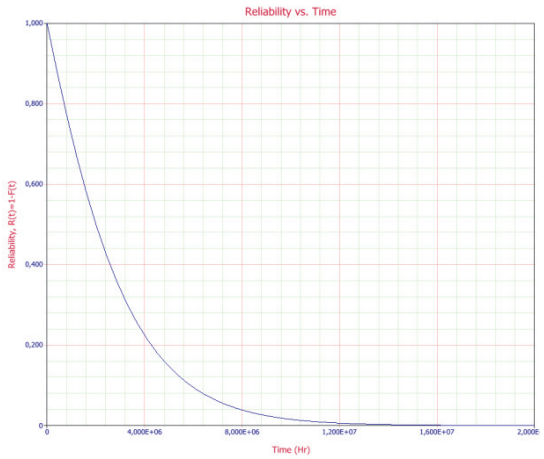


Figure 6: State space representation of the MM of the 4oo6 configuration where S3 represents the failed case.

The availability performance can be measured through the sum of the probabilities over time of the states that are not considered failed and the analytical solution can be obtained. In the same manner in Figure 7 and 8 there are the modeling of the two alternative configurations that is the 2oo6 + 3 consecutive and the 3oo6 + 2 consecutive failures respectively, while (2) and (3) describe again the system dynamics.

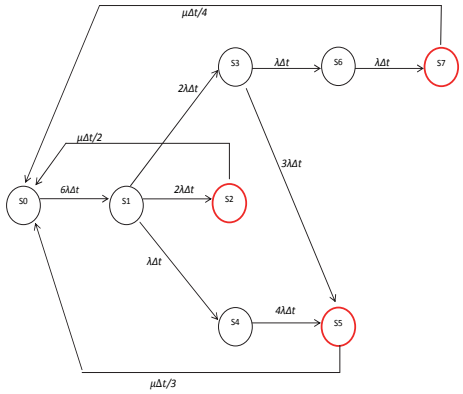


Figure 7: State space representation of the MM of the 3oo6 + 2 consecutive failures configuration where S2, S5 and S7 represent the failed cases.

Such matrices are usually sparse due to the fact that the system is not repaired until a meaningful number of failed items are present. This assumption is reasonable considering the cost of the single item with respect to a forced stop of power plants.

$$\frac{dP(t)}{dt} = \begin{pmatrix} -6\lambda & 0 & \frac{\mu}{2} & 0 & 0 & \frac{\mu}{3} & 0 & \frac{\mu}{4} \\ 6\lambda & -5\lambda & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\lambda & -\frac{\mu}{2} & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\lambda & 0 & -4\lambda & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & -4\lambda & 0 & 0 & 0 \\ 0 & 0 & 0 & 3\lambda & 4\lambda & -\frac{\mu}{3} & 0 & 0 \\ 0 & 0 & 0 & \lambda & 0 & 0 & -\lambda & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda & -\frac{\mu}{4} \end{pmatrix} P(t) \qquad (2)$$

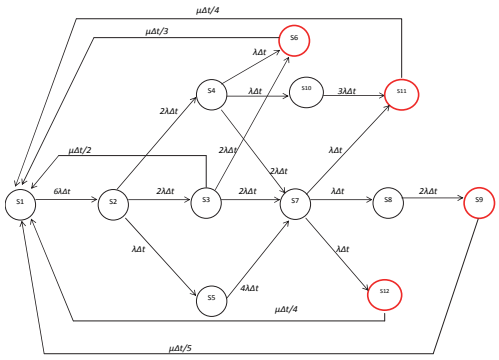


Figure 8: State space representation of the MM of the 2oo6 + 3 consecutive failures configuration where S6, S9, S11 and S12 represent the failed cases.

$$\frac{dP(t)}{dt} = \begin{pmatrix} -6\lambda & 0 & 0 & 0 & 0 & \frac{\mu}{3} & 0 & 0 & \frac{\mu}{5} & 0 & \frac{\mu}{4} & \frac{\mu}{4} \\ 6\lambda & -5\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\lambda & -4\mu & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\lambda & 0 & -4\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & -4\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2\lambda & \lambda & 0 & -\frac{\mu}{3} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2\lambda & 2\lambda & 4\lambda & 0 & -3\lambda & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda & -2\lambda & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2\lambda & -\frac{\mu}{5} & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & -3\lambda & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 & 3\lambda & -\frac{\mu}{4} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & -\frac{\mu}{4} \end{pmatrix} P(t) \quad (3)$$

In Figure 9 the comparison among the availability simulations of the three mentioned configurations supposing to have a repair rate of 1/48 [1/h] is sketched.

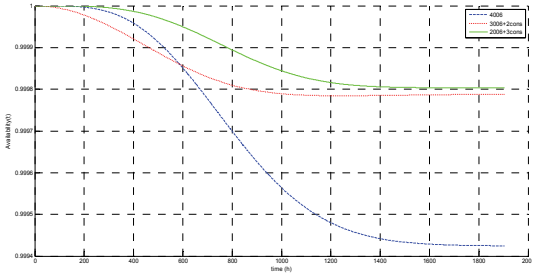


Figure 9: Availability comparison of the three configurations considering 48h as the inverse of the repair rate μ.

Out of the analysis it is evident that the best configuration representing a reasonable choice among the three proposed is the 2oo6 + 3 consecutive failures due to the fact that it shows the best steady state availability behaviour.

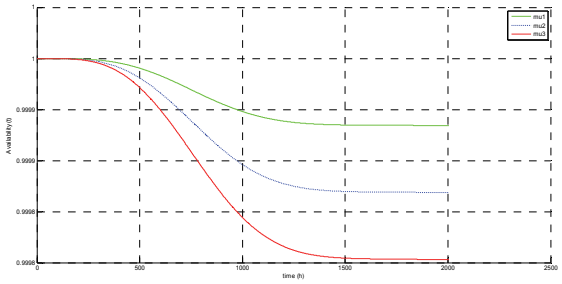


Figure 10: Availability behaviour of the 2oo3+3 consecutive failures configuration considering 16, 32 and 48h as the inverses of three different repair rates μ.

Availability modification according to different repair rates (16, 32 and 48 hours respectively) are investigated and results are shown in Figure 10.

4 CONCLUSIONS

In this paper the authors propose three different configurations to evaluate the reliability and availability of the disposition of six thermoelements used to monitor the exhaust temperature in a gas turbine system to enhance system productivity and efficiency performance over time. The study has been performed exploiting both RBD and Markov state flow modelling under the hypothesis of constant failure and repair rates. Results pointed out that the best configuration is the 2oo6 + 3 consecutive both in terms of reliability and availability.

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NRG-X-Change
A Novel Mechanism for Trading of Renewable Energy in Smart Grids

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Keywords: Renewable Energy, Smart Grids, Energy Trading, Virtual Currency, NRG-X-Change, Bitcoins, NRGcoins.

Abstract: In this position paper we propose a novel trading paradigm for buying and selling locally produced energy in the smart grid. Unlike recently proposed techniques that rely on predictions and a day-ahead market, here prosumers are billed by the distribute system operator according to their actual usage and rewarded based on their actual energy input, similar to the current state of affairs. Our mechanism achieves demand response by providing incentives to prosumers to balance their production and consumption out of their own self-interest. All rewards and payments are carried out using NRGcoin — a new decentralized digital currency similar to Bitcoin, that we introduce in this paper. Prosumers exchange NRGcoins with fiat currency on an exchange market for profit, or for paying their energy bills. We study the advantages of our proposed currency over traditional monetary payment and explore its benefits for all parties in the smart grid.

1 INTRODUCTION

Trading of locally produced renewable energy is addressed in literature from a market perspective where prosumers and consumers (or collectively: agents) participate in a double auction and trade energy on a day-ahead basis (Olson et al., 1999; Kok et al., 2005; Vytelingum et al., 2008; Vytelingum et al., 2010; Kok et al., 2012; Mockus, 2012). Buy and sell orders for energy are submitted to a public orderbook and orders are matched either in a continuous fashion (Vytelingum et al., 2008; Vytelingum et al., 2010), or at discrete market closing times using the equilibrium price (Kok et al., 2012; Mockus, 2012). The advantages of this market-based control concept are that it achieves close to optimal allocation, neatly balances supply and demand and aligns the preferences of self-interested agents. However, bidding for energy ahead of time relies heavily on predictions of future supply or demand, the inaccuracy of which translates to higher costs for both buyers and sellers. In addition, agents need to rely on advanced trading strategies in order to maximise profit (or minimise costs). For example, prosumers unfamiliar with the market may unintentionally set a too high sell price, resulting in an unmatched order for their energy. Since there is no buyer at the time when they produce and inject the energy into the grid, prosumers make zero profit, unless they invest in batteries that can store the untraded energy. Those agents can then inject the energy at the time they find a buyer. Lastly, separate energy balancing mechanisms need to be employed (Kok et al., 2012) to cope with real-time demand response.

Market-based energy trade reduces the dependency of agents on the Distribute System Operator (DSO), as energy supply and demand is matched directly between individual agents, resulting in a more decentralized and competitive environment. However, locally produced energy nowadays covers only a small percentage of all consumption and therefore the DSO still needs to supply a large portion of the energy to cover the total demand. Thus, considering the role of the DSO in a trading mechanism allows for easier implementation of that mechanism on top of the current infrastructure and state of affairs and thus a faster transition to a smart grid setting.

In this paper we propose NRG-X-Change — a novel mechanism for trading of locally produced renewable energy that does not rely on an energy market or matching of orders ahead of time. In our model locally produced energy is continuously fed into the grid and payment is received based on actual usage, rather than predicted, as consumption is measured by the DSO and billed in near real-time. Thus, our mech-

anism maintains the important role that the DSO currently plays in the energy market. The second component of our mechanism, and a novel contribution to the energy trading paradigm, is the introduction of a new decentralized digital currency for energy exchange, called NRGcoin. All payments by consumers and to producers are carried out in NRGcoins, instead of fiat money. The currency can then be exchanged on an independent open market for its monetary equivalent, e.g. Euro, Dollar, Pound, etc. In Section 2 we outline the advantages of our mechanism and elaborate on the benefits of the proposed currency. In Section 3 we summarize our approach and propose directions for future work.

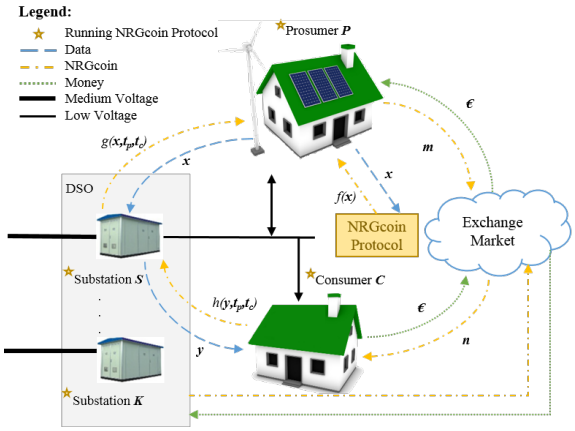


Figure 1: Example scenario.

2 THE NRG-X-CHANGE MECHANISM

In Figure 1 we present an example scenario that will help visualize the complete cycle of energy and currency exchange in our mechanism for each 15-minute period (called time slot). Note that since substations are only informed of the injected energy and not the produced energy, henceforth by produced energy we mean energy injected in the grid. Similarly, energy consumption is the energy delivered to the household from the power line, excluding the consumption of the own produced energy.

A given prosumer P generates certain amount of renewable energy and feeds x of it to the grid, simultaneously broadcasting this information to all nodes in the NRGcoin network. These nodes then update the public record of P with $f(x)$ NRGcoins, as defined by the decentralized NRGcoin protocol. Thus, function $f(x)$ is responsible for generating the NRGcoins which then enter circulation. In addition, the local substation S to which P is connected to has measured the total energy production t_p and total consumption t_c in that slot. That substation then publicly transfers $g(x,t_p,t_c)$ NRGcoins from the balance of the DSO to that prosumer, where $g(\cdot)$ is the production price function defined by the DSO. Thus, for injected energy x prosumer P obtains NRGcoins from both the NRGcoin protocol (to ensure new money is generated in the system) and the local substation (to align consumption with production). Note that the amount of received currency only depends on functions f and g (where $f \ll g$) and is not linked to the monetary value of NRGcoins on the market.

At any chosen time slot, P joins an exchange market with an order to sell m of her NRGcoins in exchange for Euro. Similarly, a given consumer C decides to buy n NRGcoins with Euro and places a buy order in the market. If according to the market regulations these two bids are matched, the seller P releases $n \leq m$ NRGcoins to the buyer and receives her asked Euro from the market, while the buyer C releases the offered Euro amount to the seller and receives his n NRGcoins. He then pays $h(y,t_p,t_c)$ NRGcoins for his energy consumption of y to local substation S. Note that P and C need not belong to the same substation. In analogy to the price function for production $g(\cdot)$, the price function for consumption $h(\cdot)$ is defined by the DSO. Below we elaborate on the two components of our mechanism — the trading of energy using NRGcoins (left part of Figure 1) and exchanging the latter for fiat currency (right half of the figure). We also describe how the above price functions balance energy supply and demand, how agents can use learning mechanisms to increase their profits and what the benefits of the new currency are.

2.1 Buying and Selling Energy

Each prosumer may use her produced energy to cover her own demand first. The excess energy is then fed into the grid. Information of local energy production and consumption is sent from smart meters of prosumers to the street-level low voltage energy substations of the DSO at 15-minute intervals. This information is then used to determine the rates at which prosumers are rewarded for their produced energy and consumers are billed for their withdrawn energy. These rates (or functions) are designed to incentivize agents to balance supply and demand, as well as lower production and consumption peaks. For example, during times of low demand or high production, the cost of energy consumption is low, and analogously, low supply or high demand drive the prices up. Thus, every 15 minutes each street-level substation determines the rates for energy consumption and for pro-

duction using the following functions. The price function $g(\cdot)$ for paying producers is shaped as a bell curve and defined as:

$$g(x,t_p,t_c) = \frac{x \cdot q_{t_p=t_c}}{e^{\frac{(t_p-t_c)^2}{a}}} \quad (1)$$

where $q_{t_p=t_c}$ is the maximum rate at which producers are rewarded for their input energy x when total supply t_p matches total demand t_c and it is defined by the DSO; and a is a scaling factor for the case where $t_p \neq t_c$. When total energy production completely covers total consumption, the function is at its peak and simplifies to $g = x \cdot q_{t_p=t_c}$. On the other hand, when $t_p \gg t_c$ or $t_p \ll t_c$, producers are paid at a rate of $g \to 0$ NRGcoins. The price function $h(\cdot)$ according to which consumers pay for their withdrawn energy y is defined as:

$$h(y,t_p,t_c) = \frac{y \cdot r_{t_c \gg t_p} \cdot t_c}{t_c + t_p} \quad (2)$$

where $r_{t_c \gg t_p}$ is the maximum cost of energy delivered by the DSO when the energy supply by prosumers is low. When production matches consumption, on the other hand, the substation charges consumers with $\frac{r_{t_c \gg t_p}}{t_c}$ per kWh. Lastly, when $t_c \ll t_p$ then $h \to 0$ and thus the cost of consumed energy during overproduction is close to 0, motivating consumers to shift their energy usage to periods of overproduction.

2.2 Earning and Exchanging NRGcoins

Similarly to Bitcoin (Nakamoto, 2008), NRGcoin is not issued or controlled by any central authority and its monetary value is determined solely by trading the currency on an open exchange market – higher demand for NRGcoins increases their monetary value, while a large number of sells drives their value down. However, unlike Bitcoins, which are generated by sheer computing power and hence energy expenditure (in a process called "mining"), NRGcoins are generated by injecting locally produced renewable energy to the grid. The rate $f(x)$ at which NRGcoins are generated depends only on the amount x of renewable energy fed into the grid. This amount is broadcast[1] by the smart meter of the producer to all other smart meters running the NRGcoin protocol, allowing all participants in the NRGcoin network to keep track of the earnings of each smart meter and their transactions. Note that although transaction information is associated with smart meters, the latter are not publicly linked to actual prosumers and therefore all earnings and transactions are anonymous as far as agents are concerned. The process of generating NRGcoins draws parallels to the process of mining in the Bitcoin protocol and similarly, the bookkeeping of earnings and transactions resembles the Bitcoin blockchain (Nakamoto, 2008). NRGcoins are earned according to function $f(\cdot)$ defined as:

$$f(x) = b \cdot x \quad (3)$$

where b is a constant specifying the rate at which NRGcoins are rewarded to prosumers for their injected energy x and is defined by the NRGcoin protocol, running on all smart meters.

As mentioned in Section 2.1, in addition to the NRGcoins generated by injecting energy to the grid, the local substation rewards prosumers based on current energy supply and demand at that substation. Note that the DSO does not *issue* the currency, but simply collects and distributes payments, based on the consumption and production price functions.

To procure or sell NRGcoins agents participate in an online currency exchange market. An agent who needs NRGcoins (e.g. in order to pay for his energy consumption) can place a buy bid on the market, and analogously, an agent with excess amount of NRGcoins can submit a sell bid. Each buy bid contains the requested amount of currency and the price at which the agent is willing to buy. In addition, the bid contains order configurations (Ilic et al., 2012), such as whether the agent prefers partial or full match of her bid, and whether the bid needs to be discarded if not matched immediately, or can stay in the orderbook and possibly be matched at a later time. For ease of exposition, in the remainder of this section we assume that all bids can be matched partially and remain in the orderbook if not matched immediately. When a buy bid is submitted to the market, all sell orders with a price lower than the buy price are matched (lowest sell orders first) until the buy quantity is fulfilled. Any remaining unmatched buy quantity is added to the orderbook. All sell bids are processed in analogous fashion, starting with the highest buys first. Thus, orders are matched only if the buy price is higher than or equal to the sell price. The buyer pays the price he has specified in his bid and the seller — her specified sell price. The owner of the market earns profit from the difference between matched buy and sell bids, as well as a possible commission fee to keep the market running.

The smart meters of agents can employ learning techniques that automatically determine the optimal quantity of NRGcoins to trade in the market and an acceptable bidding price. The learning mechanism selects a bid quantity that aims to minimize the amount of excess currency, i.e. the difference between the current amount of NRGcoins the prosumer owns and

[1] It is assumed here that security mechanisms are in place to prevent tampering with the smart meter.

the amount it is expected to need in the future. In addition, the bid price is determined by observing the inside-market, i.e. the difference between the lowest outstanding sell and the highest outstanding buy in the orderbook, and taking into account the risk preference of the prosumer. For example, placing a very high selling price bears a high return, but also a high risk, meaning that the probability of finding an appropriate match with a consumer agent is low. Thus the learning mechanism aims to maximize the revenue of the agent, considering its preferences.

Bidding strategies for trading agents have been a hot research topic for the last decade. For example, the Power Trading Agent Competition (TAC)[2] (Ketter et al., 2011) is a yearly competition simulating future retail electric power markets. The agents in the market act as retail brokers in a local dwelling, purchasing power from a retail market as well as from local sources, such as homes and businesses with solar panels, and selling power to local customers and into the wholesale market. Retail brokers use learning mechanisms for their bidding strategies in order to make profit, while balancing supply and demand (Reddy and Veloso, 2011). As the environment involves a highly dynamic setting with competitive agents, adaptive algorithms that learn by observation (Kuate et al., 2013) have proven to be very successful at this competition. The difference between our approach and Power TAC is that the latter involves self-interested *brokers* that aim at making profit through offering electricity tariffs to customers and trading energy in the wholesale market. The brokers attempt to contract consumers, prosumers and electric vehicle customers by offering specific tariffs and by negotiating individual contracts. The brokers balance the fluctuating energy demands of their contracted power consumers against the actual output of their contracted energy producers. In our NRG-X-Change model, there is no need for brokers or long-term contracts, as NRGcoins are traded between consumers and prosumers directly.

2.3 Benefits of the NRGcoin currency

NRGcoins offer a number of advantages over traditional money and other digital currencies. According to our mechanism, locally produced renewable energy is continuously "converted" to NRGcoins. Their advantage over fiat currency is that they serve as the right to receive an equivalent quantity of energy in the future independent of NRGcoin market value. Therefore, what this new "green currency" brings for agents is security towards increasing energy prices, by for example purchasing NRGcoins at low prices and then spending them on energy when prices are high. Thus, the currency can be spent to buy renewable energy at a later point in time, or traded for fiat money on a market, whichever is more profitable for the agent. In this way NRGcoins act as a form of efficient and infinite battery for agents, in the form of green certificates for companies, or simply as a business of buying and selling the currency for profit. In general, it gives individual agents accessible means to not only support renewable energy generation, but also invest in the energy market as a whole — something that is not trivial in the current state of affairs. The DSO, on the other hand, benefits from using NRGcoins as a "debt instrument" with high liquidity, allowing it to quickly convert this currency to cash. Paying prosumers with NRGcoins instead of fiat currencies enables the DSO to focus a larger portion of its cash assets on investments, rather than rely on bank credits and pay their associated interest rates.

The new currency also resembles tradable green certificates (TGCs) (Schaeffer et al., 2000; Morthorst, 2003) as a measure of produced renewable energy and as a way to purchase its environmental attributes by consumers. As such it can serve as a form of competition between prosumers or an indication of prestige, where companies can be valued for their green energy production. Whereas TGCs only benefit producers by imposing purchase obligation to some consumers, NRGcoins are, among others, a form of investment and thus of potential advantage to both types of agents, as described above. Moreover, unlike TGCs, NRGcoins can be traded across countries and serve as an international currency for green energy.

Similarly to other decentralized digital currencies, NRGcoin is not regulated by any bank or central authority and it is not tied to the stock market or fiat currencies. However, it is generated by producing renewable energy, as opposed to any other digital currency that is mined by computing power and hence energy expenditure. Although NRGcoin is not regulated, it is dependent on its community. Therefore its trade value can have large fluctuations as a result of market speculations.

It should be noted that the NRGcoin currency is an added value to the NRG-X-Change mechanism and not designed to be an indivisible part of it. The trading of energy is also possible using fiat currency instead of NRGcoins by modifying price functions g and h to consider the value of the fiat currency, and dropping function f. Nevertheless, detailed investigations need to be carried out to determine to what extend NRGcoins can be replaced by standard currency in an initial phase, e.g. to simplify deployment.

[2] http://www.powertac.org/

2.4 Balancing Supply and Demand

Price functions g and h are designed to align the objectives of agents. Since the rates at which substations pay prosumers depend on local supply and demand, different prosumers may earn different number of NRGcoins for the same amount of injected energy at different locations of the smart grid. Again, these rates are independent from the current market value of the NRGcoins. The difference in the rates is related to the balance of local energy production and consumption that the DSO strives to achieve, as well as for flattening supply and demand peaks. For example, the value of generated energy in a neighborhood full of producers will be much lower than the NRGcoins that a single producer will earn in a neighborhood full of consumers. Thus, the value difference imposed by the DSO may stimulate consumers to install renewable energy generators and become producers, while at the same time discourage excess production or consumption that overload the transmission lines. Similarly, consumers are motivated to shift their consumption away from demand peaks and towards production peaks, as that will lower their energy bill.

The more energy supply matches demand, the more NRGcoins producers receive from the substation and the fewer coins are paid by consumers to the substation, as the additional energy it needs to supply to that neighborhood is low. In this way agents strive to balance supply and demand, i.e. achieve demand response, out of their own self-interest. Prosumers are motivated to feed just enough renewable energy to the grid, while consumers minimize their costs by shifting their consumption pattern towards time slots of higher production. Note that the parameters $q_{t_p=t_c}$ and $r_{t_c \gg t_p}$ of price functions 1 and 2 need to be carefully configured to ensure that the profit of the DSO is always positive and covers the costs of energy transmission.

Learning techniques can help agents maximize their revenue using the payments from the substation as a feedback signal. For example, the learning mechanism can switch off (some of) the renewable energy generators of the prosumer during times of overproduction in order to maximize the profit according to Equation 1, while taking into account the agent's own consumption. Similarly, the energy bill of consumers can be reduced by learning to shift the consumption pattern to periods of high production, while preserving the comfort level of the agent. For example, the learning mechanism can learn to shift the operation of the washing machine to time periods when energy is the cheapest, taking into account the requirements of the agent that the operation should be completed by a particular moment in time. The learning mechanism would have to advice the agent on how much to consume at each time slot in order to minimize the price it is expected to pay while taking into account the electricity needs of the occupants. Inherently, this is a scheduling problem with multiple objectives. Various machine learning algorithms have been proposed to address multi-objective scheduling, such as reinforcement learning (Aissani et al., 2009), evolutionary algorithms (López-Ibáñez et al., 2005) and local search (Dubois-Lacoste et al., 2011).

Since locally produced energy nowadays covers only a small percentage of consumption within neighborhoods, the DSO still needs to produce electricity to cover the total demand. Bunn and Farmer (Bunn and Farmer, 1985) pointed out that a 1% decrease in forecasting error implied £10 million savings in operating costs. Therefore, reliable forecasting techniques are needed to improve the energy supply planning of the DSO and decrease its costs. Several prediction techniques can be applied here, such as autoregressive methods (Contreras et al., 2003), artificial neural networks (Khamis et al., 2011), support vector machines (Tan et al., 2010), etc. In addition to global energy prediction, the DSO can aggregate predictions of individual local substations. The advantages of predicting demand at substation level are twofold: on the one hand individual local predictions can improve the accuracy of the global prediction model by employing weighted aggregation; while on the other hand these predictions allow the DSO to exert better control over the load of individual transmission lines and thus improve the quality and robustness of the electric power infrastructure.

3 SUMMARY AND OUTLOOK

In summary, instead of relying on a day-ahead energy market to sell or purchase their energy, prosumers simply inject to or draw from the grid, as is the current state of affairs, but at prices that depend on measured supply and demand of energy. Payment is in the form of NRGcoins, the value of which is determined based on trades in an open currency exchange market. Using concepts from the rising in popularity Bitcoin phenomenon, our novel mechanism creates a microeconomic ecosystem that allows prosumers to trade locally produced renewable energy at competitive prices. At the same time agents are incentivized to balance energy supply and demand out of their own self-interest and thus flatten production and consumption peaks. Lastly, our proposed approach is scalable — newly joining agents do not increase the complex-

ity of the energy trade thanks to the local substations, or of the currency exchange, as the NRGcoin protocol is decentralized.

As this concept is still work-in-progress, extensive simulations need to be carried out, backed up by microeconomic theories, to determine the parameters of the price functions of the DSO and the rate at which NRGcoins are generated in the network. Last but not least, special attention needs to be paid to the privacy and security aspects of the NRGcoin protocol and in the design of the smart meter middleware.

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Energy Management Solutions for Polish Prosumer Systems

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Abstract: Last year the Polish government finally passed an act of parliament concerning renewable energy sources in response to the European Union Directive 2009/28/EC promoting renewable energy. This act liberalizes the interconnection of small on-site generation systems situated on the customer side, consisting of renewable energy sources (prosumer systems), with the electrical distribution system. Although most of the formal barriers have been removed, the proposed economic conditions are not likely to guarantee the expected dynamic growth in volume of renewable energy as part of the overall energy consumption. This paper introduces a solution for the economic and energy-effective management of energy generated in Polish prosumer systems. Moreover, the technical and formal conditions for implementing small-power renewable energy sources into the distribution system are mentioned as a background for the optimal choice of interconnection solution and topology. A complete energy management solution based on available technologies, such as power electronic converters, energy storage devices and home area networks has been proposed as well.

1 INTRODUCTION

Nowadays almost 90% of the overall energy consumed in the Polish electrical system is produced at coal-fired power stations. Coal and other fossil fuels, such as natural gas, still remain the cheapest primary energy sources for heat and electricity generation in Poland, although they are charged with high CO_2 emission coefficients of 0,89 Mg/MWh and 0,560 Mg/MWh for coal and natural gas respectively. Without modification of the energy generation structure this means that in the near future growing emission payments (from 30% now to full prices in 2020) will also increase the electrical energy costs for Polish consumers. In August 2013, according to the EU Directive (European Parliament, 2009) promoting energy from renewable energy sources, the Polish Energy Act has been finally modified (Parliament of the Republic of Poland, 2013), thus, small systems up to 40 kW consisting of such energy sources, referred to as RES micro installations, now have permission to transfer energy back into the distribution grid without any special concession being required by commercial energy sources other than agricultural biogas fired sources. This was a major barrier in the large scale development of on-site generation micro systems. Unfortunately, the convenience of RES interconnection with the distribution system is not supported by profitable pricing, as is commonly the case in other countries. The Polish version of the Feed-in Tariffs (FIT) system guarantees a price for energy generated in micro installations and transferred into the utility grid below the value of the average price of energy on the energy market. To be precise, it is 80% of the average price, and taking into account the prices in the Polish energy market in 2013 (0,20 PLN / kWh) it is about 0,16 PLN (about 0,04 EUR). In contrast, the prices for energy taken from the grid, including energy delivery tax, comes to 0,53 PLN / kWh (about 0,13 EUR / kWh) on a flat tariff (one averaged price for the whole day and whole year). Hence, this system rather motivates RES energy consumption inside the customer installations than energy reversing to the grid. In other countries, for example, in Germany, the prosumer systems with FIT tariffs have a guaranteed higher price for energy reversed to the grid in relation to energy taken from the same grid, so any reduction of energy consumption leads to a raising of surplus energy transfer to the grid and, as a result, to the higher profits.

In Poland, apart from RES, some other technologies are now being considered, especially

the energy passive solution allowing for a reduction of energy consumption by using an advanced metering infrastructure (AMI) and load management stimulated by dynamic tariffs. This model doesn't require the significant support, though it could give the expected effect only by involving a number of different technologies working together within one optimally composed energy management system. An example of a prosumer system is shown in Figure 1. Considering the daily load profile variation as well as daily RES power generation profiles, the optimal energy management could be provided only in a system with power electronics interfaces (PEI) working in tandem with energy storage devices (ES). Moreover, apart from using dynamic tariffs, or programs consisting of more than one pricing time zone (usually two price levels – peak power pricing and off peak power pricing geographically located according to daily load curve), or other commercial Demand Side Management (DSM) and Demand Side Response (DSR) programs there are additional possibilities for energy cost reduction such as peak power shaving and power shifting. These processes could be provided either by using a reduction of energy consumption or by using energy from a RES previously stored in ES. In the case when all the investment costs in a RES are covered by the prosumer, without any external support, the control should be performed with due regard to the best economical effect.

2 AVAILABLE TECHNOLOGY OVERVIEW

The optimal topology of a prosumer system for Polish conditions requires specific elements. There are available some market-ready applications which can operate alone, but their coordination within one common system is often impossible or does not permit anticipated functionality. Recognition of their properties and judgment of their usefulness constitute the first step in composing an optimal prosumer solution with several major functions like optimal RES energy utilization, energy storage ability and power flow control.

The technologies providing these functions can be divided into three groups: RES and interfaces, measurement and monitoring devices, energy management systems.

Presently in Poland all of the above mentioned technologies are available or are in a developmental or testing stage.

2.1 RES and Interfaces

There are three major types of renewable energy sources with the potential for commercial implementation in Polish prosumer systems: photovoltaic systems (1 MWh/m^2), small wind power systems (0,5 – 1 MWh/m^2) and biomass (biogas) fired micro cogeneration systems (energy potential dependent on biomass type).

Two first sources due to their unpredictable and unstable character, being mostly dependent on

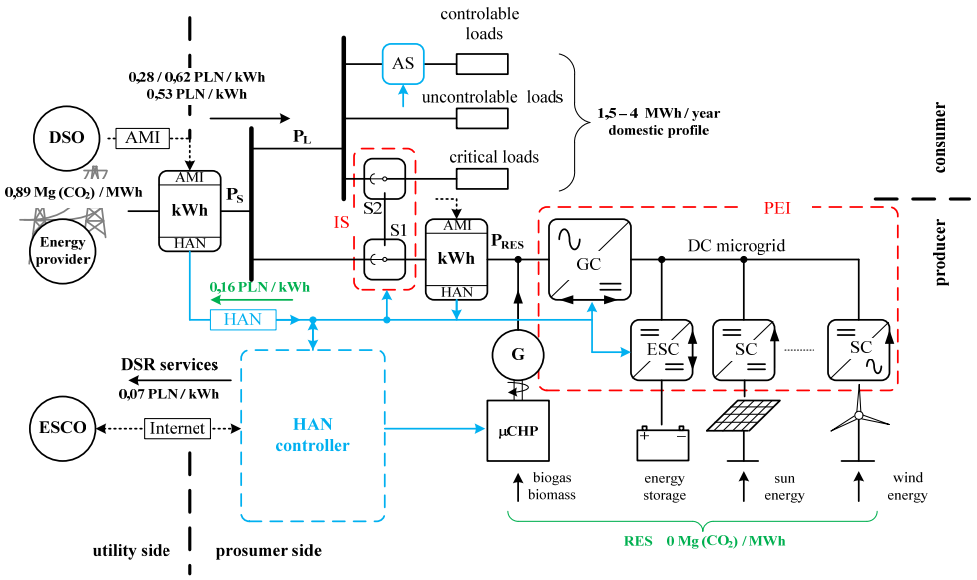


Figure 1: Unified and simplified schema of prosumer system with energy management technologies.

primary energy variations, need to be supported by interfaces based on two-stage power electronic converters with energy storage ability, although systems without ES are commonly used because of their lower prices. Micro cogeneration systems are treated as a stable source. The primary energy (biomass or biogas) in such systems is easily stored and can be more readily controlled than wind or sun. Moreover primary energy control can be used for stabilization of the output voltage characteristic or for output power management. The stable output voltage parameters of rotating generators allow the connection of a micro cogeneration system directly to the distribution system without power electronic converters. Of course, in some cases, for example in systems with a gas fired micro turbine, a frequency converter is required.

Today there are three types of RES interfaces available on the Polish market, the implementation of which is allowed for in the electrical distribution system (Benysek, G., Jarnut, M., 2013): Off Grid (islanded, autonomous), Grid Tied (On Grid, grid connected) and Hybrid. These applications have different functionalities and different abilities for energy management, but all of them can be implemented in prosumer systems.

2.1.1 Off Grid Systems

The main rule of working in Off Grid systems is the creation of local islanded circuits in prosumer systems, where the sectioned circuits are supplied by an Off Grid inverter using energy generated in RES and stored in ES. The interfaces in an Off Grid topology consist of four major parts: source-side converter (SC in Fig.1), energy storage devices, grid-side converters (GSC in Fig.1 being Off Grid inverter) and by-pass switch (islanding switch – IS in Fig.1). Such a topology allows for a power balance creation inside prosumer installations using energy source switching for sectioned circuit only, so the summary utility power (P_S) changes will be visible as step changes and will be strictly dependent on the actual load of the sectioned circuit. This limits the flexibility of power flow control and there are no possibilities in this structure for energy reversing to the distribution grid. Although this may sometimes be treated as a disadvantage, in the Polish electrical power system, where the yearly voltage interruptions last ten times longer than, for example, in Germany, such a topology allows for the possibility of uninterruptible power supply of critical circuits.

2.1.2 Grid Tied Systems

Grid Tied systems have a parallel connection in relation to the distribution grid, with their grid-side converters working in current mode, so they can be seen as controlled current sources. The typical structure of Grid Tied systems contain: source-side converter (SC), grid-side converter (GSC) and islanding protection switch (IS).

In prosumer installations with Grid Tied systems, in contrast to those with Off Grid systems, the power balance is created continuously. Unfortunately, because of the lack of an energy storage function, this process can't be intentionally controlled and is rather directed to optimal RES energy utilization. In the case of the Polish version of FIT tariffs and taking into account the daily load profile of prosumer installations it can lead to non-optimal energy costs and to relatively high power variations in the distribution system (including P_S power value as well as the power direction).

2.1.3 Hybrid Systems

Hybrid systems combine the advantages of Grid Tied and Off Grid systems in one topology controlled in a specific way (Jarnut, M., 2012). Under normal conditions in a distribution network this means that when the utility voltage remains inside the permissible range, the grid-side converter works in current mode, shaping the sinusoidal output current magnitude according to the determined power flow control strategy. This strategy, in contrast to the Grid Tied or Off Grid solution, can be flexibly programmed for cost optimal control. It is worth noting that grid-side power balance control can be provided independently on the source-side power balance. This is possible with the implementation of a separated individual, bidirectional DC/DC converter (ESC in Fig.1) in the energy storage leg and an MPPT controlled DC/DC converter (SC in Fig.1) in the source leg. Once the distribution system fails, the grid-side converter is switched to voltage mode, shaping the sinusoidal voltage on the islanded circuit and performing a UPS function. In the hybrid solution, the islanding switch (IS in Fig.1) has both a functionality typical for a by-pass switch (Off Grid systems) and an anti islanding switch (Grid Tied systems).

2.2 Energy Measurement and Monitoring Systems

Optimal energy management in prosumer systems

requires real-time information about power flow in both major circuits of the electrical installation: in the load circuit as well as in the source circuit. Moreover according to Polish Energy Law (Parliament of the Republic of Poland, 2013) the energy generated in licensed RES being subsidized by green certificates should be measured directly at source terminals or in a place of common coupling (PCC) of the source interface and utility grid. This means that in each Polish prosumer system there should be installed two independent meters. Presently in Poland public, commercial and industrial customers have installed advanced electronic meters allowing the recording and transmission of measurement data. In the last two years distribution system operators (DSO) have begun to implement widely the use of smart energy meters also for domestic customers with a connection power limit below 40 kW. Simultaneously they are developing an Advanced Metering Infrastructure (AMI) for remote data reading and meter management. According to the required structure, accepted by the Polish Energy Regulatory Office (Energy Regulatory Office of Poland, 2011), an AMI system consists of several major parts: smart meters, hubs and balancing meters, data transmission system and SCADA based data acquisition system.

In their target functionality AMI systems should be able to provide bidirectional communication of measurement data reading, as well as for commercial data transfer to the customer areas through smart meters equipped with additional interfaces to the Home Area Networks (HAN).

2.3 Energy Management Systems

The Polish Energy Regulatory Office, together with the requirements of the AMI infrastructure, prescribes the expectations of other Smart Grid components to assure their interoperability within one system. Some requirements have also been defined for customer-side energy management systems such as HAN (AT Kearney, 2012). HAN systems can cooperate with the AMI infrastructure through smart meter reception of technical and commercial information from DSO which can be used for optimal power balance control, matched for economy of use. The AMI infrastructure in Poland today is still in its developmental stage. The signals for commercial power control (reduction for peak power shaving or growth for valley filling at night) can also be transmitted using an alternative communication channel, for example, by the Internet, and can be provided by Energy Services Companies (ESCO). HAN infrastructure is not only a communication system, it is also a control system, which allows the control of instantaneous power balance. The HAN controller manages appliances according to programmed algorithms and according to research results could bring energy savings of between 4% and 15% (AT Kearney, 2012).

3 OPTIMAL CONFIGURATION OF PROSUMER SYSTEMS

The above described technologies due to their interoperability could be flexible combined to work together within one optimized energy management system. Choosing the optimal structure and control algorithms in the case of Polish prosumer systems and in accordance with the specific economic conditions is especially important in reducing investment costs (due to the lack of subsidy programs), but a choice which should also consider capacity for flexible energy management functions, such as load shifting or RES energy shifting, to match load and generation curves. To evaluate the costs and profits in different configurations and with different tariffs, the prosumer system with a standard daily load profile (domestic type, P_L in Fig. 2) and PV based RES source (P_{RES} in Fig.2) has been considered. Moreover the power of the PV system has been determined on the assumption of an ideal daily energy balance between energy consumed in loads (about 10 kWh) and energy generated in RES. To simplify analysis a day in the summer season has been chosen. Additionally the yearly irradiance variation has been ignored, so payback period has been evaluated in months (an assumption of constant irradiance during the summer season has been made). Illustrations of power management in the selected configuration of the prosumer system are shown in Figure 2. As can be seen the mismatch of power profiles of load and RES could cause a bidirectional energy transfer between utility grid and prosumer ($P_S > 0$ or $P_S < 0$) in Grid Tied systems. In systems such as Off Grid and Hybrid, controlled with an internal power balance strategy ($P_S = 0$) the energy storage devices store energy when $P_{RES} > P_L$ and supply load when $P_{RES} < P_L$ (through a grid-side inverter).

Depending on energy prices in different tariff programs and taking into account possible extra benefits in the case of providing ancillary services (DSR in Fig. 2a), the payback time of investment in

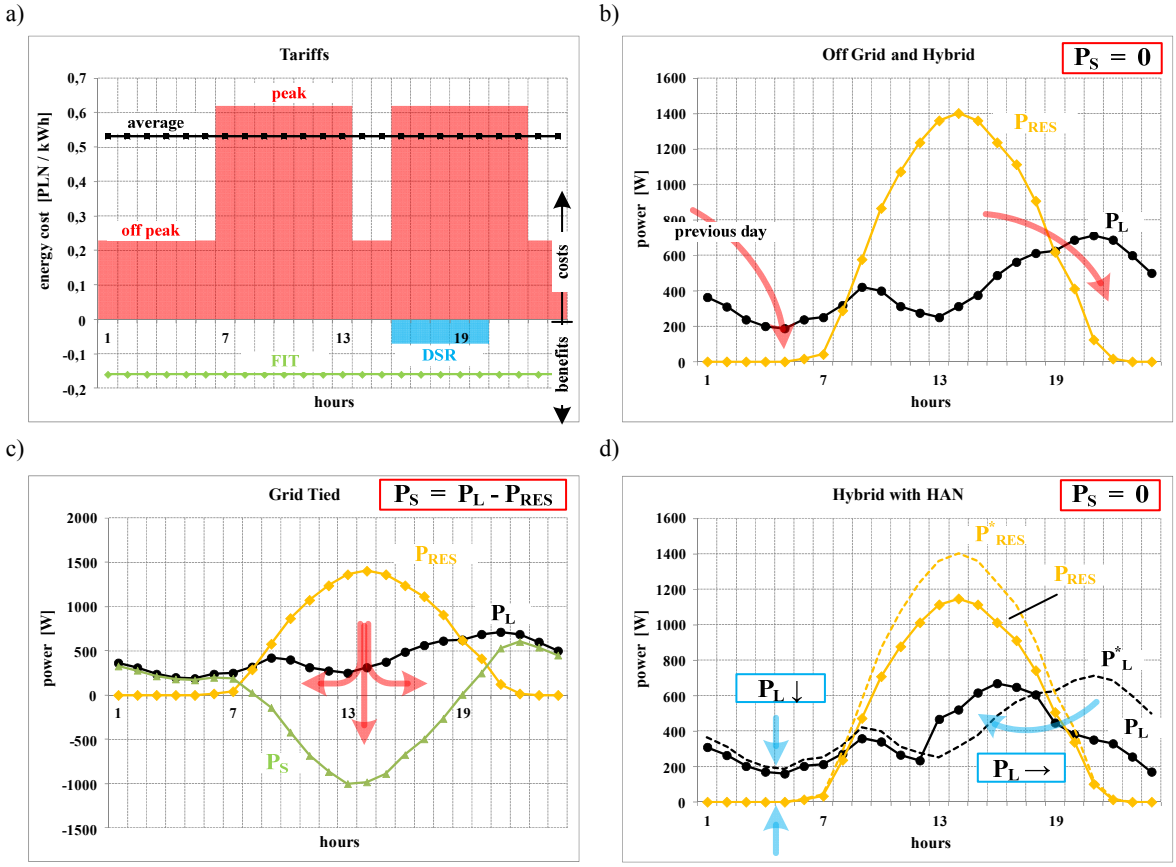


Figure 2: Illustration of power management in selected configuration of prosumer system: a) considered tariffs programs; b) Off Grid and Hybrid; c) Grid Tied; d) Hybrid with HAN based load management.

prosumer systems, working in specific configurations will be different. The overall cost of a solution is strictly dependent on the system configuration and is much higher in all solutions employing energy storage devices compared with those without batteries (almost three times higher). Thus the required capacity of energy storage devices should be minimized. This is possible using load management systems like HAN, working with strategy based on shifting operating time of programmable devices such as dish washers, washing machines, dryers, electric heaters, etc., to periods of day where the power of RES (P_{RES}) is higher than the power demand of the load circuit (P_L). This strategy has been indicated in Figure 2 as $P_L \rightarrow$. Using this strategy as well as the second one based on load power reduction ($P_L \downarrow$) it is possible to modify the load power profile (P_L instead of P^*_L in Fig. 2d) and to reduce the required battery capacity by 30% and 15% of required RES power (P_{RES} instead of P^*_{RES}, see Fig. 2d). Although this results in decreasing proportional energy storage and PV costs, additional investment is needed in the HAN system, consisting, at least, of a central HAN controller and a several active sockets (AS). The proposed Off Grid and Hybrid configurations controlled using the strategy of internal power balance ($P_S = 0$) give more cost optimal energy management than the Grid Tied configuration where the surplus energy is reversed into the utility grid ($P_S < 0$ in Fig.2c) at a price much lower (FIT = 0,16 PLN / kWh in Fig.2a) than the energy taken from the grid (average = 0,53 PLN / kWh; peak = 0,62 and off peak = 0,28 PLN / kWh), but the benefits of the former come with higher investment costs (for more details see data in Table 1).

4 CONCLUSIONS

Consideration of the results presented in this paper show very clearly that in spite of the decreasing investment costs of RES technology in small scale applications investors would not gain any

Table 1: Properties of selected configurations of prosumer system.

structure of solution	tariff program	power control strategy	estimated cost of solution [PLN]	utility energy daily transfer [kWh]		monthly energy cost without RES utilization [PLN]	monthly benefits of RES energy utilization [PLN]	simple payback period [months]
				from	to			
PV+Off Grid	averaged	$P_S = 0$	18.750	0	0	158	158	119
	peak / off peak					145	145	130
	peak / off peak + DSR					145	151	125
PV+Grid Tied	averaged	unavailable	6.750	4,4	7,12	158	122	56
	peak / off peak					145	129	53
	peak / off peak + DSR					145	137	50
PV+Hybrid	averaged	$P_S = 0$	17.750	0	0	158	158	113
	peak / off peak					145	145	123
	peak / off peak + DSR					145	151	118
PV+Hybrid +HAN	averaged	$P_S = 0$ $P_L \rightarrow$ $P_L \downarrow$	17.000	0	0	134	134	127
	peak / off peak					123	123	139
	peak / off peak + DSR					123	129	132
power control strategies: $P_S = 0$ – internal power balance; $P_L \rightarrow$ – load power shift; $P_L \downarrow$ – load power reduction								

satisfactory economic gains without any supporting programs. In Poland, the simplest prosumer systems based on the Grid Tied configuration and having effortless energy exchange between the utility grid and prosumer installations have to transfer the surplus energy at discouraging prices. Better in this field are systems with Off Grid and Hybrid configurations, which are functionally better suited for more cost effective energy management, but they need energy storage devices in their structure which increases investment costs. On the other hand one of these solutions – the Hybrid, has the flexibility which gives the prosumer the ability to control the power flow inside and outside of his installations The function of load curve modification (with or without HAN), especially in peak hours, will be the main trump of Hybrid solutions in the near future when the risk of a power deficit can occur in the Polish electrical power system with the disconnection of coal fired, outdated and relatively heavily polluting power plants. Freedom from utility grid outages is another advantage of the Hybrid solution as well as the ability for RES energy optimal utilization in this case. The small scale RES market in Poland is today still in its infancy, hence the results presented in this paper will be extended when more data becomes available.

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Battery Charge and Discharge Optimization for Vehicle-to-Grid Regulation Service

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Keywords: Regulation, Plug-in Electric Vehicles, Battery.

Abstract: Electric vehicles should be connected to power system for charge and discharge of battery. Besides vehicle's battery is charged for a power source, it is also reversibly possible to provide power source from battery to power system. Researches on battery usage for regulation resources have been progressed and could cause cost increase excessively because they distribute regulation capacity equally without considering the battery wear cost of SOC, temperature, voltage and so on. This causes increase of grid maintenance cost and aggravate economic efficiency. In this paper it is studied that the cost could be minimized according to the battery condition and characteristic. The equation is developed in this paper to calculate the possible number of charge and discharge cycle, according to SOC level and weighting factors representing the relation between battery life and temperature as well as voltage. Thereafter, the correlation is inferred between the battery condition and wear cost reflecting the battery price, and the expense of compensation is decided according to the condition on battery wear-out of vehicle.

1 INTRODUCTION

Interest in energy conservation and the environment increases, the technology (Electric Vehicle, EV) of electric vehicles has been developed rapidly, attempt of practical use have been carried out consistently. Cooperation of the power grid connection for charging the battery as a power source in the practical use of electric vehicles is essential. Therefore, vehicle to grid has been studied about the characteristics of the battery of an electric vehicle and utilization of charging and discharging. Especially, it is possible to improve the quality of power by using battery for ancillary service. For ancillary services such as regulation is required fast response time. And it provides the actual power is as small as about 10% compared to contract capacity ratio. Therefore, EV battery is suitable for providing the regulation service. Thus, when it comes to providing regulation service using the battery of an electric vehicle, additional charging and discharging are needed without charging and discharging for running EV. Additional charging and discharging of battery is responsible for the reduction of battery life time. Cost for the decrease in battery life due to additional operation is compensated in the form of incentives for vehicle system operator is participating in V2G services. Providing regulation service using EV leads to a reduction in revenue by increasing the operating costs. Therefore, in this paper, life time cost is estimated by using the relationship between battery life according to voltage, temperature and cycling characteristics of the DOD(Depth of Discharge) of the lithium-ion battery. And regulation service scheme that minimizes life time cost is proposed.

2 MODELING OF EV

2.1 Battery of Electric Vehicle

In this paper, the characteristics of lithium-ion batteries which are used the most widely in EV are considered for simulation. Capacity of lithium-ion battery has 10-20kWh generally. This capacity makes it possible to drive about 150km. The charging time of battery takes 6-7 hours from 20% to 100% of SOC. The number of cycle is evaluated about 1000. And price of battery is $800 per kWh.

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2.2 Cycle Characteristics of Lithium-Ion Battery

The main factors that affect the lifetime of the lithium-ion battery are a level of SOC charge and discharge, temperature, voltage, and time. In this section, equation is shown in the cycle of the battery considering four factors described above.

The possible number of times of charge and discharge of an electric vehicle battery is dependent on the SOC. And it is shown as in (1).

$$L = 694(1 - SOC)^{-0.795} \tag{1}$$

Battery cycle is assumed 1 cycle when battery is repeated charge or discharge as 20% of SOC. It is possible to calculate the number of cycles when the SOC is increasing or decreasing linearly by using (1).

The equation of battery cycle can be changed by the form of equation about the number of cycle using (1) and assumption. And it is shown in (2).

$$n_{i,t} = 0.5 \times (0.8)^{-0.795} \left| \frac{1}{1-(SOC_i(t))^{-0.795}} - \frac{1}{1-(SOC_i(t+1))^{-0.795}} \right| \tag{2}$$

Life factors are associated with the temperature of the battery, voltage and time to use that is represented by (3), (4) and (5).

$$\frac{C(t)}{C_{init}} = 1 + c_a c_V^{V-V_0/\Delta V} c_T^{T-T_0/\Delta T} \sqrt{t} \tag{3}$$

$$V(SOC) = -1.031e^{-35\,SOC} + 3.685 + 0.2156SOC - 0.1178SOC^2 + 0.3201SOC^3 \tag{4}$$

$$T(x,t) = T_{av} + T_{am} \times \exp(-x \times \sqrt{\frac{\omega}{2a}}) \times \cos(\omega t + 0.77 - x \times \sqrt{\frac{\omega}{2a}} + C) \tag{5}$$

It is possible to obtain the integrated expression of the cycle of the battery (6) in consideration of the temperature, voltage and time at which the SOC is changed.

$$N_{i,t} = n_{i,t} c_V^{V(SOC)-V_0/\Delta V} c_T^{T(x,t)-T_0/\Delta T} \sqrt{t} \tag{6}$$

2.3 Lifetime Cost of Battery

Lifetime cost of battery is calculated by (7).

$$C_{total} = \sum_{t}^{T} \sum_{i}^{n} \frac{N_{i,t} P_{bat}}{L_{20\%}} \tag{7}$$

P_{bat} is the mean cost of EV battery. And $L_{20\%}$ means the total possible number of battery cycle.

The minimum SOC is required because of the unexpected use of EV and decreasing the battery life time from full discharge. Therefore, the constraint of SOC is show in (8)

$$SOC_{\min,t} = \frac{0.8}{T_{charge}}(t - T_{off}) + 1 \tag{8}$$

3 REGULATION SERVICE BY EV

3.1 Estimation of Regulation

In order to keep the balance at all times, power generation is controlled automatically to compensate supply and demand for the difference between the predicted demand and the actual demand. In this paper, the calculation of regulation demand is estimated by the actual loads and 5-minute schedule model to compensate difference.

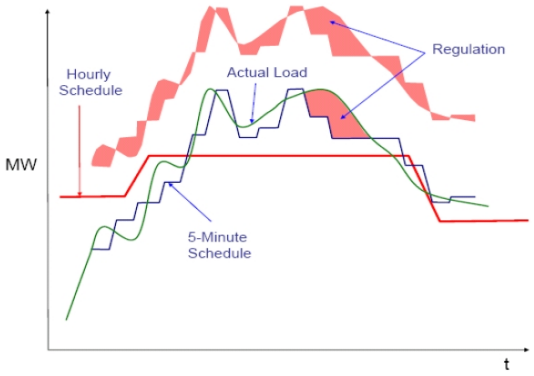


Figure 1: The Concept of Regulation.

3.2 Algorithm for Regulation Service

Figure 2 shows flow chart about charging process of the battery management and the provided regulation power. As shown in the flow chart, each plug-in EV has the order of priority to supply regulation service according to voltage, temperature and SOC when a regulation signal is provided every minute. Then, regulation power is provided differentially according to the order of priority if SOC is satisfied $SOC_{min,t}$. At the end, it starts operation again without the vehicle removing the plug-out the system. If vehicles are newly connected, the process is repeated. In the proposed process, there is a difference to distribute the amount of regulation service to each vehicle to compare with the

conventional method.

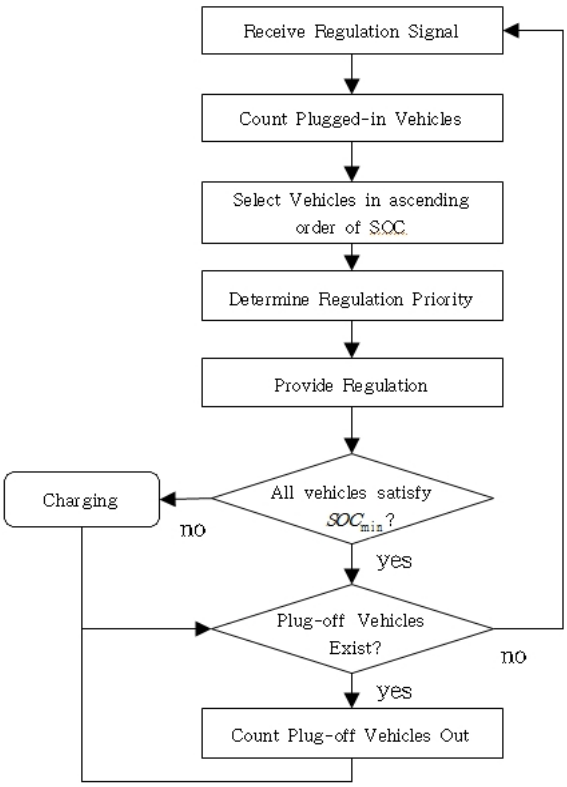


Figure 2: The Proposed Flow Chart of Regulation.

4 CASE STUDY

4.1 Background of Case Study

In the case study, it was applied to a vehicle of 12,329 units that provides battery power regulation of the electric vehicle for simulating the operational scheme. There are three scenarios in the case study that is shown in table2.

Table 1: Characteristics of EV.

Scenario	A	B	C
Time to start regulation service	As soon as (connected to grid)	According to SOC	According to SOC and condition of battery
Amount of regulation to EV	equally	differentially	differentially

To simulate by applying the operational scheme that was presented in this paper, consider the operation situation that target the users of the EV. The total number of vehicles is 12,329 units. 58% are used for commuting, 30% are used for leisure, remainder are used for business. Assuming the vehicle is used for commuting to be interconnection to the grid from attendance to closing hour during the week and is not connected during the weekend. The vehicle used for leisure is always connected except weekend. It was assumed that commercial vehicle, did not participate in the regulation service because works always use the car. Thus, considering time to connected, estimated number of grid-connected EV is shown in figure 3 using normal distribution. And regulation demand is also shown in figure 4.

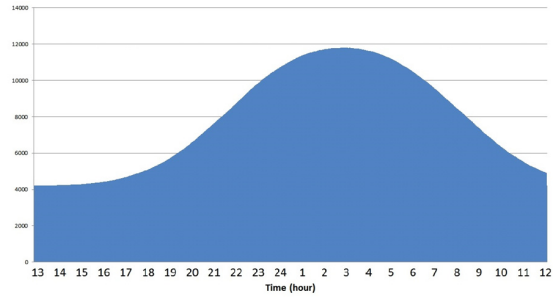


Figure 3: The number of grid-connected EV.

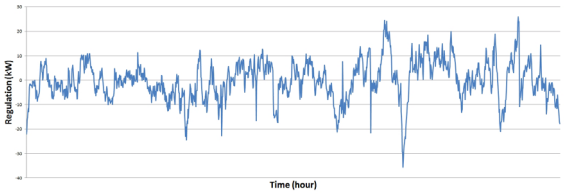


Figure 4: Regulation Demand.

4.2 Results of Scenarios

Figure 5-10 show that change of SOC and cycle of battery by each scenario.

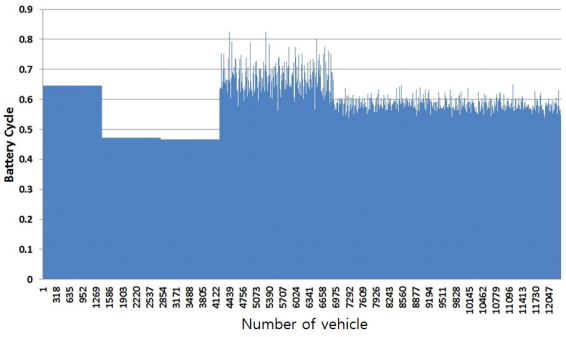


Figure 5: Battery Cycle(Scenario A).

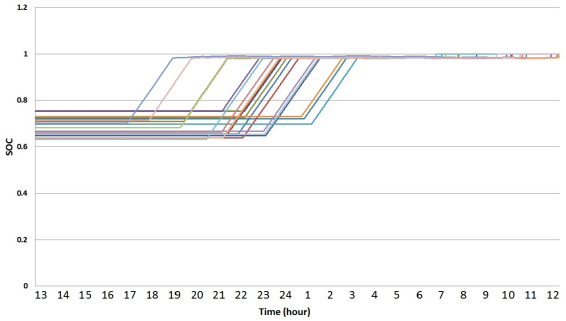


Figure 6: Change of SOC (Scenario A).

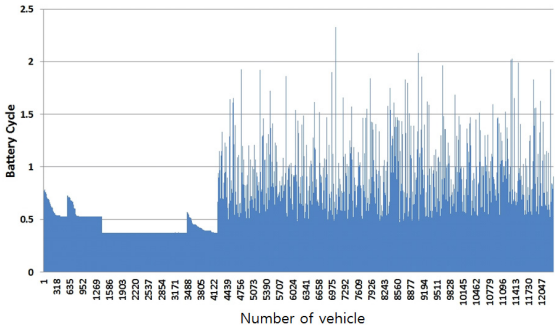


Figure 7: Battery Cycle(Scenario B).

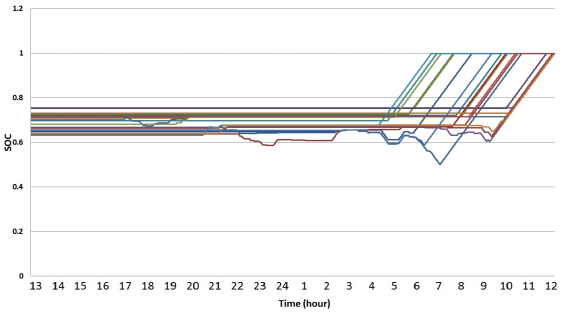


Figure 8: Change of SOC (Scenario B).

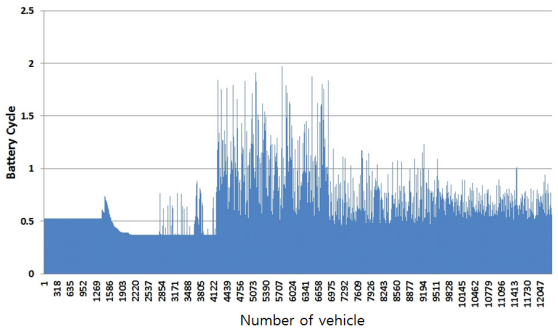


Figure 9: Battery Cycle (Scenario C).

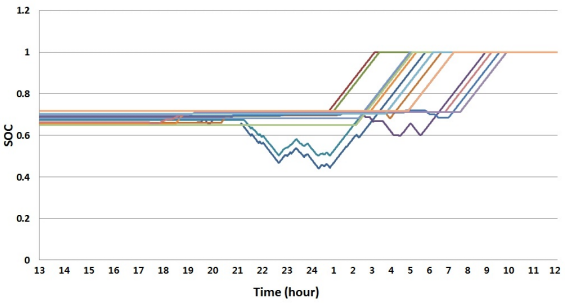


Figure 10: Change of SOC (Scenario C).

Figure 5-10 show that charge and discharge schedule is changed in various ways depending on each scenario. According to previous studies, the repetition of charge and discharge in high level of SOC adversely affects to the battery life. However, the proposed method brings a reduction life cost because it provides the regulation service while the level of SOC is low. The overall results are represented by the tables 2 and table3.

Table 2: Lifetime Cost.

Scenario	A	B	C
Battery cycle	6,497.7	6,073.8	5,987.8
Cost($)	97,465	91,108	89,817

Table 3: Benefit between Each Scenario.

Scenario	A/B	B/C	A/C
Deference of Benefit($)	6,357	1,291	7,648
Improvement(%)	6.52	1.42	7.85

It was confirmed that the differentially division of regulation service corresponding to the SOC has a major impact on reducing life time costs through the improvement ratio between each scenario. And additional reduction of cost occurs according to consider voltage and temperature.

5 CONCLUSIONS

In this paper, life time cost is estimated by using the relationship between battery life according to voltage, temperature and cycling characteristics of the DOD(Depth of Discharge) of the lithium-ion battery. And management scheme for regulation service to minimize the cost of battery life time is proposed. The proposed method decreases total cost without additional investment of infrastructures. Also, it can be applied to batteries of other types according to its characteristics. In addition to

regulation service, it can be extended to another ancillary service, load levelling and cost optimization.

ACKNOWLEDGEMENTS

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Communication Reduced Interaction Protocol between Customer, Charging Station, and Charging Station Management System

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Keywords: Charging Station, Interaction Protocol, Authentication Protocol, Reduced Communication Effort, QR Code.

Abstract: The emerging build-ups of charging station infrastructures require sufficiently secure and economic authentication protocols. Existing protocols for the purpose of authenticating a customer against a charging station have the inherent disadvantage that they expect a network connection to the management system, produce a communication overhead, or might reveal sensitive customer data depending on the protocol. The protocol, provided by us, enables a multiple-operator customer-to-charging station authentication system. The particularity of the protocol is that it does not require a permanent network connection between charging stations and a corresponding management system, reduces the communication overhead between the involved entities, and protects sensitive customer data at a high rate.

1 INTRODUCTION

The availability of a charging infrastructure is one of the decisive factors for the success of electric vehicles. Thus, one can currently observe significant efforts in Germany and many other countries to expand the existing charging infrastructure. In the course of this expansion, costs must be kept in check. Besides the acquisition costs, installation and maintenance costs should be kept as low as possible. One factor within the operational costs is the need for a continuous communication channel between charging stations and a corresponding charging station management system.

The interaction protocol we propose in this paper enables a dynamic control of charging stations without the necessity of a constant communication channel to a management system. This is achieved by leveraging the Internet connection of the customer's smartphone as a communication channel between charging station and charging station management system for authentication purposes.

The remainder of the paper is organized as follows: In Section 2 we describe authentication protocols for charging stations that are currently in use. Section 3 and 4 provide a detailed description of the our solution and optional protocol extensions. In Section 5, we discuss core design decisions and give a summary of the advantages of our protocol and the provide the possibility to extend its application field in Section 6.

2 RELATED WORK

In the following we present the state of art of protocols used to authenticate customers against charging stations. The major disadvantage of those protocols is the costly communication effort needed before and after each charging process between the charging station and the charging station management system. The interchanged data basically consists of customer's authentication data, information for the adjustment of meter readings, as well as control commands, e.g., the activation of the charging station. Partially, the protocols enable a local authentication by utilizing *whitelists* (OCPP Steering Group, 2012). However, this jeopardizes the confidential customer data which are deposited within the charging station.

Furthermore, the following protocols rely on a network connection, i.e., a network connection is essential for the commissioning of a charging station. Below, we will show that a network connection is not absolutely necessary to fulfill the requirements of those systems.

2.1 Authentication Via RFID-card (OCPP Steering Group, 2012)

The customer owns an RFID-card which enables him to authenticate against a charging station with an integrated RFID-reader. If the read ID appears on the charging station's local whitelist, the user is successfully authenticated against the charging station without involving the charging station management system into the authentication process. Otherwise, if the ID does not appear on the whitelist, there has to be a data exchange between the charging station and the charging station management system. The customer logoff works analogously. Meter readings and control data is communicated using the network connection to the charging management system.

2.2 Authentication Via Plug and Charge (ISO, 2013)

The costumers connects his vehicle with a charging station by a charging cable carried along. The authentication is done in two steps. The charging cable plug is endued with an RFID-chip. If the plug of the charging cable is in an appropriate range the ID is read by the RFID-reader of the charging station. Reading a valid ID induces the charging station to open it's socket. For the second authentication step the communication channel established by the charging cable is used. A certificate which is deposited within the vehicle is used in the underlying protocol to authenticate the customer against the charging station. The charging process is terminated by unplugging the charging cable.

The verification of the authentication data and the exchange of meter readings is ensued via the network connection to the charging station management system.

2.3 Authentication Via Hotline

The customer dials the operator's hotline which is fixed on the charging station and communicates his user ID, password and the charging station ID. A successful verification induces the activation of the charging station for the authenticated customer. The customer logoff works analogously.

Meter readings and control data is communicated using the network connection to the charging management system.

2.4 Authentication Via Internet

The authentication via Internet proceeds analogously to the authentication via hotline. The customer communicates user ID, password, and charging station ID by filling the appropriated form on the website of the charging station operator or using a provided smartphone application for this purpose.

3 THE BASIS PROTOCOL

Before we describe the details of our protocol, we give a concise overview with Section 3.1. The protocol flow is given by the sequence diagrams depicted in Figure 1 and 2. During an initialization phase each charging station (CS) is endued with a public/private key pair (pk_{CS}, sk_{CS}) and the public key(s) of the respective charging station management system(s) (pk_{CSMS_i}), respectively. The charging station management system (CSMS) retains a matching private key and the public key of each charging station. Keys are stored in a non-removable secure storage, from which they cannot be extracted by unauthorized entities. When a new user signs up with a provider, he receives a set of unique credentials to authenticate at the CSMS.

3.1 Protocol Flow

On the push of a button integrated into the CS, it generates a QR code and shows it on its display. The customer scans the QR code using his smartphone and communicates its content in combination with his authentication data to the CSMS. Optionally, the user can provide additional position information using the provided smartphone application, e.g., his GPS coordinates. The CSMS provides the user with authentication information for this CS, which the application on the user's smartphone displays as a QR code. The CS scans this QR code from the phone's display. If the authentication information is valid, it unlocks / enables the power socket. Charging ends when the electric vehicle's battery management signals sufficient charge, the customer presses a button at the CS and presents the QR code again, or the customer manually releases the power cable using a mechanical release device integrated in his vehicle. When charging ends, the CS creates a data tuple to be used for billing and stores it in temper-evident memory. The CSMS periodically tries to connect to every CS. When successful, it recovers all billing data tuples retained within the CS.

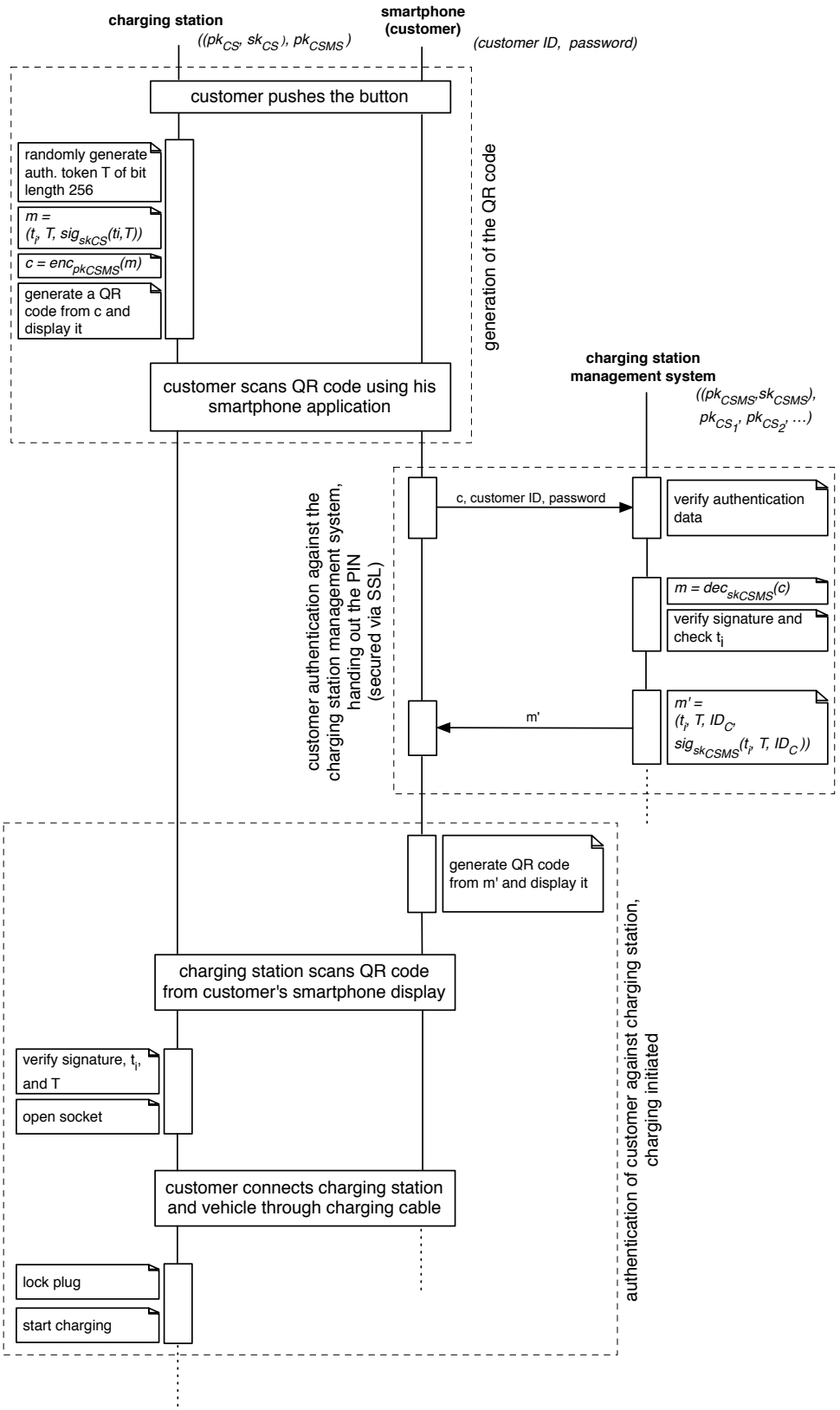


Figure 1: Basis Authentication Protocol (Part 1).

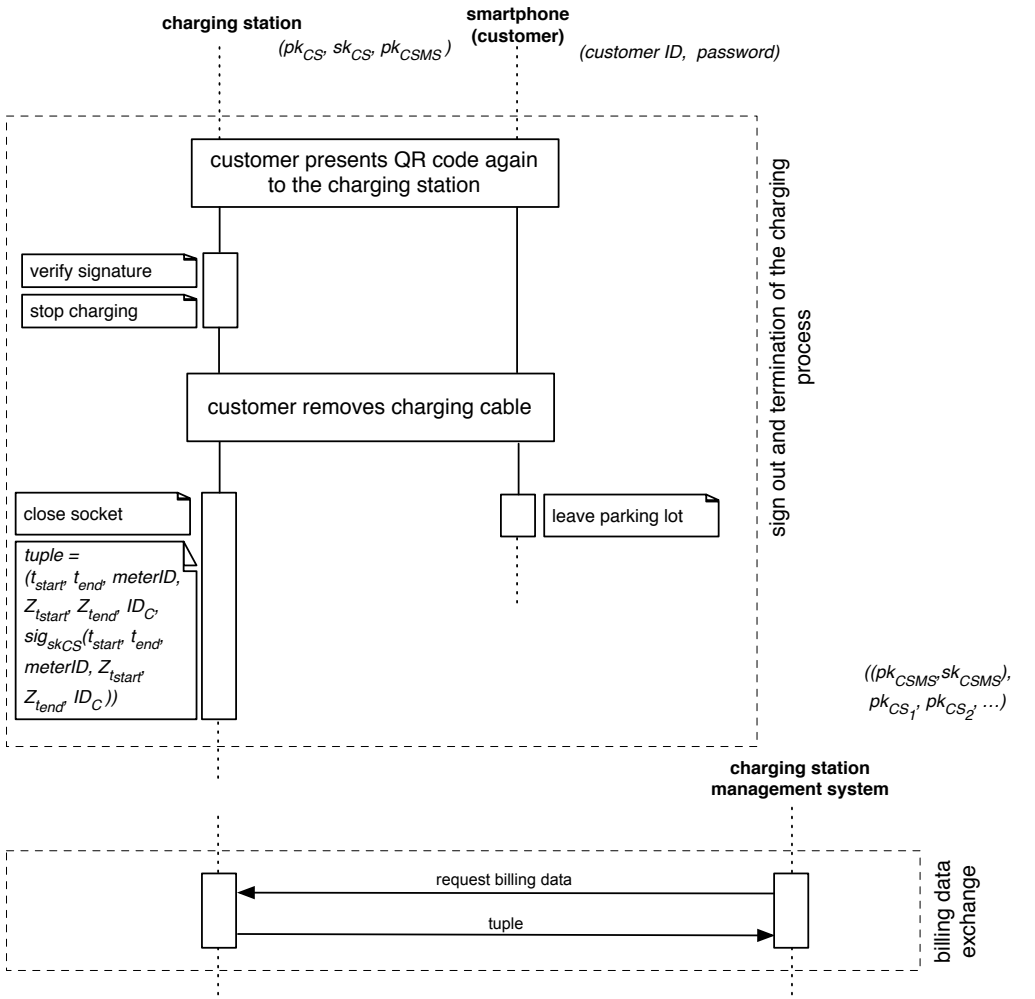


Figure 2: Basis Authentication Protocol (Part 2).

3.2 QR Code Generation

On the push of a button the CS randomly chooses an authentication token T of 256 bit length. It only creates n tokens per time t. n,t are chosen as a compromise between usability and security. Here, usability primarily concerns the fact that each customer willing to use the system should be able to receive an unused token. Under a security perspective one must consider that the source of randomness must not be exhausted or the system overloaded by very frequent pressing of the button, where each button press triggers a set of cryptographic operations that consume system resources.

The CS creates a message $m = (timestamp = t_i, token = T, signature = sig_{sk_{CS}}(t_i, T))$, creates $c = enc_{pk_{CSMS_i}}(m)$, and creates a QR code containing c that it displays to the customer. t_i is a timestamp produced at message creation, in a non-ambiguous time representation. The customer scans this QR code using his smartphone application.

3.3 Customer Authentication

The smartphone application connects to the CSMS using a secure variant of Transport Layer Security (TLS), a cryptographic protocol frequently used to secure a cornucopia of communications on the Internet, e. g., for online banking. We recommend to use TLS-DHE, which has recently been proven to be secure by Jager et al. (Jager et al., 2012).

The user authenticates himself at the CSMS and establishes a secure session. Within this session the application transmits the message c contained in the CS' QR code which the CSMS decrypts and verifies. After successful verification the CSMS checks

whether t_i is within a defined time period to be considered *fresh*. Optionally, the user can provide additional position information using the provided smartphone application, e.g., his GPS coordinates. We discuss this extension in Section 4. The CSMS transmits a message $m' = (timestamp = t_i, token = T, customerID = ID_c, sig_{sk_{CSMS}}(t_i, T, ID_c))$ back to the application. ID_c is a unique identifier for the authenticated customer. The application creates a QR code from m', which the user presents to the CS. The CS scans the QR code and verifies m' and T. If T and the signature over $T, customerID$ is valid, and t_i is within a defined time period, the power socket is unlocked / enabled.

3.4 Storage and Transmission of Billing Data

Upon the end of the charging process, the CS creates a data tuple for billing and ensures its authenticity during transport and storage by means of a digital signature. The tuple is formed as

$$\begin{aligned} tuple = (&t_{start}, t_{end}, meterID, Z_{t_{start}}, Z_{t_{end}}, ID_c, \\ &sig_{sk_{CS}}(t_{start}, t_{end}, meterID, Z_{t_{start}}, Z_{t_{end}}, \\ &customerID)), \end{aligned}$$

where t_{start} is a timestamp recorded upon starting to charge, t_{end} is a timestamp indicating the end of charging, $meterID$ is the unique identification number of the energy meter (if required by local regulation), $Z_{t_{start}}$ and $Z_{t_{end}}$ are the energy meter values at beginning an end of charging, respectively. We chose digital signatures over symmetric methods such as Message Authentication Codes, as both can ensure message integrity and authenticity, but the former can also provide non-repudiability. Non-repudiability is essential to be able to prove that only the respective CS could have created the signed tuple. However, this objective cannot be reached using means of symmetric cryptography.

The CS stores the data tuple in temper-evident memory, such that any attempt to erase a billing tuple can be discovered. The CSMS periodically tries to connect to each CS. Upon successfully establishing a secure connection, it recovers all billing data tuples and stores them centrally, such that they are available for the billing process. When the CSMS has successfully stored and verified a tuple, this tuple is remove from the CS' memory.

4 PROTOCOL EXTENSIONS

In the following we describe further optional extensions to the basis protocol which affect the security of the protocol and the cooperation between different charging station operators.

4.1 QR Code Relay Attack Prevention

We consider the following theoretical attack scenario: An attacker positions a manipulated charging station with the ability to receive QR code data generated by the attacker and to display it to the customer.If an authentication token is read by the manipulated charging station, it has to be transmitted immediately to the attacker whereas an error message is displayed to the customer. An existing connection to the charging network is not necessary to accomplish this task. Utilizing the manipulated charging station to his own authorization process the attacker is enabled to charge his vehicle for free or at the cost of the victim.

The attacker positions his vehicle in front of an authorized charging station, reads the displayed QR code, sends the QR code data to the manipulated charging station (e.g. using an implemented smartphone application for this purpose), and waits until the valid QR code, provided by the customer at the manipulated charging station, is received. If the QR code loses validity during the transmission, the attacker repeats the proceeding with a fresh QR code. In this scenario, the charging station management system provides an authentication token for an authorized customer and connects the billing information to his account. Once the customers presents the QR code to the manipulated charging station, an error message is displayed, informing about a defective and referencing to another charging station. Since the customer cannot distinguish between the authorized and the manipulated charging station, he is not aware of the fact that an attacker positioned at another charging station uses his QR code to charge a vehicle at his cost. Under certain assumptions, this attack can be thwarted by integrating spatial data into the authentication protocol: The mobile application determines the customer's GPS coordinates during authentications. This position is then concatenated to the message c the customer transmits to the charging station management system.

With this protocol extension, the charging station management systems checks if the customer's GPS coordinates match with corresponding charging station's coordinates considering a certain tolerance. Only if this additional condition is satisfied the management systems issues m'. The assumption for this

security feature is that the manipulated and the authorized charging station the attacker uses are sufficiently wide apart from each other exceeding the maximal accepted tolerance.

4.2 Multi-operator Authentication

A simple extension to the basis protocol of Section 3 enables a multi-operator authentication without the necessity of sharing customer data between operators. Each operator obtains an operator ID. Instead of just pressing a button, the customer chooses the operator at the CS. The CS encrypts the message m using the respective operator's public key pk_{CSMS_i} and then incorporates the appropriate operator ID within the QR code in plaintext. Basing on the operator ID, the provided smartphone application decides which operator the authentication message is forwarded to.
Manipulating the operator ID can not harm the system because the assigned operator is not able to decrypt the data which is necessary to return an authentication token to the customer.

4.3 Privacy-preserving Solution

Locational privacy can be defined as 'the ability of an individual to move in public space with the expectation that under normal circumstances their location will not be systematically and secretly recorded for later use' (Andrew J. Blumberg and Peter Eckersley, 2009) and has become increasingly relevant with rise of long-term data retention – itself made facilitated by increasingly cheap data storage.

While the solution we presented so far does not preserve a customers location privacy – it allows for the creation of a movement profile based on the spatio-temporal location of each charging process – a limited set of changes can mitigate this threat: Instead of sporadically connecting to the Internet to allow for the CSMS to retrieve billing data, each CS uses this temporary Internet link to connect to the Tor network (Mathewson et al., 2004), such that it is addressable as a location-hidden service. This means, it is known to the CSMS via its `.onion` address, but not via its IP address or physical location. While this may sound far-fetched and impractical in reality, the Tor network is a highly redundant, distributed system that can provide connectivity with sufficient throughput and latency for the application at hand (Frosch et al., 2013). The authenticity and non-repudiation of messages from CS to CSMS does not longer depend on classical signature algorithms. Instead, messages are signed using a group signature scheme, like XSGS (Delerablée and Pointcheval, 2006). Message m will be formed as $(timestamp = t_i, token = T, address = onionaddress_{CS}, signature = gsig(t_i, T, onionaddress_{CS}))$, while c will still be created as $enc_{pk_{CSMS_i}}(m)$. Instead of signing the billing data tuple with a conventional signature, the CS uses the a modified eXtremely Small Group Signature as proposed by Frosch et al. (Frosch et al., 2013).

5 DISCUSSION

In the following we discuss the potential of a completely offline solution, the advantages of using a random binary token over a numeric Personal Identification Number (PIN), as well as, the issue of a trustworthy time source.

5.1 Offline Solution

In the unlikely case that a charging station is located such that it can never access the Internet, small changes can be made to the protocol leverage the user's communication with the CSMS to transport most billing relevant data within. Including the current energy meter value Z_{t_i} in message m, such that $m = (meter = Z_{t_i}, timestamp = t_i, token = T, signature = sig_{sk_{CS}}(Z_{t_i}, t_i, T))$. The charging process can only be terminated by performing the authentication procedure again, such that a message $m_2 = (meter = Z_{t_j}, timestamp = t_j, token = T', signature = sig_{sk_{CS}}(Z_{t_j}, t_j, T'))$ is transmitted to the backend. However, as many electric vehicles come with a manual unlock mechanism for the power connector, even a honest, but curious, customer can evade the transmission of m_2 and thus charge without paying. Additionally, t_i, t_j are created when the customer presses a button and not at the exact time the charging starts. Depending on local legislation, this may not be precise enough.

5.2 Random Token vs. Random PIN

Although numeric PINs are frequently used to authenticated customers, e. g., at automatic teller machines (ATMs), the keyspace of usable-length PINs is very limited. PIN lengths up to 6 digits can be considered acceptable to the customer, as they are used in commercial applications. However, as the character repertoire is limited to $[0..9]$, the keyspace is limited to 10^l. The probability that an attacker guesses a valid password is thus $\frac{1}{10^l}$, i. e., on average an attacker needs $\lfloor \frac{10^l}{2} \rfloor$ guesses. As this limitation is well known, many PIN-based authentication systems require not only the

knowledge of the PIN but also the possession of physical token, e. g., a bank card. Additionally, usability is further reduced by the fact that a customer may only mistype a PIN n times, before the physical token is automatically invalidated or confiscated. n is often chosen as 3.

By choosing a QR code reader as input method to the charging station, instead of a PIN pad, we avoid the usability issue altogether. The user is not forced to enter an arbitrary set of numbers correctly, but simply presents his smartphone to the reader. Thus, we can choose to a much longer knowledge-based authentication token. We choose a binary token of 256 bit length, which results in a keyspace of 2^{256}. This allows for a significantly more secure authentication process and also improves usability as there is no need enforce arbitrary limitation on how often a user may try to enter a credential. Vandalism-proof QR-code readers are widely in use today, e.g., at airport boarding terminals.

5.3 Time Source

We use a timestamp as a freshness parameter in our protocol. However, this implies that we have a trustworthy time source at our disposal. This is also a basic assumption for post-paid systems, as many regulations require to inform the customer when a service or a good has been delivered. When an attacker can trick a CS into assuming a time in the past as being current, he can thus replay an old message m'_{old}, which will be accepted if the CS's time and the message timestamp are within a tolerated interval. Even existing customers can use erroneous system times to their advantage, as the energy provider will have a hard time arguing how it can bill, e.g., for a charging process with at timestamp dating from before the customer ever signed up with this provider.

However, a trusted time source is not easy to come by. DCF-77, the Network Time Protocol (NTP), and GPS are popular time sources. However, none of these protocols provide information on the authenticity of the content and can thus be manipulated. DCF-77 transmitters can be built for very limited costs[1] or even using standard soundcards[2]. NTP packets can be manipulated in the path of communication. Alternatively, DNS entries can be hijacked by an out-of-path attacker (Leyden, 2013), pointing to an NTP server the attacker controls. While Tippenhauer et al. (Tippenhauer et al., 2011) have shown that the spoofing of a GPS signal is feasible, this attack induces significantly higher costs for the attacker than the aforementioned ones. For the time being, GPS should be the preferred time source for outdoor CS installations. In indoor areas, such as parking garages, the GPS time signal can be forwarded via internal network. Alternatively, `tlsdate` (Applebaum, 2013) may provide a coarser, but possibly more secure alternative time source when used as consensus source.

[1] http://endorphino.de/projects/electronics/timemanipulator/index_en.html

[2] http://0x7.ch/text/dcf77.pdf

6 CONCLUSION

We presented a protocol that enables providers to operate charging stations without a continuous communication channel connecting them to the charging station management system. This allows a more economical operation and a higher security of the charging station infrastructure, as the charging station has no privileged access to the backend infrastructure. Involving QR codes enables a multi-operator authentication of the customer against the charging station without any communication between the charging station and the management system and without depositing sensitive data on the charging station.

While we focus on the application of recharging electric vehicles, our solution is flexible and can also be adapted to a wide variety of application fields, such as time-limited access of rental cars, pedelecs, and bicycles.

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ENERGY-AWARE SYSTEMS AND TECHNOLOGIES

FULL PAPER

Energy Aware Communication in the Smart Grid

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Abstract: Recently some countries have investigated the transformation of their existing power grid to the so-called Smart Grid. A Smart Grid adds a communication network, which is the integration of a monitoring and control network, to the power network. In this research we have developed and implemented a communication network architecture for the neighbourhood sub-Grid level of the electrical network where monitoring has not previously been deployed. Since energy efficiency has been identified as one of the major limitations of such networks we have utilized a number of different techniques to tackle this problem. As such, we analyse the optimal topology of network for collecting and transmitting data to the local control unit for applying finer-grained control. Also, we have developed a data reduction algorithm suitable for Smart Grid applications, which can significantly improve the energy efficiency of the communication network by minimizing the communication energy cost and optimizing the network resource consumption while maintaining the integrity and quality of data. To the best of our knowledge, our work is one of the very first efforts to propose an energy efficient ICT architecture, combining power grid objectives, real data characteristics, and application-aware considerations.

1 INTRODUCTION

In the recent years scientists have identified a number of problems associated with the conventional power grid and tried to tackle them. This has led to the birth of the concept of a Smart Grid. According to the US Department of Energy (DOE) (Miller et al., 2008) the Smart Grid should contain the following characteristics; self-healing, consumer friendly, reliable with good power quality, resistant to cyber-attack, and facilitating new service and markets. To achieve these features necessitates the incorporation of the Information and Communication Technology (ICT) along with the power network.

Deploying a large number of monitoring devices in the Smart Grid environment that transmit huge volume of data will saturate the device resources and consumes their energy. Some of the key constraints of wireless sensor devices are their limited resources such as memory, battery and processing power. Since battery technology used in the sensor network has a slower development rate than both the sensor device technology and the processor technology (Miao et al., 2009), the energy constraint problem has emerged as one of the main limitations of these network when wireless communication is proposed. In such networks difficulties arise when the deployed sensors are short on power, thus a specific area of the grid is no longer being monitored at a sufficient rate, which will lead to incorrect decision making by the control mechanisms and operators of the grid.

In this paper we will summarize and integrate different aspects of an experimental Smart Grid project taking place in the University of Manchester. We will briefly discuss our proposed ICT architecture, which involves the integration of various monitoring devices, storage and control units for the neighbourhood area network (NAN) of the ICT network within the Smart Grid. Implementing our proposed architecture in the real environment rather than solely in a simulation-based environment, enables us to identify a number of drawbacks associated with such networks. One of the major problems which we will discuss in this paper is the energy efficiency consideration of the communication network. These limitations necessitate development of the techniques to consume sensor resources more efficiently to achieve better quality of the network, longer lifetime and time between maintenance sessions.

Observing that 50% of energy is spent during the

data transmission process, we realize that it is not practical to broadcast full resolution data over long distances. Therefore, we investigated how to configure the communication network of the wireless monitoring devices and also how to apply the data reduction techniques to decrease the size of transmitted file before transmission process. These result in more effective utilization of available resources and offer better energy efficiency to the system.

2 PROPOSED ICT ARCHITECTURE FOR SMART GRIDS

In (Pourmirza and Brooke, 2013c) we proposed two related architectural structures and discussed our experimental results for the ICT infrastructure of an urban environment in the Smart Grid. These two architectures are: a communication network architecture and a software architecture. In this section we summarize the communication architecture and its constituent components. In the next section we will demonstrate the techniques we have used to provide energy efficient communication architecture specially designed for the NAN of the Smart Grid.

The proposed architecture is a modular architecture that integrates the peer-to-peer hierarchical architectures, tailored to hybrid communication technologies for transmitting data. It is being implemented on the medium voltage power network substation 6.6kV of the University of Manchester campus which owns its own distribution grid. This allows us to validate our architectural designs on real equipment, real data, and input from experts in power engineering. This architecture (figure 1) comprises five layers that cooperate to offer four main functions of monitoring, data movement, data storage and control. Our proposed architecture offers modularity, scalability, fault tolerance, energy efficiency and future proofing against changes in networking technology. Each of these characteristics are discussed in details in (Pourmirza and Brooke, 2013c).

The first layer in the figure 1 consists of smart meters as monitoring devices, which are situated in all the buildings of the University of Manchester. They are responsible for monitoring building level data that provide information about power usage and permit the management of the power generation and consumption. The information collected at this level is valuable for prosumers (producer-consumer), because by integrating such data with data on real-time energy prices we can offer effective demand response control.

The second layer comprises hundreds of sensors located in the street areas that are responsible for monitoring environmental data such as temperature, light, and humidity. The data collected at this level is essential for understanding the response of demand on the electrical system to variables such as number of people, weather, temperature, humidity and so on. It also can help in controlling the power grid by delivering data that can be used to anticipate demand and improve control actions.

The second layer itself is divided into two sub-layers. This division is due to the energy constraints of the Wireless Sensor Network (WSN). Consequently we have utilized cluster based communication as a method of communication instead of direct communication as a more energy efficient data transmission technique (Abbasi and Younis, 2007). In order to evaluate the WSN at this level, we extended the TinyDB (MADDEN et al., 2005) (WSN query processing engine) by adding a Smart Grid component to it. The extension to TinyDB enables us to run and test our prototype implementation in the laboratory-based environment as well as in a real physical environment.

The third layer comprises the monitoring and control devices situated in 6.6 kV substations in our test bed. They are responsible for monitoring three phase voltages, currents, active power, power factors, voltage's spectra (eight channels for each phase) and current spectra (eight channels) and frequency. These data are useful for fault identification, power quality analysis, and many other applications. This layer is also divided into three sub-layers: namely a reconfigurable real-time control and acquisition system called Compact RIO (cRIO), data storage, and a control unit which is a program responsible for applying control over the substations only, that is called LabVIEW (LabVIEW, 2007). The next layer (fourth) is the database (DB) layer responsible for storing data received from the layers below.

The final layer is the Neighbourhood Control Unit (NCU) which extracts data from the database layer or directly from the sensors. We have developed a Geographical Information System (GIS) enhanced display tool (Pourmirza and Brooke, 2013b) for this layer which is beneficial for visualizing the live/historical data on a map view, and for tracking and identifying the faulty part of the system in advance.

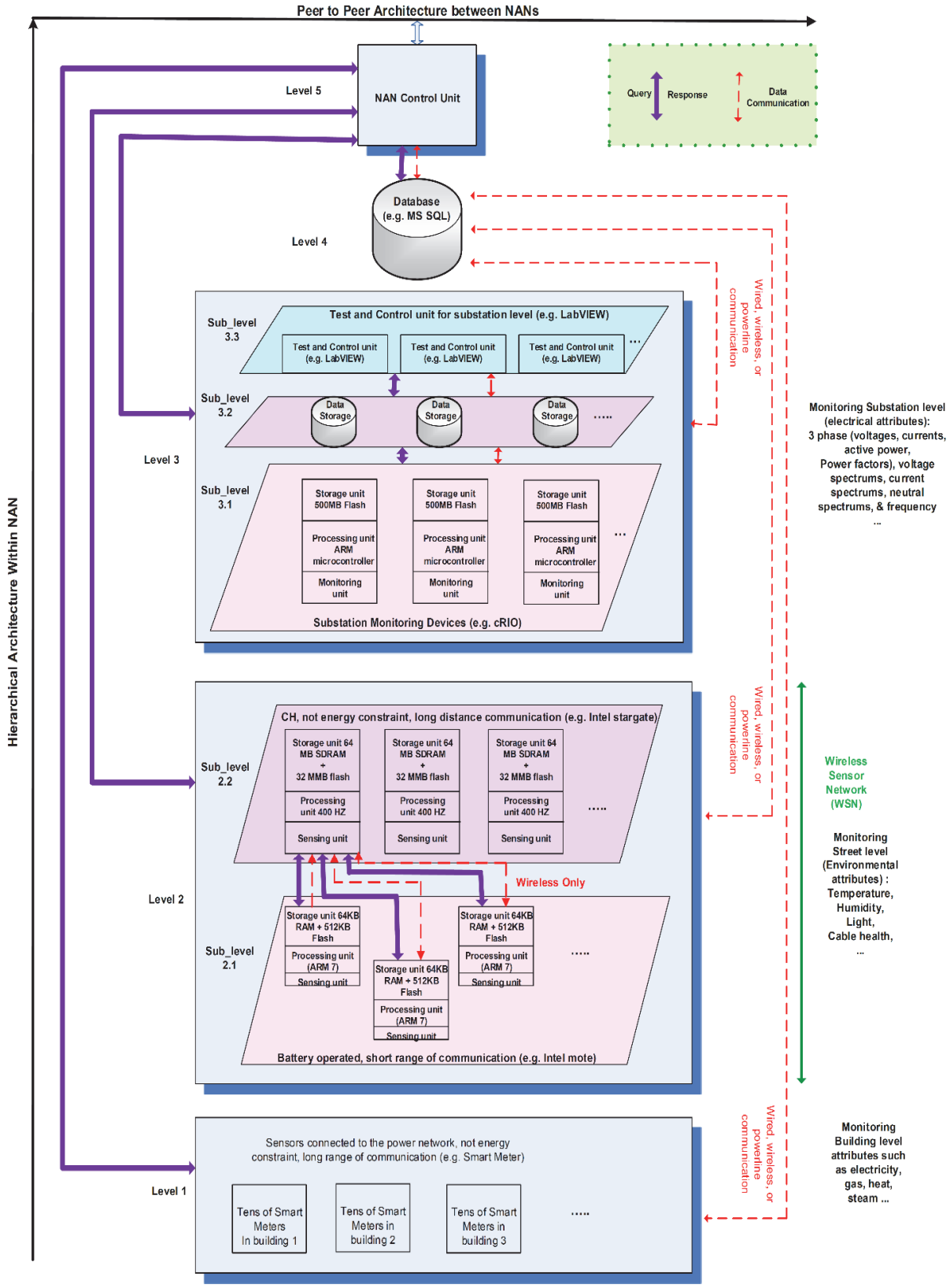


Figure 1: An ICT architecture for the NAN in the Smart Grid (Pourmirza and Brooke, 2013c).

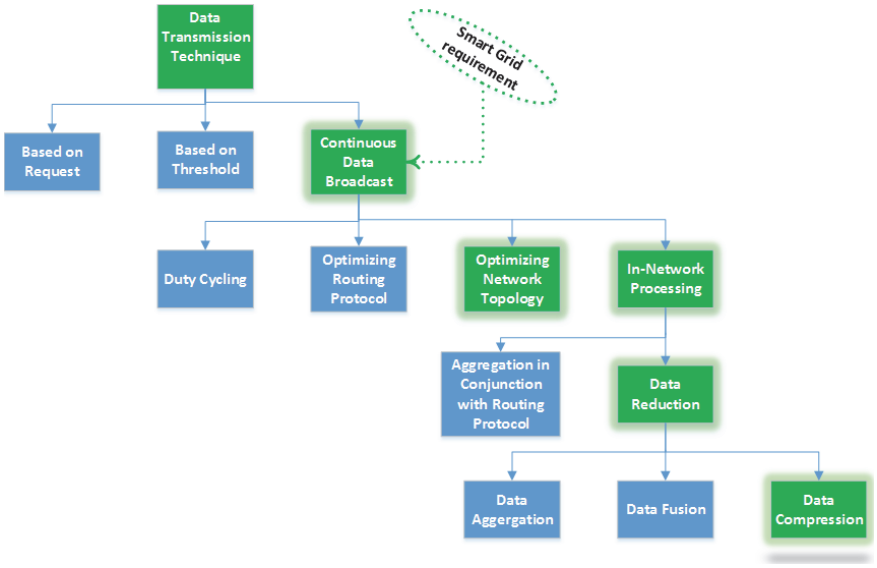


Figure 2: Efficient data transmission.

In an urban environment multiple NAN systems should join to form a higher sub-grid network. Therefore, we have added another layer of communication over the top of the architecture to enable these systems to communicate and coordinate their control actions.

3 TECHNIQUES TO PROVIDE ENERGY EFFICIENT DATA TRANSMISSION

We have classified the data transmission technique, which is the technique devices use to transfer their data to the NCU, into three different categories. The first category is used when sensors transmit their data after receiving requests from the sink. The second category is when sensors send data indicating that a threshold condition is violated or when an emergency situation has occurred. The third category is when sensors collect data and broadcast them continuously. Although the first and second category are more energy efficient methods of data transmission, because data are being shipped with lower frequency or only occasionally, our NAN monitoring network in the Smart Grid also necessitates the third category, because electrical engineers want to monitor data collected from the grid at all times. Thus full data collection is needed in such networks.

Our survey of the literature reveals that the energy efficient radio communication can be accomplished through different means, such as; duty cycling, optimizing the routing algorithm, optimizing the network topology, and in-network processing. Duty cycling can be achieved through scheduling the sleep/wakeup program of sensors (Anastasi et al., 2006), which is not, however, an appropriate technique in our context, since our sensors are continuously sensing and sending data without going back to sleep mode. Optimizing the routing algorithm can be accomplished by developing a multi-hop routing algorithm that can identify the next optimal hop to route the message to the sink. In our network design we assume we have direct communication instead of multi-hop communication; therefore, optimizing the routing protocol is out of the scope of this research. Optimizing the network topology can be achieved through managing the communication distance, which is the first technique we have utilized in our research. Finally in-network processing can be classified in two classes. The first class is the data aggregation techniques being implemented in conjunction with WSN routing protocols. A survey of data aggregation techniques in WSNs (Thangaraj and Ponmalar, 2011) has introduced and analysed several such data aggregation protocols. The second class of in-network processing methods is called data reduction, which is performed by implementing data reduction algorithms to reduce the communication cost by minimizing the size of transmitted data. Applying data reduction will result in efficient bandwidth utilization and also power saving caused by data transmission, which will increase the network lifetime (Naoto and Shahram, 2005). The technique used in this research to offer

energy efficiency to the communication network belongs purely to the second class of in-network processing, i.e. the data reduction method.

Data reduction itself can be classified into data aggregation, data fusion, and in-network data compression. Data aggregation is useful when the goal is to reduce the communication overhead and cost. This method will reduce the message size by utilizing one of the aggregation functions such as Min, Max, Sum, and Average (Tan et al., 2007).

Data fusion is a more elegant method in comparison with the data aggregation. In this method various unreliable data will be combined to eliminate the related noise and produce a more accurate signal (Abdelgawad and Bayoumi, 2012). Data compression can be described as the procedure of processing raw data into a condensed structure rather than its original format. One of the challenges in the data compression technique is the accuracy of the decompression algorithm while reconstructing the data. The data compression is usually used in the applications where the full data collection is required. Since electrical engineers working on the Smart Grid applications are still evaluating the data we do not use fusion or aggregation. Thus, our data reduction algorithm is purely a compression method which keeps the quality and integrity of data. Figure 2 demonstrates the categories and subcategories of efficient data transmission, and highlights (in green) the contribution of our research to this area.

3.1 Optimizing the Network Topology

As discussed earlier, the first technique we have used to provide more energy efficient architecture is to optimize the WSN topology. In this section we focus on the second layer of the architecture and identify the optimal topology of the WSN by analysing the optimal number of clusters for specific application in our test bed. However, it should be noted that these results may vary due to changes in the networking topology, communication protocol, and Quality of Service (QOS) requirements. As shown in figure 3 the second layer of the architecture is going to be deployed in the University of Manchester sub-Grid. The university campus is embedded in a city, containing streets and road. The whole campus is connected by rectangular grid.

Since we are dealing with an urban area the sensors are located at fixed locations which, to a first approximation, can be located on a rectangular grid reflecting the pattern of the urban streets, as shown in figure 3.

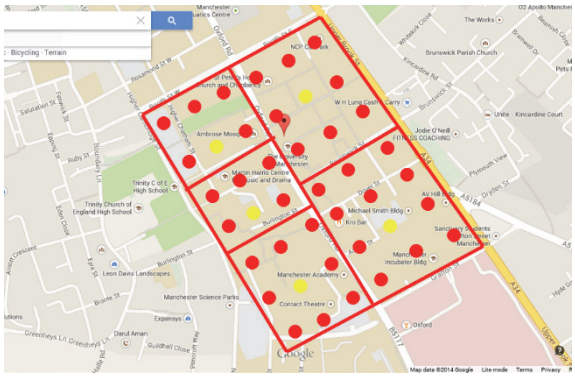


Figure 3: The University of Manchester campus, representing a rectangular grid, being divided into clusters. The red dots show normal sensors, while yellow dots are considered to be a cluster head.

In order to obtain the most energy efficient topology of a grid we must find the optimal number of cluster. Therefore we divide the network into various number of clusters and maintain a fixed number of sensors. Then we start simulating each of these networks by varying the number of sensors in the clusters, cluster shapes and locations for 12 different configurations, all of which preserve the number of clusters. We have considered different configurations, because in real projects it is not always possible to deploy the nodes in the most optimal topology, thus we estimate the variance. Figure 4 shows total energy consumption against the number of clusters. The curve demonstrates a minimum at 8 clusters. The result that the minimum occurs at 8 clusters is a function of the total size of our rectangular grid (10x10) and the amount of energy consumed by the CHs; however, the methods could be used on grids of arbitrary size and CHs. More details are described in (Pourmirza and Brooke, 2013d).

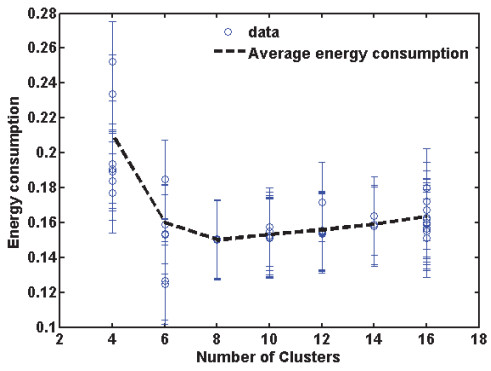


Figure 4: Energy cost analysis of a grid with different number of clusters.

Finally our experiments reveal that the two other factors that affect the energy consumption of a system are the shape and location of the clusters. We observe that, if the clusters are rectangular, then the best result is when the rectangles of the grid are square. Moreover if we consider different size of clusters in a network, by locating the smaller clusters near the data sink, and bigger clusters farther from the sink, we can also improve energy efficiency of the WSN.

3.2 Developed Data Reduction Algorithm

The second technique utilized in this research to offer communication energy efficiency is to develop a data reduction algorithm. The exponential increase of the number of monitoring devices in the Smart Grid will lead to an explosion in the data volume. The recent evidence (Allalouf et al., 2011); (IBM, 2012); (McNamara and Meynardi, 2010) has confirmed this conclusion. As current communication methods deployed in electrical Grids are not yet prepared to manage such volume of data, we have to start developing new methods and techniques to ease the transmission and storage of such data. An effective data reduction technique would be an effective approach in this context.

Previously, in (Pourmirza and Brooke, 2013a) we proposed a data reduction algorithm for data that is sampled at a higher rate than the rate at which successive values change significantly. Recently, we have improved our data reduction algorithm to further compress the data before transmission. Our first data reduction algorithm is called DRACO-1 (Data Reduction Algorithm for Correlated data) and the improved version is called DRACO-2. In the rest of this paper we will summarize DRACO-1, introduce DRACO-2 and demonstrate our experimental results.

In the Smart Grid applications, where the metering devices collect data with a high acquisition rate and transmit them to the NAN control unit, a great degree of data correlation occurs. Taking this fact into consideration, we have developed a data reduction algorithm (DRACO-1) that discards the redundant bits by applying XOR on each two consecutive measured values, and transmits the changing bits only. The changed bits are a small portion of the binary representation which will be converted to digit-based representation before transmission. DRACO-1 is discussed in detail in (Pourmirza and Brooke, 2013a). This algorithm can improve the energy efficiency of the communication network by transmitting smaller value of data while keeping the data integrity.

The difference between the DRACO-1 (method 1) and DRACO-2 (method 2) is that on the transmitter side, after applying XOR and converting the binary representation back to digit-based representation, if any consecutive values are similar, DRACO-2 will only send one instance of that value together with the number of repetition times. Although DRACO-2 is not as stable and general as DRACO-1, DRACO-2 is very helpful in compressing high volume data with strong correlations (such as frequency and voltage data) and in these cases it can perform better than DRACO-1.

In order to evaluate the compression efficiency of both DRACOs, and also assess their performance on different hours of a day, and check the behavior of the electrical grid during the peak hours and non-peak hours, we have examined both DRACOs on 24 hours of real data (these data are collected from 8:00 24th April 2013 to 8:00 25th April 2013 with frequency of 1 Hz from a 6.6 kV substations in our test bed). Figure 5 compares DRACO-1 (blue line) and DRACO-2 (red line) using the voltage data. It shows that DRACO-2 gains a higher compression ratio and is a more efficient algorithm for voltage compression. Moreover, it reveals that after 16:00 (4 p.m.) we can gradually achieve better compression (over 89%) ratio until 1:00, which means the electrical grid is steadier and as the result the data correlation is higher during this period of time. Checking the load profile of the system has confirmed our results.

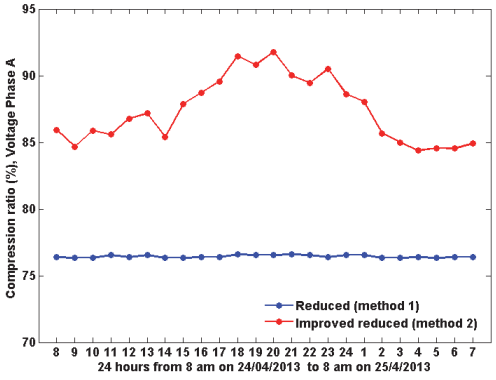


Figure 5: 24 hours of compressed voltage data.

Additionally, another experiment has been designed to assess the effect of various sampling rate on the efficiency of our data reduction algorithm. We have examined the data being logged with different frequency. Figure 6 shows that, as the

frequency of data acquisition rate increase, the original size of the data will increase, which is simple to understand. However, as we start to sample more frequently the gap between the original data size and the reduced data will grow as well. Thus, with higher sampling rate we are transmitting more information about the grid, and with the use of the DRACOs we can send this information more efficiently. This result confirms the observation that when data are being sampled at a faster rate, the correlation between each two consecutive value is higher, and DRACO performs best on data with stronger correlations. Moreover, we conclude that the size of the reduced data file (DRACO-1) with data being logged once every second is roughly equal to the size of original data being logged once every 3 seconds. This result is beneficial in terms of bandwidth utilization and hence energy consumption.

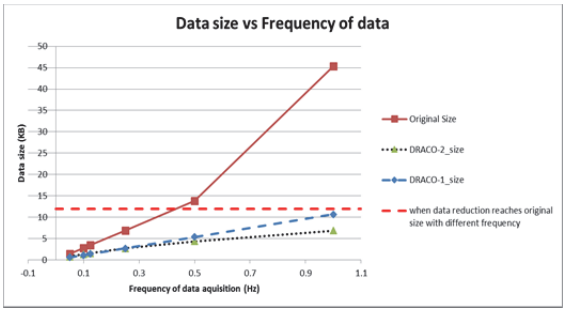


Figure 6: Data acquisition rate evaluation.

4 CONCLUSIONS

In this paper we present a practical energy efficient ICT architecture for the NAN in the Smart Grid. Although we had previously discussed about different aspects of this research separately, this is the first time that all these finding are integrated to present a completed project.

At the beginning of this research we proposed a communication network architecture and analysed its design in terms of offering energy efficiency for a local control system. Then we evaluated the techniques to offer more energy efficient data transmission. As the result we follow two approaches, optimizing the network topology and applying a data reduction technique at various level of the architecture. Regarding the optimization of the network topology, we present our experimental results that the number of clusters, their shapes and the way the clusters are geographically grouped are all important to offer deeper a minimum of energy consumption. Then we presented an updated version of our data reduction algorithm (DRACO.) We confirmed experimentally that the data from the NAN of the Smart Grid conformed to the pattern required by both DRACOs. An important part of this work is that we have been able to validate and test DRACO on data, which are produced at a very high sampling rate. This is useful in terms of identifying key changes in behaviour of electrical systems. One significant contribution of this research is that the algorithm can reduce the power consumption and improve the overall energy efficiency of the communication network in the proposed architecture. Finally, it can provide an efficient flow of information by reducing data traffic and accelerating data transmission speed. Since, in such networks, the bottleneck is caused by the fact that thousands of sensors are sending their data to the central point, in some cases by applying DRACO and reducing data roughly by an order of magnitude (to base 10) we can reduce the risk of bottleneck.

In future we will monitor the performance of DRACO over extended period of time to estimate how much energy and storage could be saved in an ICT network with this technique.

ACKNOWLEDGEMENTS

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SHORT PAPERS

EnergyAware
Mobile-based Architecture for Maximizing Energy Savings during Computer Idle Times

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Keywords: Energy Efficiency, Energy Saving Policies, Computer Networking, Smart-Phones.

Abstract: Energy consumption of computers in office buildings remains an issue of concern for companies. For example, for a university campus, they might represent between 50% and 80% of all the power consumed. Besides that, computer usage behavior sometimes makes the application of energy saving policies a difficult task, as many users prefer not to be annoyed by waiting for computers to wake up. We present in this paper a novel software architecture to enable dynamic and static appliance of energy saving policies in office computers while observing and taking into account user behavior. The key is taking advantage of idle periods for the computers and the localization of the user to determine when to turn Off or On the PC and maximize the savings. We ran a study at our campus where we found that idle periods represented between 30% and 50% of the On periods. We simulated the savings for our policies and could potentially achieve savings between 32% and 38% of current power consumption numbers. With even more tuning, we believe savings could be higher and similar techniques could be used for other devices in buildings.

1 INTRODUCTION

Energy consumption in personal computers remains a problem of concern especially for office buildings managers. An example is an empirical study in (Agarwal, 2009) which found that between 50% and 80% of all electrical power consumption in the buildings at the University of California San Diego campus comes from IT equipment, from which most of it would be desktops. Different energy saving techniques have been applied with relative success during the past decade. The fact that the user still has the last word about how and when such techniques are applied might prevent such techniques to be applied in most of the computers or during most of the time. In developed countries users might be switching desktop use to laptops, tablets and smartphones, but annual shipments of PCs are still high, about 80 million per year, counting desktops and laptops, according to an IDC report. And in emerging and developing countries, office setups still have desktops as the main computing device. Companies, according to the report, still consider replacing PCs which might even help at least maintaining sales in upcoming years.

As a result of this, different PC managing solutions have emerged to help offices to administer their energy consumption and focus especially on the computers. The most popular is Verdiem, a company that offers a system to manage energy consumption of IT equipment in an office. Their advertising promotes that default energy saving options are not enough to achieve maximum savings. In the personal level, there are many applications that can be used to monitor the energy usage and apply static energy saving policies. One of the missing features in the available software is the possibility of creating user-centered policies that could be changed on the go as the situation changes with the least intervention from the user. In this paper we propose architecture composed of a server, a software application for PC and a software application for a mobile phone that combined could increase energy savings when compared with the use of typical energy saving policies. The architecture relies on a very detailed monitoring of the computers usage to detect the exact moments at which the user is not present and put the PCs to sleep during those periods. The architecture also relies on the constant monitoring of the location of the user to achieve a

better experience by decreasing the annoyance and also increasing energy savings at the same time. Thus, the contributions of this paper are: 1) A software architecture to monitor PC usage, energy consumption and apply savings policies. 2) A behavior-centered dynamic energy saving policy. 3) A user location-based energy saving policy that accommodates to user location to improve both savings and user satisfaction.

The rest of the paper is divided as follows. Section 2 summarizes the related work, Section 3 describes the EnergyAware architecture. In Section 4 the location-based energy saving policy is designed. In Section 5 the implementation and evaluation is shown, and the paper is concluded with a discussion of future work.

2 RELATED WORK

Computers in n offices can achieve substantial savings in energy consumption. In a report from EMA, 2008, the authors conducted a survey among hundreds of professionals where they responded that their computers work were kept On during 43% of the total non working hours or the equivalent of 55 hours of consumption during a week. This equates to an additional cost and unnecessary $73 per computer annually. Although computers have the ability to be configured to sleep or hibernate, it does not always take advantage of it. In the survey it was found that from the people who did the survey including teachers, secretaries, assistants and administrative staff, only 12% of them have ever changed their energy savings on their computers (specifically suspend and hibernate). This shows that even if companies have the option, energy saving policies are not mandatory in all companies, and users are left with the choice of saving energy or not.

In (Lin et al., 2011) the authors explained several methods with which they could generate energy savings in computers. The most interesting was RFID. RFID is used to save energy in the computers that are used in classrooms. When the computer is not in use, it turns Off or suspends automatically, avoiding energy waste. To implement this technology, a sensor that identifies when a person leaves should be installed at the entrance of the office or room. It will automatically send a signal to the computer and thus start sleeping. The authors used a server that retrieves data using an RFID reader. It allows knowing when a user is close to or away from the computer. The server decides to put the computer to sleep if the user is away for 10 minutes, or decides to turn it off if the user spends more than 30 minutes away from the computer.

In (Korn et al., 2004) the authors show a framework for energy savings on computers. They proposed the creation of profiles for each computer or group of computers and in turn make them have Off-time schedules depending on the profile assigned to it. The authors did however not take into account how the users will handle the decision of turning off the computer in the case he/she needs to leave it on to complete long-running tasks.

The Engineering Department of the Samsung Institute of Technology has a system that allows you to suspend the device when not in use. They managed to implement it using a hardware that recognizes when the user gets up from his chair. It orders the device to go to a suspended state, and when the user returns to his/her desk, it resumes the operating system (Reilly et al., 2011). This however restricts its use by requiring a piece of hardware. The Department of Electrical Engineering and Computer Science at the University of Fukuoka in Japan proposed a technology similar to the one Samsung proposed, but differs in the presence verification process. Instead of verifying if the user is present or not in his/her desk, the University of Fukuoka checks whether the user is currently looking at the computer screen (Kim, J.-Y., 2011) or not. This is done by means of a webcam, a presence sensor/vision and an algorithm called EYE-TRACKING. In this way if the person comes completely out of the camera range, it means that it is not in front of the computer and therefore is not using it. The implementation turns off the screen and suspends the computer to achieve energy savings. This also depends on hardware.

Mobile phones are used as an authentication mechanism and could be used to determine if the computer owner is close to it. One of the authentication methods most difficult to control is that which uses tokens or any mechanism created to store security passwords. An example is the proposal made in (Jaros and Kuchta, 2010), where the authors performed a token-based authentication through mobile devices. The communication between the mobile and the computer is done via Bluetooth. Another proposal tries to overcome the problems with GPS by using Bluetooth and Wi-Fi to improve location calculation accuracy (Almuairfi et al., 2013).

In this article, we like to combine several of the technologies used in other applications. We will use the mobile phone as an authentication token. We will propose an energy saving mechanism that relies

on the knowledge about the location of the user and its phone at any given time. To achieve confident levels of accuracy about the location of the person, we will combine GPS and Bluetooth to achieve more precision. We considered that it differentiates from previous propositions in the granularity of the computer usage statistics and the dynamism of the energy saving policies based on the behavior of the user.

3 THE EnergyAware ARCHITECTURE

The main purpose of the EnergyAware architecture is to achieve improved energy savings in a group of computers, when compared to existing energy savings strategies. This is achieved by giving to the user certain remote management capabilities and statistical information about the group of monitored computers. At the same time, the PC could be put in energy saving states during idle times to maximize savings. Figure 1 shows the 3 main parts of the architecture: the managed PC, on which we ran software agents to monitor activity, the web server to store the usage information from the managed PCs and an administrator that could be either an IT staff or a regular user. We will explain in detail the different components.

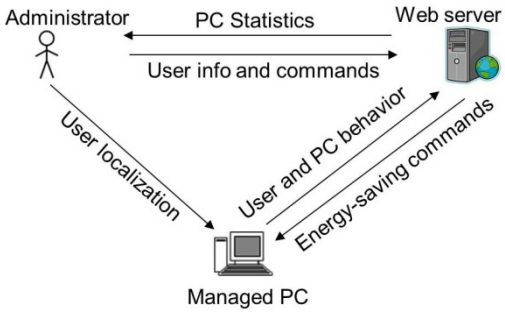


Figure 1: Components of the EnergyAware architecture.

3.1 PC Software Agents

The PCs that will be managed need a software agent running on them. This agent will record user activity with a granularity that could be modulated by the administrator. The purpose of this is to have real time information about how the PC is being used, for example how often is actually used, applications running, and bandwidth usage. The data to be recorded is as follows:

- Keyboard and mouse activity. A 1 is stored if there is input, otherwise a 0 is stored. We would like to know actual time that the PC is used as a fraction of the time it was kept in an On state.
- Current network bandwidth usage.
- List of processes running. We store a short list of processes ordered by amount of CPU used. This information could be later crossed with keyboard and mouse activity to detect idle periods during which certain programs could be using CPU time without user interaction.
- PC Energy State: This is state is not recorded directly but it can be calculated in the server by comparing timestamps of previous logs of user activity.

The variables listed above are retrieved at the same time but this could be tuned according to the needs.

3.2 Web Server

The main purpose of the web server is to act as bridge between the manager and the managed PC itself. It can be considered as a proxy of the commands the manager will send to the computers. The list of tasks to complete is the following:

- Store usage and profile information from each monitored computer.
- Send Hibernate, Sleep or Turn-off commands on behalf of the user to one or more computers
- Serve as web platform for managing application.

The information is stored in a database and the communication is achieved through web services. The reason for choosing web services is that it does not depend on open ports in the server and the computer. The server could be running inside of the company or in the Internet. Every time the computer needs to upload information, it will call a method in the web service. There is a method for creating a new entry (associating a computer to a user in the database) and another method for inserting collected usage data as often as needed.

The commands from the server to the computers can be sent as responses to the web services requests from the computers. The information uploaded from the computers needs no response from the server. If the user needs to send a command to the computer, the web server will get the command and wait for the next upload from the computer. Because the updates are done often, no more than a minute should pass before the PC receives the command. At this time, the server will respond with the command sent from the user. The computer then will interpret it and execute the necessary steps to go to the

requested energy state. Commands can also be sent automatically whenever an energy saving policy is activated.

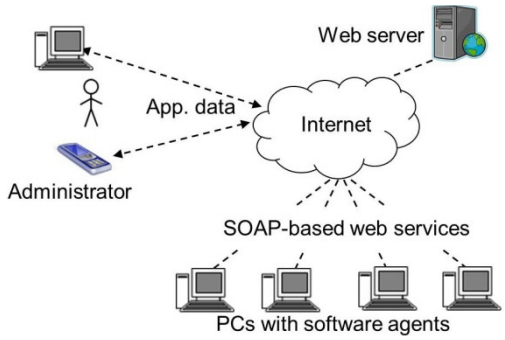


Figure 2: Architecture while used by an administrator.

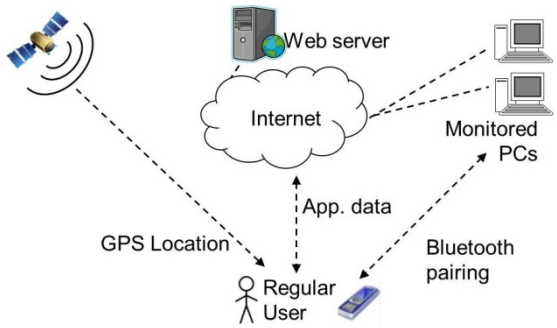


Figure 3: Architecture while used by a regular user.

3.3 Administrator Software

This part of the architecture gives control to the user. It has the expected functionality of showing reports about the different monitored variables in the managed computers. The most important function is to actually control the energy consumption of computers, either automatically or by manually sending the command.

- Automatic control of energy consumption: The localization of the user is used to guarantee that the managed PC will be put in an energy saving state if the user is not close to the computer anymore. The mechanism used will be explained in more details later in the paper.
- Manual control of energy consumption: The user has a choice of disabling the automatic control and turning off the computer whenever it considers necessary.

It makes more sense to be used in a mobile phone, to give more freedom to the user. If the functionalities are accessed through a website in the server, the automatic control is not used. In this case, just the manual control would be of use.

3.4 User Specific Features

Figures 2 and 3 both show the two different scenarios: Figure 2 explains the communication between a group of PCs being managed and the IT staff in charge, and Figure 3 shows a single PC being managed by its owner or user. An administrator might use its mobile application to mostly get almost real time power consumption from the monitored computers. It could also put PCs to sleep if no user input is detected after a long period of time. It is assumed in this case that the computers are not monitored at the same time by its users. In the case of a PC monitored by its user, the options in the mobile application allow it to either manually or automatically save energy by putting its computer to sleep. To calculate power consumption, the IT staff would only need to measure power consumption levels of monitored computers and use the values for the different periods recorded.

4 ENERGY SAVING POLICIES

The proposed architecture is complemented with two energy saving policies. We will calculate later in this paper how their implementation could benefit savings in an office environment.

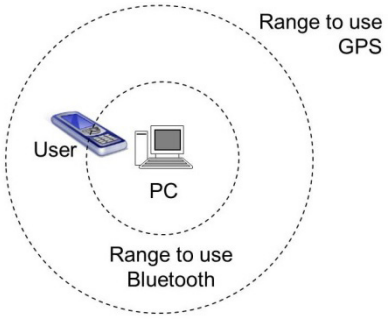
4.1 Location-based Dynamic Energy Saving Policy

With the information gathered from the mobile phone, we tried an approach to save more energy given the current position from the final user. The purpose of the policy is put the PC to sleep when the person goes away from the computer and wake it up if the user is close enough. The novelty of this mechanism relies on that we didn't need extra hardware to apply it. It can be assumed that the monitored PCs have Bluetooth interfaces. We explain now how the PC is associated with the user.

4.1.1 PC-user Binding and Location

The software agent in the computer has an option in the menu where you can register the computer in the server's database. With this, the MAC address of the computer is bound to the user's ID. The user can register as many computers as he/she wants. The same computer can be registered with a new user, but this will erase the previous registration, meaning a computer can be associated with only one person. The software in the phone has also an option to

register the location of the monitored computer. The user and its phone need to be in front of the computer to register its location. It is assumed that the GPS mechanism used by the phone would be able to find an approximate location for the computer the user wants to register. This means that the office should be relatively close to a window for the phone to be able to calculate its position.



1) Start with Bluetooth if possible
2) If connection lost, switch to GPS
3) Use GPS when away. If Bluetooth available, switch

Figure 4: Location mechanism to wake or put PC to sleep.

Once the computer has been associated to a user and its approximate location has been registered, the user can later use this information to turn the computer On or Off automatically. The mechanism to do this is now improved with the use of Bluetooth besides the use of GPS and is shown in Figure 4. We can merge both technologies to improve reliability of the proximity measure. GPS is used to determine initial approximate distance. If the distance is shorter than a threshold, the application will use Bluetooth instead to check if the person is within a reachable distance from the computer. The system requirements are the following:

- The monitored computer will not move from the position it was at when it was associated with the user. If it needs to be moved, the user will have to update its position.
- The phone needs to have Bluetooth activated and the application constantly running in the background to detect if it is close to the computer.
- The computer needs to have a built in Bluetooth receiver.

If the Bluetooth is Off in the phone, there is no way to associate the user's current position with the computer's energy state. The user can still manually send a power management command to the computer. The following steps are used to determine if the user is close to its registered computer:

1. Determine user location using GPS and compare it with the position saved in the server for the monitored computer.
2. If the computer is closer than a threshold then activate Bluetooth to improve accuracy.
3. Activate location algorithm and determine if user passes threshold to suspend/start computer.

4.1.2 PC Sleeping Command

We designed two ways in which the PC can be put to sleep:

- Automatic message delivery: When the mobile application detects that the computer is beyond a threshold distance, it will send a command to the web server, which will forward the message to the computer the next time it is contacted.
- Manual message delivery: The user has an option in the mobile application to put the PC to sleep when it desires. This can be used in case the automatic message delivery didn´t work. It can also be used when the Bluetooth is disabled either at the phone or at the PC.

The manual delivery of the message is more intended for an administrator that could send the command to all the computers left On after work time.

4.1.3 Pc Wake-up Command

The PC Wake-up mechanism was designed but not implemented in our prototype. The ideal scenario would be that where the server and the computers are on the same network. In companies networks this is usually not possible due to security restrictions and the size of the network itself. Taking this into account we designed the mechanism with 2 approaches:

1. Using a Magic Packet sent from a Proxy Software Agent located in the same network of the monitored PCs.
2. Using the same Bluetooth interface used for calculating actual location of the user.

The Magic Packet mechanism is the most reliable but implies using a PC in the same network that is guaranteed to be On all the time, so that it can be used anytime to wake up its fellow computers. The design for this mechanism has the following requirements:

- The PC needs to be in the same network than the Proxy in charge of waking it up.
- The PC needs a Network Interface Card (NIC) with the Wake On Lan (WoL) option available

and enabled.

The mechanism that uses Bluetooth to wake up the PC needs this option to be available and enabled in the motherboard. This is not as common as the WoL option which has been available in motherboards for many years already.

4.2 Static Energy Saving Policy

The second energy saving policy is a static policy which works by putting the PCs to sleep after the idle time reaches a desired threshold. It is static because the administrator can set the threshold beforehand and all the computers should go to sleep after that threshold is reached, no matter what. Although PCs already have energy management options like this available, they are many times not enabled, and cannot be monitored or modified easily by administrators.

Our architecture leaves the opportunity of using the cellphone or not. With the phone there is potential for more savings because a dynamic policy could be fed with the information received from the phone. However, a static policy can still be applied if no phone is available.

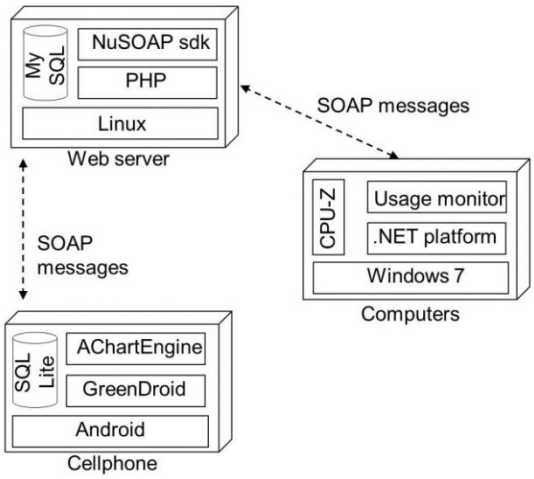


Figure 5: Implementation of the architecture.

This policy could take into account the user's perspective about what could be annoying or not. For this purpose we interviewed 23 users to determine what could be an accepted period after which the PC could go to sleep without causing annoyance. Table 1 shows the results. We selected those intervals to compare them with typical idle periods for computer usage. We will see in the Evaluation section what we observed about the user behavior. We used the 30 minutes limit because it can be considered that after that, the person might be away from his/her desk for a long period, e.g. taking lunch. However, in this case, the architecture could learn from each user's behavior and improve savings. For example, at about 12:00 pm this person usually takes lunch, and it might not be necessary to wait for 30 minutes because chances are, the person will leave for 1 hour.

Table 1: Respondents for each time interval in minutes.

1-5	6-10	11-15	16-20	21-25	26-30	31-more
6	2	5	2	0	1	7

We can see from this, that about 30% of the users prefer the computer to remain On for at least 30 minutes. This is probably due to the annoyance caused by the resume times from the operating system (Mostly Windows 7 in our campus). It is also interesting to see that about 25% of the users are fine if the computer goes to sleep quickly (less than 5 minutes). We consider that those users are the ones with the highest level of consciousness about their impact to the energy consumption of the company. We are running a long version of this interview to detect how user's perspective about energy consumption affects the final time spent using the computer. Although this is not a conclusive finding, we will use this empiric result to determine when we could put the PCs to sleep with the least amount of annoyance to the user.

5 IMPLEMENTATION AND EVALUATION

5.1 Implementation

Figure 5 shows the three parts of the architecture as we implemented them. The parts are the following:

- Cellphone: The application is designed for Android smart-phones. The code contains about 1000 lines.
- Server Application: it is responsible for receiving the information that the mobile application or desktop application send. The server has a web service that is called by the PC application. The service receives usage information to be stored in the database. The server is also in charge of sending Sleep commands and eventually the Wake-up commands. The code contains about 500 lines.
- PC Application: The desktop application (software agents) runs under Windows operating system and it was developed using C#. It has a

computer usage collection component, a data upload component and a power status command component. The usage collection relies on a simple C program called IdleCollect, developed by Professor Ken Christensen from USF. It outputs keyboard and mouse usage every minute. The data is uploaded every hour to the server. The power status command component applies the Sleep command received from the server. The code contains about 1000 lines.

- DataSet: A table stores PC usage information represented in one record per minute containing PC usage state (0, 1, or 2 if the PC was used, not used, or suspended/hibernated), a timestamp, and the identification of the user that owns the PC. Another table identifies the user with IP, MAC, and PC hardware information.

5.2 Evaluation

We ran a study with a group of employees from our university campus. We installed the software agent in their PCs to measure computer usage activity.

We picked for the study users with different job functions looking for different computer usage behavior. In this way we obtained valuable information such as how many hours was the computer Off and On during the day, and were able to corroborate expected behavior. We collected usage information from professors, administrative staff, research assistants, and secretaries. The study ran during 2 months in the summer period, thus some users were not so strict with their arrival to the office when compared to the other periods of the year. We also experienced some issues with the software agents in the computers, especially because of security restrictions from the antivirus.

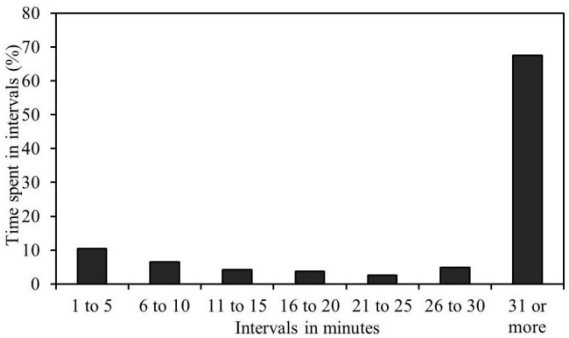


Figure 6: Time spent in idle periods for all users.

We were first interested in checking how the idle periods distribute among the intervals we created before. We can use that to apply energy saving policies for certain intervals. With the study, we were also interested in checking how much idle periods represent when compared to actual busy times for the computers. Another important task was to observe if there was any difference in computer usage between weekdays. This could be used to establish energy saving policies that could be customized for weekdays.

5.3 Results

Figure 6 shows the percentage of idle time distributed in each of the idle periods for all the 12 users for which we collected computer usage information. We divided the idle time in intervals, which could be used to determine the energy saving policies to be applied to different intervals. We could apply a Sleep policy to the computers when their idle time reaches a threshold interval. The last interval holds all the minutes spent in periods of 31 minutes or longer. It means then that the majority of the idle time is spent in long periods. The largest amount of idle periods might be in the left part of the figure, but the total amount of time spent there is less at the end.

We calculated for 3 users the percentage of idle time spent during each day for a period of 3 weeks. Each idle time was the summation of all the short periods spent in all the idle periods' intervals. The averages ranged from 30% to 60%, which means for example that at a peak point, 60% of the On time was wasted. We picked the 3 users with the largest amount of data. We can however not conclude from our data about the influence of the weekday in the average idle time for the computers.

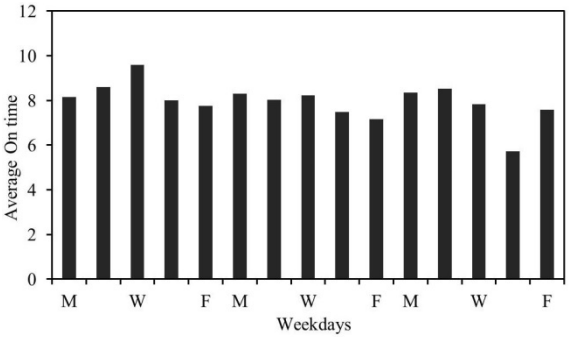


Figure 7: Average On time during weekdays.

Figure 7 shows the On time for the same 3 users during the same 3 weeks period. You can see from the figure that the average behavior from the monitored users looks like what we expected: a working day ranging from 7 to 10 hours. We will

use this information later to simulate for the whole campus the potential energy savings.

5.4 Potential Energy Savings and Discussion

With the previous observations, we gathered enough information to estimate how much energy could be saved in our university campus if policies such as the explained here were put into practice. We are using for this the following inventory of computers in our campus:

Table 2: Inventory of computers in our campus.

Location	Desktops	Laptops
Offices	1766	605
Labs	400	0
PC Rooms	300	0
Total	2466	605

Now, we will use a conservative power consumption of 80 Watts per desktop PC. For this we measured one of the HP typical desktop used in our campus and ranged between 50W and 60W when On, plus 20W for the screen. We use an average of 8 hours per day to calculate a yearly power consumption of 166 kWh per desktop PC. We have to warn here that usually related work calculate power consumption assuming PCs are left On 24 hours during the whole year. And savings are compared to that amount. We assume that at least most of the PCs are turned Off during nights and weekends. When we consider only the desktops in the offices and labs (2,166), we have a yearly power consumption of 360 MW for all the campus. We picked only offices and labs because users should have a similar behavior, i.e. users following some sort of working schedule. However, users in computer labs (PC Rooms) circulate often, meaning different people might use the same computer and there is no fixed schedule. Costs for kWh for the industry worldwide might vary. We will use US value of $10 cents per kWh.

Now, using the results about idle periods we can apply the two energy saving policies proposed and typical ones in the following way:

- Dynamic: put the PC to sleep when user is far from the computer, assumed to be after 30 minutes.
- Static: put the PC to sleep after a threshold, of 15 minutes.
- Traditional: Putting all PCs to sleep only after working hours (8 hours according to our study).
- No Policy: No monitoring at all, which implies some PCs might remain On during the night. It is assumed that about 10% of the PCs are left On and the rest are turned Off.

Table 3 shows yearly power consumption for the computers in our campus, and how much savings we could get when compared to regular scheduling. We made a conservative calculation of yearly savings for a company the size of our university. The most beneficial is the static policy so far. However the one with more potential is the dynamic, because it can be further be adapted more aggressively to the user behavior by applying different techniques. We plan in the future to run experiments with such techniques and explore the potential benefits of the dynamic policy. These savings could be improved if factors like the following are taken into account:

- If employees are educated about energy efficiency, their habits might change or at least they might be more open to accept aggressive energy saving policies.
- Policies could be also implemented in other types of devices like office lights.

Table 3: Power consumption and savings for energy saving policies.

	Energy saving policies			
	Dynamic	Static	Usual	No Policy
Yearly Power (MW)	262	247	360	476
Savings	28%	32%	0%	-32%
Yearly Savings	$9,803	$11,390	$0	-

6 CONCLUSIONS

We built an architecture that can be used to detect computer user behavior in a company campus with energy savings in mind. The purpose of our proposal is to adapt energy saving policies to how the computers are actually being used and not just apply computer shutdowns in fixed schedules. Results showed that we can achieve important savings and we consider that our proposal can be easily applied in any company campus.

There might be some concerns that we think our architecture handles but we can check in the future improved versions to handle the following problems better:

- Privacy of user location: the current location of the user is never stored in the server, only the location of its PC. The cellphone will get the PCs location from the server and compare it every time with its own location, without sending it to

server.

- Annoyance of being managed by someone else. This scenario applies to office environment, where usually IT department decides over each user's computer. There is still no personal information stored. In a home scenario, the administrator is the same user, so there is no privacy concern.
- Annoyance of automatically putting PCs to sleep. With the information gathered from the user, we could realize if the user is for example downloading something through the night. This will prevent the PC from being put to sleep. An option in the software interface could be put to allow the user to disable automatic energy state switches if desired.

We will conduct short interviews with computer users to acquire more knowledge about how users behave. This could help us understand how to they conceive power consumption of the devices they are using and how can we apply more efficiently energy saving policies in computers and electronic devices in general in a company campus. We would like to explore implementation alternatives in the phone that would alleviate its power consumption without decreasing energy savings.

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Energy Consumption Model and Charging Station Placement for Electric Vehicles

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Keywords: Electric Vehicle(EV), Energy Consumption Model, Charging Station Placement, Reachable Range Estimation, Energy Constraint, Google Maps Api.

Abstract: A detailed energy consumption model is introduced for electric vehicles (EVs), that takes into account all tractive effort components, regenerative braking, and parasitic power users. Based on this model a software tool for EV reachable range estimation (EVRE) is developed and implemented. This software tool uses real driving distances and elevation data from Google Maps and can therefore much more accurate predict the reachable range of a given EV than the typical Euclidean distance models. Furthermore, an optimization model for the placement of charging stations to maximize the number of reachable households under energy constraints is established using EVRE. These results are illustrated by a number of examples involving the cities of New York City, Boulder Colorado, and South Bend, Indiana. The developed methodology can easily incorporate additional constraints such as popular destinations, preferred parking, driver habits, available power infrastructure, etc. to initially reduce the search space for optimal charging station placement.

1 INTRODUCTION

Advances in battery technology have already put a significant number of electric vehicles on the road (Dickerman and Harrison, 2010). Innovative technologies to reduce manufacturing costs and increase battery capacity are needed to make such vehicles more appealing to the public. Allowing EV users to reach charging stations conveniently is crucial for the popularization of electric vehicles.

For accurately predicting and simulating vehicle range, an accurate energy consumption model based on the tractive effort is needed. Simplified EV power train models were developed for new and existing production vehicles(Hayes et al., 2011). An energy usage model based on tractive effort has been constructed for electrically powered utility vehicles traveling a route with significant elevation variations(Prins et al., 2012). In our energy consumption model, a more detailed tractive effort model is provided. The driving distances and elevation data for routes on Google Maps are used in an infrastructure model for increased accuracy.

The problem of charging station placement has been investigated by many researchers. A maximal coverage model to optimize the demand covered within an acceptable level of service has been investigated in (Frade et al., 2011). An optimization model was developed to maximize total fleet-wide charging levels for the location of a public EV charging infrastructure (Xi et al., 2013). In (Ge et al., 2011), a grid partition method has been investigated for locating, sizing and service area division of the charging stations. A two-step clustering process was proposed in (Ip et al., 2010) for optimizing the allocation of fast charging stations. A coordinated clustering algorithms was programmed for mapping the charging infrastructures in (Momtazpour et al., 2012). (Andrews et al., 2013) studied how EV would perform in meeting the driving needs of vehicle owners and then proposed an optimization model based on a user charging model to find locations for charging stations. In (Lam et al., 2013), the electric vehicle charging station placement problem was formulated to minimize the total construction cost subject to the constraints for the charging station coverage and the convenience of the drivers for EV charging. The NP-hardness property of the problem was studied and an efficient greedy algorithm to tackle this problem was proposed. In (Wang et al., 2013) a location model of charging stations is established based on electricity consumption along the roads among cities. Furthermore a quantitative model of charging stations was presented based on the conversion of oil sales

in a certain area. Driving patterns have been widely used to optimize the charging station placement. An agent-based decision support system was presented for identifying patterns in residential EV ownership and driving activities to enable strategic deployment of new charging infrastructure(Sweda and Klabjan, 2011). An improved charging station location solution was developed by providing behavioral models to predict when and where vehicles are likely to be parked (Chen et al., 2013). An optimization model based on driving patterns was proposed to find locations for charging stations needed to support EV usage (John et al.,). Another important method is based on the Voronoi diagram. In(Koyanagi and Yokoyama, 2010) and (Koyanagi et al., 2001), the candidates of charging facilities for EVs were analyzed by using Voronoi diagrams for the equilibrium arrangement in Musashino city. In (Feng et al., 2012), a weighted Voronoi diagram was used for the research of locating, sizing and service area division of the charging stations. The problem with Voronoi diagrams is that Euclidean distance is used instead of the real driving distance.

The placement of charging stations can be approached from a number of different angles, that may for example include the energy deficit of EVs, the available power infrastructure, popular parking locations and stay times, minimizing overall energy, minimizing congestion, etc. We address the problem of optimal charging station placement from the viewpoint of reaching the most customers or households, i.e. something a private charging station owner would typically consider. On the other hand, this problem is also of interest for municipalities, power companies, and federal agencies such as the environmental protection agency and the department of transportation. The developed concept can easily be used in conjunction with the other above mentioned criteria, if the placement methods based on these criteria can narrow down the number of possible locations for charging station placement a priori. Therefore, these criteria would be used in form of location constraints. In this paper, the optimization problem for charging station placement is investigated based on an EV energy consumption model including driving distance and elevation. Given an energy bound, the corresponding reachable contures in Google Maps for different possible charging station centers are determined. Maximizing the number of households in this range is discussed subsequently.

This paper is organized as follows. In Section 2, the energy model for EVs is presented. In Section 3, an optimization model for charging station placement is provided. The simulation results are discussed in Section 4. Conclusions are provided in Section 5.

2 ENERGY MODELS FOR ELECTRIC VEHICLES

In this section we will introduce a detailed energy consumption model that has two main components: a tractive effort model with air drag, rolling resistance, acceleration, and hill climbing components, and a lumped loss model for the mechanical and electric powertrain, that is described by individual efficiencies of powertrain components. Together, both components provide a fairly accurate description of the energy usage of an EV in almost any driving situation.

The air drag power component is modeled by:

$$P_{air}(t) = \frac{1}{2}\rho C_d A(\frac{ds(t)}{dt})^3 \tag{1}$$

where A is frontal cross sectional area, ρ the density of air, C_d is the drag coefficient, $s(t)$ is the driving distance, $\frac{ds(t)}{dt}$ is the corresponding velocity at time t.

The rolling resistance power component is modeled by:

$$P_{roll}(t) = f_r M g \frac{ds(t)}{dt} \tag{2}$$

where f_r is the coefficient of rolling resistance, M is the mass of the EV, g is the gravitational acceleration, which is 9.81 m/s^2.

The hill climbing power component is given by:

$$P_{hill}(t) = Mg\frac{dh(t)}{dt} \tag{3}$$

where $h(t)$ is the elevation at t, $\frac{dh(t)}{dt}$ is the vertical velocity component.

The acceleration power component is given by:

$$P_{ac}(t) = M\frac{d^2s(t)}{dt^2}\frac{ds(t)}{dt} \tag{4}$$

where $\frac{d^2s(t)}{dt^2}$ is the acceleration at time t.

The efficiencies of battery, power converter, e-motor controller, e-motor and mechanical powertrain are denoted by η_{bat}, η_{conv}, η_{contr}, η_m, η_{mp} respectively.

Therefore, the overall propulsion power balance equation can be written as:

$$\begin{aligned} &P_{bat}(t)\eta_{bat}\eta_{conv}\eta_{contr}\eta_m\eta_{mp} \\ &= P_{air}(t) + P_{roll}(t) + P_{hill}(t) + P_{ac}(t) \end{aligned} \tag{5}$$

Now denoting parasitic power losses at the battery (lights, heater, stereo, etc.) as P_{para}, we obtain:

$$\begin{aligned}&(P_{bat}(t)-P_{para}(t))\eta_{bat}\eta_{conv}\eta_{contr}\eta_m\eta_{mp}\\&=P_{air}(t)+P_{roll}(t)+P_{hill}(t)+P_{ac}(t)\end{aligned} \quad (6)$$

In the case of regenerative braking we need to reverse the powerflow and hence use the following modification of the above equation:

$$\begin{aligned}&P_{bat}(t)-P_{para}(t)\\&=(P_{air}(t)+P_{roll}(t)+P_{hill}(t)+P_{ac}(t))\eta_{bat}\eta_{conv}\eta_{contr}\eta_m\eta_{mp}\end{aligned} \quad (7)$$

with η_{bat}, η_{conv}, η_{contr}, η_m, η_{mp} being the efficiencies of the respective components for reversed powerflow.

3 OPTIMIZATION FOR CHARGING STATION PLACEMENT

The optimal placement of charging stations has been intensely researched and many methods have been developed((Xi et al., 2013),(Chen et al., 2013),(Feng et al., 2012),(Frade et al., 2011),(Sweda and Klabjan, 2011),(Koyanagi and Yokoyama, 2010)). This method is based on the energy consumption model of electric vehicles. We focus on maximizing the reachable households with a given battery energy bound. Given this constraint, the reachable range can be derived on Google Maps. To get the amount of covered population in the reachable range, the population distribution for the considered area must be known. A reasonable way is to divide the city by ZIP code zones and then use the population in each ZIP code area.

Suppose there are N possible positions $X=\{x_1,\ldots,x_N\}$ for charging station placement. There are M ZIP code zones $Y=\{y_1,\ldots,y_M\}$. The model for a ZIP code zone is $y_j=(ycp_j,ypop_j)$, where ycp_j is the center position of y_j and $ypop_j$ is the population number of y_j. For each possible position x_i, function $Range(x_i,E_{bound})$ is used to get its reachable range R_i, where E_{bound} is the energy bound constraint. This range can be obtained by the software tool EVRE, which is implemented based on Google Maps Javascript API. Define $Z_{ik}=(Zpos_{ik},Zpop_{ik})$ as the kth ZIP code zone covered by range R_i, where $Zpos_{ik}$ is the center position and $Zpop_{ik}$ is the population number. Then we can get the following optimization model for maximizing reachable households.

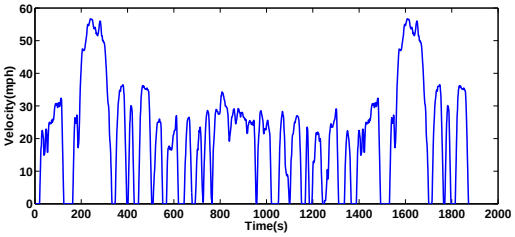


Figure 1: FTP-75 Driving Cycle.

$$\begin{aligned}\underset{Z_i}{\text{Maximize}}\quad&\sum_k Zpop_{ik}\\\text{subject to}\quad&x_i\in X=\{x_1,\ldots,x_N\}\\&y_j\in Y=\{y_1,\ldots,y_M\}\\&R_i=Range(x_i,\,E_{bound})\\&Z_i=\{Z_{ik}|Z_{ik}\in Y\ and\ Zpos_{ik}\in R_i\}\\&i=1,\ldots,N;\ j=1,\ldots,M;\ 1\le k\le M\end{aligned} \quad (8)$$

Model (8) is easy to implement, but only the center position is used to represent the whole ZIP code zone, which may cause errors when the center lies near the boundary of the range. To obtain a more accurate, implementable and computable optimization model, each ZIP code zone can be further divided into subareas.

4 SIMULATION RESULTS

4.1 Reachable Range Estimation

The electric vehicle reachable range estimation(EVRE) software tool is implemented based on the Google Maps API (Google,) by applying the energy model we constructed.

To estimate the reachable range, the driving distance, elevation data and velocity information are needed. The driving distance and elevation data along the route between two positions on Google Maps can be obtained directly using the corresponding APIs. FTP-75 driving cycle in Figure 1 is used to mimic the driving velocity for EVs in the urban area, which are a series of tests defined by the US Environmental Protection Agency (EPA). It consists of starting with a cold engine and making 23 stops over a period of 31 minutes for an average speed of 20 mph and with a top speed of 56 mph. The average velocity derived from the driving distance and duration information is used for the suburban area. With this data, the energy consumption can be calculated by applying the energy model.

Given the energy constraint, the reachable range is represented by a polygon and a breadth-first search

method is used to estimate it by determining its vertices. In each search step, a set of positions on one circle serves as the possible origins and the charging station position is the destination. Each pair (origin and destination) has its corresponding energy consumption value. Comparing them with the energy constraint is done to judge whether these positions can be the vertices of the reachable range polygon. Different radii of the circles for these possible positions are used in different steps. Once all the vertices are found, the searching process is complete and the reachable range is determined.

Tesla Model S is selected as the electric vehicle prototype. Its mass is 2108 kg, frontal area is 2 m^2, drag coefficient is 0.24, rolling resistance coefficient is 0.01, battery capacity is 85 kWh and nominal range is 265 mile.

Boulder, Co and New York City are selected as the example areas. These two cities have different terrains. Boulder is a small city with many mountains on the westside with drastic elevation changes. New York City is a metropolis with a complicated street system and less elevation changes. Since our model considers the real driving distance and elevation, the reachable range is expected to be totally different.

Given the battery energy bound 2 kWh, the reachable range (charging station is marked as the center and serves as destination) in Figure 2 is derived using EVRE. Both of the ranges are unsymmetric, because different driving directions have different routes and elevation in both cities. Figure 2 shows that the reachable range in Boulder is much larger than in New York City. There are at least two reasons for it. First, the driving direction is from positions outside of the city center. In Boulder, there are many downhill routes, which casuses the EVs to have a larger driving range, because the EV's regenerative braking plays a dominant roll. While in New York City, there is less potential energy reused with little elevation change. Second, New York City's complicated street system makes the EV's velocity more like the FTP-75 cycle. There are many accelerations and decelerations, which will be a large energy cost. Hence, under the same energy bound constraint, the reachable range in New York is much smaller than in Boulder.

Figure 2 also shows the comparison results with the Euclidean model. The Euclidean model is typically calculated using the following method.

$$\frac{Range}{Capacity} = \frac{265mile}{85kWh} = 3.12mile/kWh$$

Two concentric circles are set in Fig. 2, one with radius 3.12 miles, the other with radius 6.24 miles for a energy bound of 2 kWh. The reachable range

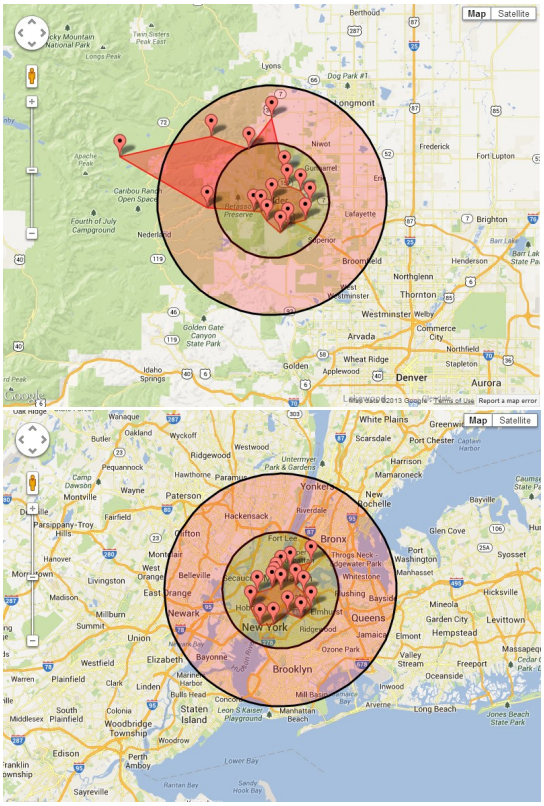


Figure 2: Top:Reachable range estimation(2kWh)in Boulder Bottom:Reachable range estimation(2kWh)in New York.

derived from EVRE is significantly different from the range created by the Euclidean model. Because driving distance and elevation data are considered, our model and software can provide a more accurate range for EVs than the Euclidean model.

The intersection area is shown in Figure 3, the red coverage is obtained by traveling from the suburban area to the charging station center in the city; the blue coverage is obtained by traveling in the opposite direction. The elevation is changed when the route direction is reversed, which makes the energy consumption unsymmetric with regard to direction, especially in Boulder. There are many other factors that change, for example, the route choice(there are many one-ways in New York.) Hence we can get two different coverage areas. From Figure 3, we can see that the difference in Boulder is much larger than that in New York. This shows the elevation change is responsible for the energy consumption difference when reversing the driving direction. The intersection for these two coverage areas is where EVs can commute between its position and the charging station by using up to 2 kWh energy. The intersection area should be the real coverage range for the corresponding charging station

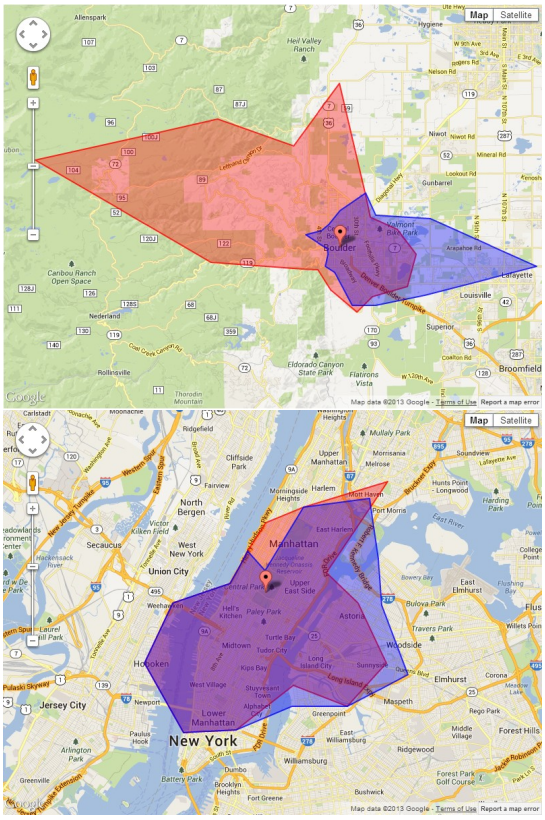


Figure 3: Top:Intersection Area in Boulder(2kWh) Bottom: Intersection Area in New York(2kWh).

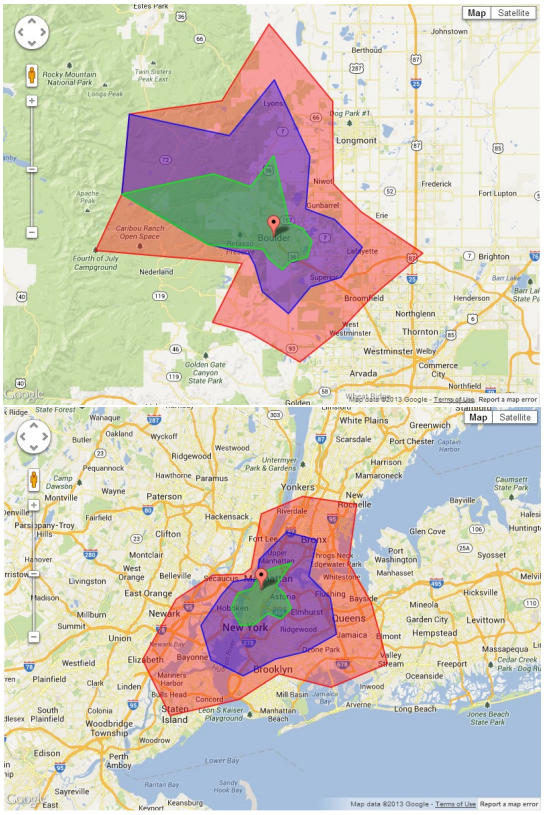


Figure 4: Top: Energy radius in Boulder, Bottom: Energy radius in New York (Green: 2kWh, Blue: 3kWh, Red: 4kWh).

considered by the EV owner.

Figure 4 shows the results with different energy radii for these two cities. Each coverage area represents a reachable range with the given amount of energy. Three kinds of energy radii are considered: 2 kWh, 3 kWh and 4 kWh. Figure 4 shows that these coverage areas are no longer concentric circles, they become irregular and the resulting polygons are not similar for the different energy levels.

4.2 Charging Station Placement for South Bend

South Bend, IN, a midsize city in the US, is selected as a showcase area. As stated in the optimization model (8) , to model the population distribution, the area can be divided according to ZIP codes. There are 13 ZIP codes in South Bend area, which means $M = 13$. Table 1 includes the ZIP codes and their corresponding population information. For possible charging station positions, five possible places are selected as examples, which means $N = 5$. They are listed in Table 2. We need to choose one for these five possible positions to maximize the reachable population.

Table 1: Population Distribution in South Bend.

Y	ZIP Code	Population
y_1	46544	30695
y_2	46545	28445
y_3	46556	7424
y_4	46601	8460
y_5	46613	11526
y_6	46614	27041
y_7	46615	16905
y_8	46616	6431
y_9	46617	11644
y_{10}	46619	22489
y_{11}	46628	25319
y_{12}	46635	4172
y_{13}	46637	13829

With these ZIP codes and their population information, EVRE is used to calculate the covered population for each possible position. The energy bound E_{bound} for the reachable range is 2 kWh. Figure 5 shows the coverage of two possible charging station positions, one is the Century Center and the other is

Table 2: Charging Station Placement in South Bend.

X	Possible Position	Covered Population
x_1	Century Center	187719
x_2	University of Notre Dame	97310
x_3	McKinley Town Center	125702
x_4	University Park Mall	62434
x_5	South Bend Airport	74225

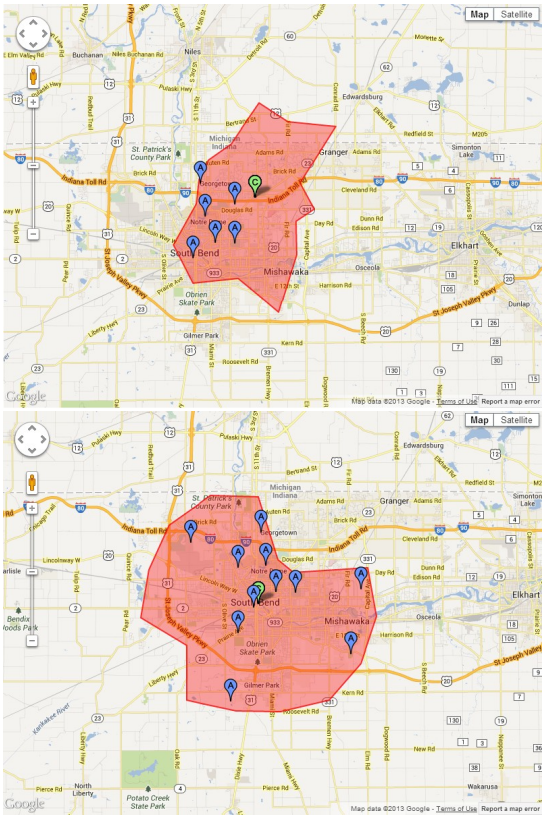


Figure 5: Coverage Range in South Bend, IN. Top: University Park Mall, Bottom: Century Center

the University Park Mall. The Blue markers are the centers of the covered ZIP code zones, and the green markers are the charging station positions. From Figure 5, we can see that they have different reachable ranges and will cover different ZIP code zones. After we know the covered ZIP code zones, we can calculate the corresponding covered population. The covered population is listed in Table 2.

From the results in Table 2, we can see that Century Center has the largest covered population, which means that under this gain function and the 2 kWh battery energy bound constraint, it is the best position to place the charging station among these five possible positions.

5 CONCLUSION

In this paper, a detailed energy consumption model for EVs has been introduced. It includes a vehicle as well as an infrastructure model aided by Google Maps. The combination of these two models allows to predict vehicle driving range in any geographic location supported by google maps. A software tool (EVRE) was developed that accurately predicts this driving range from a specified starting point or to a specified destination. In a second step, this software tool was used to solve the problem of optimally placing charging stations, with the goal to reach the maximum number of households. EVRE allows to solve this problem efficiently. In addition, the developed concept allows to perform other types of charging station optimizations and can take a number of practical constraints into account. In fact constraints such as power infrastucture, popular parking destinations, energy constraints, etc. can easily be incorporated to narrow down the initial search space for candidate locations of charging stations.

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Energy Monitoring and Management Methodology for the Banking Sector

Portuguese Case Study

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Keywords: Energy Efficiency, Smart Buildings, Monitoring & Control.

Abstract: This paper addresses the problem of the worldwide electricity consumption increase, namely in the building sector, with the focus on the office (banking) market segment. Buildings are dynamic entities, with constantly changing needs and occupancy. An energy audit shows only a snapshot of the building profile because it is driven at a specific time, and utility bills can be viewed as "rear-view mirror" since they only show past consumptions and not real-time consumptions. In this way, this paper presents an energy monitoring and remote management methodology for the banking sector and the case study accomplished in one of the most well established Portuguese banks. The presented methodology reached measured annual savings of 18,5% of the total consumption of the 19 central buildings and the 358 branches involved in the project.

1 INTRODUCTION

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was an environmental treaty with the goal of preventing "dangerous" anthropogenic (i.e., human-induced) interference of the climate system. As part of the Kyoto Protocol, many developed countries agreed to legally binding limitations/reductions in their emissions of greenhouse gases (Walker et al., 2007).

Cities play a crucial role in sustainable development. According to the United Nations, global population will reach 9 billion in 2050, of which majority will live in cities. The majority of European cities have already been acting to increase their energy efficiency. Continuing improvements will require strong actions, in particular through improving the existing building stock.

According to IEA's World Energy Outlook 2008, 67% of global energy is used in urban areas, and cities are responsible for 76% of energy related CO2 emissions. Furthermore, cities play an essential part in sustainable development; with UN estimates of global population reaching 9 billion from 2050, of which the majority will live in urban areas. The majority of European cities have already been acting to raise their energy efficiency. Ongoing developments will require solid actions, in particular through tracking the current building stock (International Energy Agency, 2008).

According to Eurostat, the annual energy consumption in EU27 countries is about 3 400 TWh of electricity and 2 600 000 TJ of heat. Of these, about 25% of electricity and 10% of heat is consumed in the Commercial and Public Service sector, mostly in buildings (Eurostat, 2009). A saving potential estimated in nearly 28% of Europe's total energy consumption has been recognized as being accessible through increasing in energy efficiency (Eurostat, 2009). The European Union has specified that Public Building must lead the way in cultivating energy efficiency habits which have an unquestionable role in motivating savings.

Bank facilities – both buildings and branches – are nowadays subject to intense energy usage, because they operate many hours a day, and include an increasing number of equipment and systems. Bank branches can be responsible for up to 50% of total consumption in a retail bank since they are attended by multiple users, with different habits and customs, different terms of services in facilities and inefficient behaviors in energy usage users (characteristic user that don't pay the electricity bill) (Evo-world).

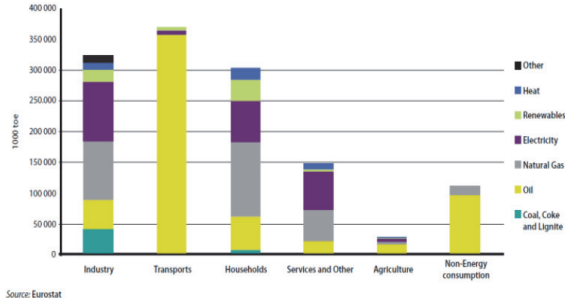


Figure 1: Europe's energy consumption by fuel and end-use sector (CEC, 2010).

Banks can seek in this reality an opportunity to reduce thei0r energy consumptions and respective costs. Advanced metering and management solutions can enable banks to identify energy, cost and carbon savings by providing detailed information about the way in which they use their energy.

In this way, and under a policy of continual sustainability, was designed a project and developed a real-time energy monitoring and management methodology for an international Portuguese bank, which covered 19 buildings and 358 selected branches in a total of 830 facilities. The main objectives were:

- Reduce energy consumption in office buildings and branches;
- Centralize the energy management information;
- Introduce and establish policies of energy consumption;
- Change employees behavior for proper use of energy resources at their disposal;

This paper will present in section 2, the global architecture, the energy monitoring and management solution developed for the banking sector. In section 3 will be presented the methodology of the project, following by the section 4 where will be presented the case study results, and finally in section 5 the main conclusions.

2 GLOBAL ARCHITECTURE

This section will show the global solution architecture, as well as, the main components that constitute, as can be seen in Figure 2 and 3. This solution methodology allows gathering detailed information, realize where energy is being consumed (remotely and in real time), and identify anomalous situations of energy consumption is shown in the figure below:

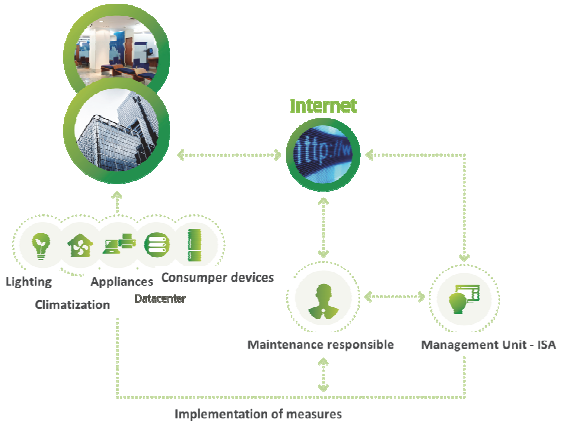


Figure 2: Scheme of the methodology implemented in the bank facilities, the flow of the information and the relation between the components

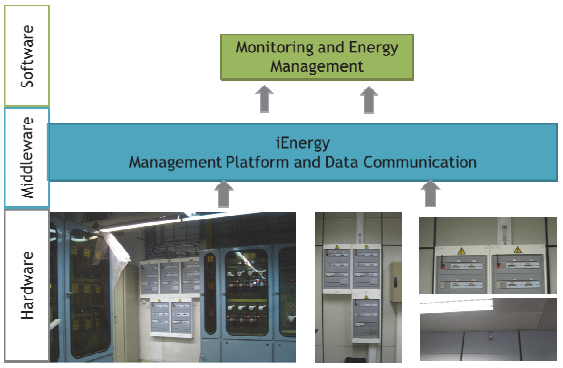


Figure 3: Global solution architecture.

The solution is divided in three main components: Hardware, Middleware and Software.

Hardware. The iHub is multifunctional data logger and gateway equipment used in energy monitoring and management solutions, which enables to collect data and remotely manage other equipment. One of the main advantages of this device is that it doesn't require permanent connection to the internet. The iHub has the ability to store collected data during a variable time period and send it to server when at programmed time frames our when network is available. This gateway receives data from two different protocols:

- RS 485 MHz (Modbus RTU) - from the iMeter Rail, which enables awareness in consumption, since it includes a LCD display providing the consumer with power status and the reading regarding specific circuits within an electrical switchboard. The single phase and three-phase mounted meters are integrated in a standard meter and are widely used in small enclosure and switch gears.

- RF 868 MHz – from the iPoint, a comfort sensor that measures different environmental variables, such as, temperature and relative humidity, and communicate using wireless technologies to the iHub.

Middleware. The middleware is a management and communication platform (iEnergy). iEnergy is a middleware platform that can be used to remotely monitor electrical consumptions. The platform is able to receive data readings from thousands of units of hardware placed in several different geographical locations. The kinds of readings that are received vary from device to device. For example in the case of electricity one could expect to receive readings regarding the energy consumed (kW) among others. iEnergy receives these data, stores it and processes it providing its clients with higher level analytics. Besides calculating and storing these analytics, the platform also provides a web interface that allows other systems to import these data into their domain.

Software. The end-user software, KiSense, is monitoring software for energy management, designed to help companies reduce energy consumption and associated costs. It consists of an integration platform for all energy consumption data, with a simple and intuitive interface. Accessible anywhere, KiSense supplies and analyses energy consumption, in real time, offering to end-users relevant information and knowledge for appropriate decision-making regarding energy consumption in the bank, in order to influence energy behaviour transformation.

Some of the main functionalities of KiSense are:

- Data explorer – Analyse and perform operation on energy consumption data, knowing when, how and where energy is consumed. It is possible to compare consumption of different areas and installations.
- Alarms – Define when and how to be warned of anomalous occurrences, such as excessive consumption, consumption out of defined timetable and consumption exceeding defined objectives.
- Events – Signal the key moments of energy consumption by scheduling relevant behaviours.
- Savings – Define saving goals and permanently keep up with its evolution, using alerts when they are not being achieved and it is possible to visualize the gains obtained through specific implemented measures.
- Reports – Obtain periodic reports for a better monitoring of energy consumption.
- Tariff rates - Analyses consumption patterns by periods of time and obtain fundamental data, in order to choose the best tariff plan, reports of consumption according to period of time.
- Control – Remotely control equipment and circuits, scheduling periods and parameters, switching on and off remotely.

3 METHODOLOGY

To meet the needs and challenges of the bank, it was developed an energy efficiency project focused on the architecture explained above which enabled the maintenance responsible of the bank to:

- Know when, where and how energy is consumed;
- Define KPI (Key Performance Indicators) regarding their business;
- Estimate energy costs;
- Analyse consumption values;
- Define measures and actions in order to achieve savings;
- Check the effects of implemented measures;
- Compare areas and facilities;
- Define alarm mechanisms for anomalous situations, excessive consumption or underachievement of reduction goals;
- Remotely control equipment (in real time or scheduled);
- Integrate systems installed in a single energy management platform (HVAC, GTC, BMS, etc.);

In this way the project was developed in six main stages:

1st Stage – Detailed specification of the EMS (Energy Management System)

2nd Stage - Installation of the monitoring and management solution

In this stage the monitoring and management solution was installed in all 19 office buildings and 358 selected branches. The solution was composed by:

Meters and sensors to monitor the energy consumption and environment parameters (temperature and humidity), with the capacity to control and actuate remotely over the equipment;

3rd Stage – Energy Auditing. In this stage an energy survey was executed for all office buildings and representative branches. The energy survey resulted

in audit reports, with conclusions to reduce energy consumption, carbon footprint and costs.

4th Stage – Design of the best practices guide and the communication program to the bank employees

5rd Stage – Energy Data analysis. In this stage, the data collected by the energy monitoring system were analyzed, in order to, identify opportunities for energy savings based on the electricity bill provided by EDP – Energias de Portugal.

6rd Stage – Energy Management. The implementation of the actions indicated in the audit reports were implemented, managed and supervised, and mensal reports of activities and energy savings and cost saving were delivered.

Besides that, training was given to the maintenance responsible of each building and branches, and a behavior campaign was created in order to promote energy behavior changing in each user of the building and branches.

4 RESULTS

Before the project and in order to define this baseline, the meter of the power distribution company was used as a start point. The use of this meter is a requirement of the IPMVP – EVO (International Performance Measurement and Verification Protocol), once in the reference period is the only existing meter (Evo-world).

The International Performance Measurement and Verification Protocol (IPMVP) is the widely referenced framework for measurement and verification (M&V). M&V activities include site surveys, energy metering, monitoring of independent variable(s), calculation, and reporting.

During the 5rd and 6rd stage of the project, it was possible to conclude that simple measures, such as, remote control in HVAC system allowed energy savings of 32% in this circuit, and approximately 7% in the total consumption. Measures related to good practices, energy behaviour, allowed to achieve average savings of around 15%.

The baseline of 2010 (year before the project), based on the energy bills, for the 345 branches, can be seen in Figure 4, and in central buildings, can be seen in Figure 5.

The total annual consumption of the branches of the bank in the year of 2012 was 17.325.406 kWh, with a total cost of 2.746.514 €. The average consumption per branches was 50.219 kWh with a cost of 0,16 €/kWh.

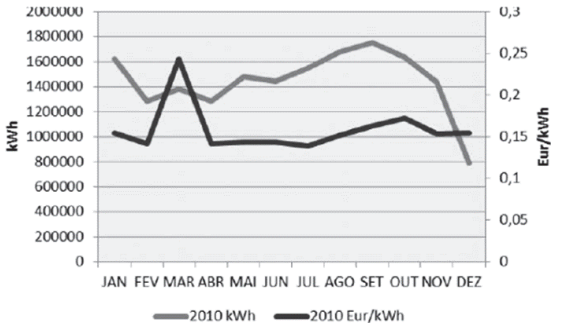


Figure 4: Energy consumption and energy cost – Branches.

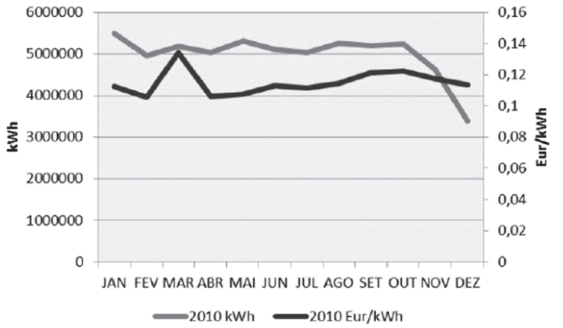


Figure 5: Energy consumption and energy cost – Central Buildings.

The total annual consumption of the central buildings of the bank in the year of 2010 was 59.794.853 kWh, with a total cost of 6.877.587 €. The average consumption per central building was 3.321.936 kWh with a cost of 0,11 €/kWh.

In the year of 2011, after the 3st stage of the project, it can be seen a reduction of the energy consumption equivalent to 26%:

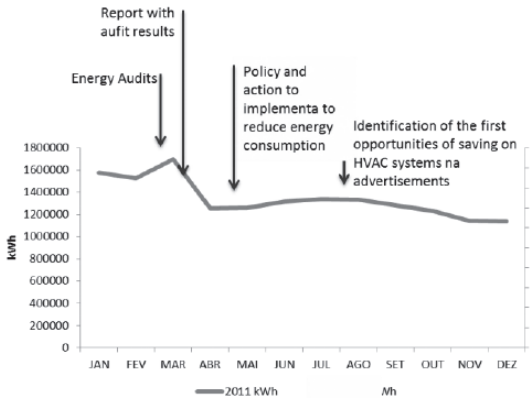


Figure 6: Energy consumption of branches in 2011.

The total annual consumption of the branches of the bank in the year of 2011 was 16.085.602 kWh, with a total cost of 2.643.174 €. The average

consumption per branches was 3.885kWh with a cost of 0,16€/kWh.

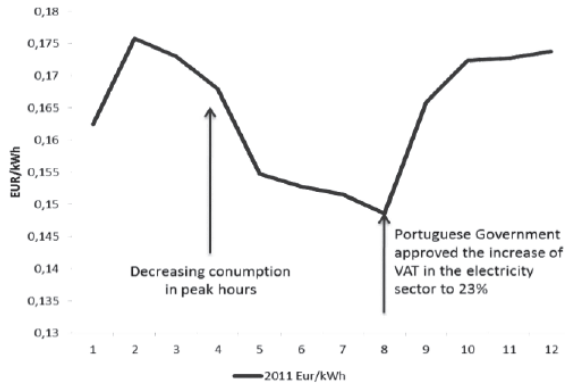


Figure 7: Cost of energy spent in branches in the year of 2011.

In the year of 2012 (until September) was clearly identified the consumption reduction, as can be seen below:

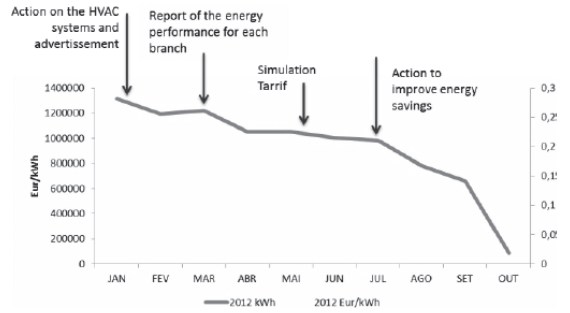


Figure 8: Energy consumption on branches in 2012 (until September).

The total annual consumption of the branches of the bank in the year of 2012 was 9.271.562 kWh, with a total cost of 1.939.632 €. The average consumption per branches was 2.986kWh with a cost of 0,18 €/kWh.

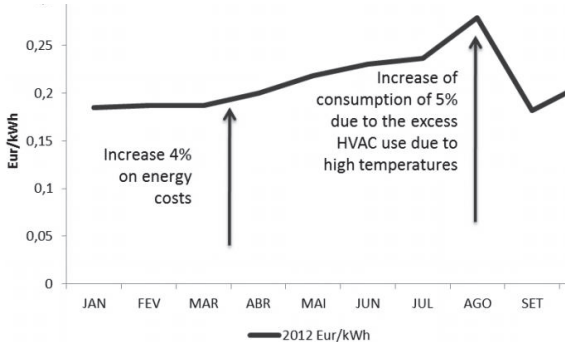


Figure 9: Cost of the electricity bill for branches in 2012.

At the end of March 2012 the Portuguese regulator for the energy services approved a gradual increase of 4% in costs with active energy consumption. This is the reason for the increasing average cost of the energy despite of the consumption reduction.

The Figure 10 represents the reduction on the energy consumption along the three-year project. Comparing 2010 to 2011 the energy saving was 1.239.804 kWh (7,16%) with a cost saving of 103.341 €, equivalent to 3,76%, including the increase of VAT on the electricity tariffs.

Comparing 2 years, from 2010 to 2012 the energy saving was 4.192.089 kWh (31%) with a cost saving of 183.062 €, equivalent to 8,6%, including the increase of VAT on the electricity tariffs.

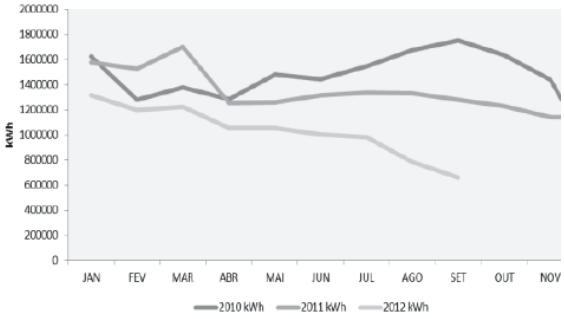


Figure 10: Energy consumption of the branches in 2010, 2011, 2012.

With the implementation of this solution it's possible to achieve direct benefits and indirect benefits.

The direct benefits are:

- Energy cost reduction;
- Central management of all facilities;
- Greater efficiency in management of maintenance equipment, and consequent increase of its lifetime;
- Definition of energy regulations, according to consumption profiles;
- Reinforcement of sectors sustainability policies along energy efficiently and carbon footprint reduction
- The indirect benefits are:
- Improved corporate image with stakeholders – corporate sustainability and eco brand;
- Improve working conditions for staff: air quality, lighting conditions, etc;
- Improve ecological awareness of staff.

5 CONCLUSIONS

Monitoring energy use can provide up-to-date information on energy use and carbon emissions so companies can identify energy conservation measures, adjusts usage quickly, and reallocate savings where needed. The solution for energy monitoring and remote management presented in this paper can monitor building energy efficiency and actively look for opportunities to further energy saving opportunities.

Evaluate and measure continuously the energy consumption in the banking sector to know how much, where and how energy is consumed, it is essential to evaluate waste properly, the inefficiencies and priorities, in order to reduction the energy consumption.

The geographical dispersion and diversity of bank facilities was a pressing concern. It prevented a correct vision of reality, whether in branches, whether in headquarters, particularly regarding the value of energy consumption, the terms of supply contracts, disparities in consumption patterns, peaks of consumption, etc.

In order to meet the different needs identified, ISA installed equipment's network and energy consumption monitoring and management software.

The results obtained increased efficiency significantly and enabled the implementation of measures that, without further investments, led to a major reduction in consumption and an investment payback of less than 2 years.

ACKNOWLEDGEMENTS

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Medicool European Project
A Demonstrative Example of Smart Solar Cooling/Heating System

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Keywords: Solar Cooling/Heating System, Energy Efficiency, Absorption Chiller, Solar Energy.

Abstract: The main objective of this paper is focused on describing a demonstrative example of a thermal cooling/heating system. The proposed solution has been implemented in the pharmaceutical distribution sector, which involves strict and rigid European and national regulations regarding storage temperature conditions. The developed installation is one of the largest systems ever built in Europe based on solar cooling/heating technologies. It has a collecting surface of 22,500 m^2 by using one of the latest technologies: the Ultra High Vacuum (UHV) collectors. These collectors reduce significantly both convection and conduction heat losses. The proposed system has two absorption chillers of 675 and 855 kW respectively. It is expected to provide an annual energy savings estimated of around 795 MWh, only for the cooling system representing more than 70% of the global energy currently needed for conditioning the selected warehouse. This solution can be easily extensive towards other industrial sectors in areas with similar energy characteristics and thermal requirements: large conditioning spaces and buildings with high cooling/heating power demand during the peak power periods.

1 INTRODUCTION

The decreasing of traditional fossil energy sources, combined with pollutant emission reduction agreements, have leaded most developed countries to propose special tariff systems and tax reductions for renewable energy solutions. In this upcoming scenario, new technologies have a remarkable short-term impact and play an important role towards a sustainable energy system. As an example, PV power plants are proposed in (Valentini, 2008) as a crucial new supply solution. In a similar way, the useful impact of wind farms on power system operators is analysed in (Wan, 2005), showing that load fluctuations even can produce more changes in the interchange than wind power fluctuations. But not only supply-side is proposed to be analysed and modified, in (Kirschen, 2008) is suggested that consumers should be also considered as a genuine demand-side capable of making rational decisions, and not only as a load that needs to be served under all conditions. However, this desired active participation in electricity markets by the demand-side remains minimal, though there is a strong need to increase customer participation in markets to enhance system reliability and reduce price volatility (Kueck, 2001).

With regard to the industrial sector, the cooling/heating power demand is increasing more and more in most developed countries. Moreover, in moderate climates such as most EU member states, this fact usually produces a dramatic increase of electricity power demand during hot summer days, involving undesired increases of both fossil and nuclear energies and, furthermore, threaten the stability of electricity grids. These combined cooling/heating power plants are also becoming popular in residential and commercial sectors, aiming to meet desired thermal and electricity demands.

Since these systems integrate cooling, heating and power generation capabilities at one site, they result in potentially lower capital and operating costs and facilitates ease of maintenance and operation (Wu, 2006). Another remarkable aspect very related with the cooling/heating power demand is energy sustainability. In fact, several political incentives have been already proposed to emphasize their

importance into the building sector, taking into account the existing potential of energy savings as well as the increased social awareness on energy-related issues. Indeed, in industrially developed countries, buildings are contributing with more than one-third of the total energy consumption, being major contributors to greenhouse gas emissions.

Consequently, and considering cooling-heating requirements as well as building aspects, the use of renewable resources and energy efficiency for space heating and cooling purposes must be considered as a relevant topic of interest for the current industrial sector. In fact, there is a relevant interest in evaluating and assessing the performance of solar thermal solutions for those applications, mainly in countries such as Spain, where the climate offers appropriate opportunities. For these purposes, solar refrigeration is more and more recognized as a priority in developing countries, due to the needs for minimizing the energy expenditure and improvement the thermal requirements. In this context, the use of solar energy for absorption refrigeration research has been one of the hot issues along this last decade (Wang, 2000). According to several authors, refrigeration is particularly attractive as a solar energy application due to the near coincidence of peak cooling loads with the available solar power (Sumathy, 2003). The absorption system is one of the promising solar thermal refrigeration methods, and it is environmentally friendly along with low cost and low maintenance requirements. Furthermore, operating costs are 15% less than conventional air conditioning systems. By installing solar assisted cooling systems in southern European and Mediterranean region, about 40–50% of primary energy can be saved (Balaras, 2007). Under this framework, the present paper is focused on describing a demonstrative project financially supported by the European Union aiming of providing a real example of sustainable solution for cooling large storage or commercial spaces, such as logistic buildings, warehouses, wholesaler… where temperature requirements are very restrictive.

The rest of the paper is structured as follows: Section II gives detailed information about the proposed solution Innovative aspects of the demonstrative project is discussed in Section III. Preliminary results are described in Section IV. Finally, conclusions are given in Section V.

2 SYSTEM DESCRIPTION: GENERAL OVERVIEW

From the different industrial sector activities, the pharmaceutical distribution network in Europe involves by around 1500 operating sites, delivering more than 6400 hospital pharmacies, 135000 community pharmacies and around 8000 dispensing doctors. They account for more than 80% of the pharmaceutical distribution in Europe, delivering each operating site around 329 pharmacies and 1.11 million people −on average−. This pharmaceutical distribution system can be also considered as a current warehouse for most hospitals, which rely on this system the storage of medicines due to its efficient and safe delivering systems (set by law, up to 5 delivers a day and even instant delivery). Nowadays, there is even a tendency on increasing the number of those warehouses in Europe, since logistic companies are getting into the market and developing the export of medicines by setting logistic warehouses around Europe. Regarding the Mediterranean countries, about 630 warehouses are operating, mainly in Italy, France and Spain, with a surface of about 2 million m^2 and generating the emission of around 62,000 Tons of CO_2. In Spain, there are 192 warehouses with a surface of around 600,000 m^2, with a global energy costs of about 3 million €/year and generating about 18,600 Tons of CO_2/year.

With regard to storage temperature conditions, this industrial sector presents strict and rigid European and national regulations, being necessary to follow properly severe temperature requirements. Indeed, this industrial sector is very sensitive facing environmental and economic problems. The severe thermal conditions (25º C ± 2º C and humidity levels of 60% ±5%) must be fulfilled in every medicine warehouse located in Europe. These storage conditions are set by the Directive 2001/83/EC −amended by Directive 2004/27/EC− and the subsequent national regulations and codes of good practices in each country.

In Spain, the Law 29/2006 about guaranties and rational use of medicines and health products is in charge of regulating these requirements. However, this regulation framework is currently fulfilled at very high economic costs and, in some cases, with no-efficient technological solutions, involving remarkable environmental costs. Under this scenario, the *Medicool* project gives an alternative solution to this problem by applying, testing and validating new industrial processes implemented

under real conditions. This demonstrative project gives a real example of the suitability of thermal cooling-heating solutions under severe temperature range requirements. It also offers remarkable results regarding technical adjustments and maintenance tasks.

The specific characteristics and requirements of the pharmaceutical warehouses –large conditioning spaces and buildings with high power demands and strict temperature range requirements to meet usually during peak power demand periods− are very similar to other buildings devoted to different activities, such as services buildings, malls, sport centres, food processing and storage industries, or wine cellars. This conditioning space problem, in terms of quantitative and qualitative energy demand, has at this moment a great interest in Europe. Additionally, there is a remarkable replication potential of the present project in the rest of the Mediterranean countries. Indeed, some pharmacy industries and governments of South-Mediterranean countries have already expressed their interest in the results of the project.

As it can be seen in Figure 1, the selected warehouse for the installation of the present prototype is located in the Region of Murcia, South-East of Spain. It has a surface of about 30,000 m^2 −one of the biggest in Europe−, with a global energy demand of over 4000 MWh/year, energy costs of around 140 m€/year and 932 Tons of CO_2/year generated by the whole installations. The solution provided by this European project involves one of the largest systems ever built in Europe, based on solar cooling/heating technologies. It has a collecting surface of 22,500 m^2 with the main objective of reducing the current cooling time periods that can be varied from 5 hours/day during the winter to 12 hours/day during the summer period. On the other hand, it must be pointed out that this pharmaceutical warehouse is considered as a general pharmaceutical storage, being used by public regional hospitals that are not currently available to be equipped with their own pharmaceutical warehouses.

The selected pharmaceutical warehouse provides services to all hospitals and pharmacies in the Region of Murcia (Spain). This pharmaceutical distribution is owned by HEFAME, which is one of the three national leading companies in the sector of pharmaceutical distribution and owns 6 more warehouses, mainly in the Mediterranean regions of Spain (Hefame, 2013). In reference to the storage of pharmaceutical products, and considering the annual cycles of outdoor temperature and humidity in the South-East of Spain, the company presents severe problems to keep the conditioning space temperature below 25 ºC. This temperature requirement has been set by European and national regulations as well as international codes for pharmaceutical products.



Figure 1: Geographical localization of the demonstrative project and general information.

Over the past years, some initiatives have been proposed by different agents to solve the conditioning large space problem. Indeed, this issue has been considered as a high priority by the public administration of the Region of Murcia (Spain), which has also participated actively in this project through the Regional Energy Agency of Murcia. This particular interest is due to there are only a few projects devoted to assess and implement solar cooling/heating systems and, most of them propose smaller systems or prototypes not designed for the industry. Additionally, there are no examples of projects in Europe for thermal solar systems larger than 1MW, being most systems below 100 kW.

3 INNOVATIVE ASPECTS OF THE MEDICOOL PROJECT

The proposed thermal cooling/heating system works as follows: the Ultra High Vacuum (UHV) collectors heat the thermal oil until getting the set-point temperature (<120º C), adapting the flow to maintain this value. Afterwards, a heat exchanger is in charge

of heating the water up to 90 ºC. This water is then sent to the absorption chillers, using 1 or 2 machines depending on the thermal power available (Medicool, 2012), see Figure 2. These machines cool the water of the cold circuit from the conventional chillers before water crosses them. These conventional chillers are responsible for the last regulation of the temperature. The energy saving of the system is provided by the cold absorbed by the solar system that is produced with renewable energy source (solar). Conventional cooling backup system and hot water storage are both foreseen to complement the proposed system. Hot water storage is part of the system as well; and its associated benefits are included in the global energy reduction of around 70% of the total energy. Conventional cooling system, already installed in the pharmaceutical warehouse, covers the rest of the cooling energy needs (30%). The final objective of this technological solution is to be able to cover the whole energy requirements without conventional cooling backup systems, since it would make the system more efficient in terms of energy consumption and economically cheaper to install and maintain. The design of the proposed solution involves that all storage centres have these conventional systems already installed and available.

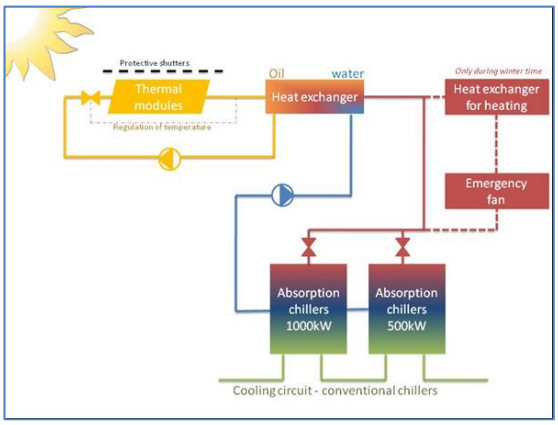


Figure 2: Proposed solution based on solar thermal cooling-heating system.

In reference to the innovate aspects of the proposed demonstrative project, new collectors with the latest technology have been selected, supposing one of the key elements of the system: the Ultra High Vacuum (UHV) collectors. These collectors reduce convection and conduction heat losses. Each collector is provided with a “Getter” pump that assures the vacuum. The collectors are composed by high absorbance (>90%) and low emittance (<7%) elements, which are exclusive for this kind of collectors and have not been provided by any other collectors. This system has been successfully tested at laboratory and pre-industrial level.

These UHV collectors avoid evaporation problems of water by heating oil, reaching higher temperatures with lower pressure, which implies a simpler valve system. Evaporation is a major problem for this kind of installations, since the evaporation of water leads to the breakage of the collectors. In reference to the use of oil in the collectors instead of ordinary water, this solution presents several advantages based on the higher boiling point of oil: over 355°C at normal conditions. In the proposed prototype, UHV panels with a selective treatment of high absorbency and low emissivity collectors, provided with concentrators, have been selected. In these conditions, film temperature can reach higher values and, at these temperatures, exceptionally good thermal stability of the transmitting fluid is required. The proposed mineral oil has bulk temperatures up to 320°C, and the rates of cracking and oxidation are very small, providing an efficient fluid heater with good pump circulation. Moreover, the use of oil decreases considerably the working pressure values, reducing then the exigencies and requirements of the piping, instrumentations and collectors. Due to the extremely high film temperatures in the collectors, the use of water would imply high-pressure values to avoid evaporation processes that may reduce the performance of the system. Figure 3 shows some details about the collecting surface as well as the installation process. Each collector group (126 components) has his own control of temperature on the oil output, managing each group in order to keep the collector group within the temperature set value and avoiding undesired heating or cooling process. The system is provided with 4 oil circuits connected in parallel. This layout allows us to give a higher selectivity in case of breakdown and reduce costs, due to the use of smaller components.

The system is provided with two absorption chillers of 675 and 855 kW cooling capacity, instead of a single one of 1.5 MW cooling capacity. With both absorption chiller machines is possible to fit the capacity of cold production according to the real heat production necessities, being able the system to use 1 or 2 machines. The use of 2 machines makes possible a wider range of uses for the installation and the simultaneous supply of heating and cooling towards different areas of the building. A PV power plant has been also integrated as an additional way to reduce the whole power demand, increasing the

whole benefits of the solar energy source. In this case, the PV power plant has 888 *kWp* nominal power rate, using PV modules from Schott monocrystalline 185W (Schott Solar).



Figure 3: Solar thermal cooling-heating system: Installation process and collecting surfaces.

The innovations of the project are focused on management issues as well: while ordinary systems have been provided as an additional support to other classical refrigeration systems, this demonstrative prototype constitutes the base of achieving and maintaining the required temperature conditions. Furthermore, instead of developing a specific system devoted to store the excess heat resulting from the process, the management system is responsible to assure a permanent and accurate supply of cooling. This is a major conceptual difference with other regulation systems: the final regulation goal instead of an initial one. Gas boilers could be considered a solution to make the system simpler, but it would waste most of the saved energy to provide the corresponding security heat store requirements. The proposed control system thus optimizes the cold production with the objective of making the installation able to speed up a response to modifications in demand, reliable in its performance and safe. This fast response is possible due to the maximum reduction of the used oil fluid. Accumulators are not used since they need larger volumes, increasing the size of the installation and the fixed and operating costs. Moreover, they would be used only few time periods and make the system slower in its regulation and considerably less efficient.

The final solution adopted is a system managing in real time, where the output temperature in each closed loop (126 components) is compared with the set-point value, modifying the input valve if it was necessary. Subsequently, the temperature is fitted according to the thermal requirements and the volume of oil changes with the available solar power. An additional regulation system is devoted to control the use of one or two absorption chillers. This system is in charge of selecting how many machines must be connected/disconnected according to the necessities and availability of energy.

Finally, the system also involves sensors to collect a sort of variables, giving a precise management of the system with stored data in real time. This makes possible to take fast and clear responses. In order to increase the global safety of the system, steel shutters have been designed to protect the installation facing abnormal climatic ranges or system malfunctions. These shutters can perform automatically and be used as a regulation tool for the energy output.

4 PRELIMINARY RESULTS

The proposed system is expected to provide an annual energy savings estimated in around 795 MWh only for the cooling system, which represents more than 70% of the global energy currently needed for conditioning the warehouse. It means about 105 m€, expected to increase according to the energy price modifications, and reaching up to 1.13 GWh and 150 m€ if the heating energy savings in the offices were included.

These energy reductions are even more relevant in daily and seasonally energy demand peaks, being the system more productive according to the energy demands are higher. In terms of CO_2 savings, and considering a CO_2 production of 0.233 kg/kWh of CO_2, the proposed thermal cooling/heating system is expected to save between 185 and 263 Tons of CO_2/year. Other types of emissions that can also be reduced are the following (per year): 766 Tons of SO_2, 626 Tons of NO_x, 4140 cm^3 of radioactive residues of low and medium activity, 508 gr of high radioactive activity residues. At the same time, the implementation of this solar thermal technology in other warehouses with the same characteristics and

the potential of transferability make these amounts to be much higher. The economic savings have to take into account indirect issues, as the decreases in electricity demand on peak power periods, especially in hot summer days.

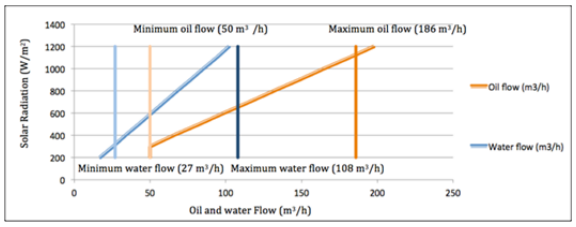


Figure 4: Estimated oil and water flow absorption chiller. 675 kW nominal cooling capacity.

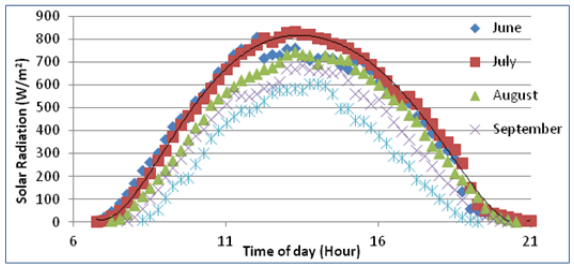


Figure 5: Estimated solar radiation data.

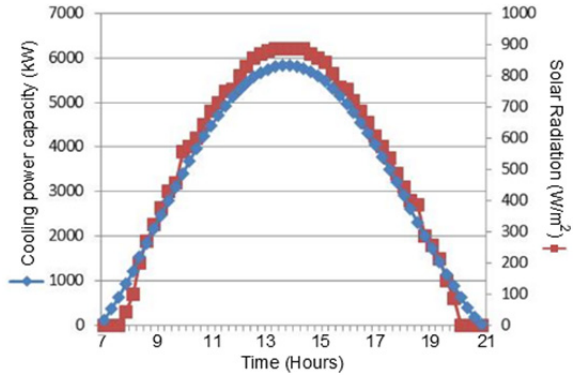


Figure 6: Estimated cooling power capacity (kW).

This fact implies a decrease in the use of fossil and nuclear energy and reduces the threatening to the stability of electricity grids, allowing energy managers to design less over-sized electricity grids. As an example of the estimated absorption chiller performance, Figure 4 and 5 show respectively the flow heat exchanger values as a function of the estimated solar radiation data. As can be seen in Figure 6, significant power reduction can be achieved in comparison with conventional solutions as was previously discussed.

5 CONCLUSIONS

A demonstrative project financially supported by the European Union aiming of providing a real example of sustainable solution for cooling large commercial spaces has been discussed and described in the present paper. This project, called *Medicool*, provides a new solution for the pharmaceutical distribution sector, which presents strict and rigid European and national regulations regarding storage temperature conditions. This solution involves one of the largest systems ever built in Europe based on solar cooling/heating technologies, with a collecting surface of 22,500 m^2 with the main objective of reducing 795 MWh only for the cooling system. This reduction represents more than 70% of the global energy currently needed for conditioning the warehouse. It implies about 105 m€, expected to increase according to the energy price modifications, and reaching up to 1.13 GWh and 150 m€, if the heating energy savings in the offices were included.

With regard to innovative aspects of the proposed system, new collectors with the latest technology have been selected, supposing one of the key elements of the system: the Ultra High Vacuum (UHV) collectors. These collectors reduce significantly both convection and conduction heat losses. The proposed system has with two absorption chillers of 675 and 855 kW each one. For both absorption chiller machines, an additional control system is included to fit the capacity of cold production according to the real heat production necessities, being able the system to use 1 or 2 machines. The estimated energy reductions are even more relevant in daily and seasonally energy demand peaks, being the system more productive according to the energy demands are higher.

In terms of CO_2 savings, and considering a CO_2 production of 0.233 Kg/kWh of CO_2, the proposed thermal cooling/heating system is expected to save between 185 and 263 Tons of CO_2/year. Other types of emissions that can also be reduced are the following (per year): 766 Tons of SO_2, 626 Tons of NO_x, 4140 cm^3 of radioactive residues of low and medium activity, 508 gr of high radioactive activity residues.

Finally, this solution is easily extensive towards other economic and industrial sectors in areas that present similar energy characteristics and thermal requirements: large conditioning spaces and buildings with high cooling/heating power demand during peak power periods.

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A System for Enabling Facility Management to Achieve Deterministic Energy Behaviour in the Smart Grid Era

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Keywords: Energy Management, Smart Grid, Facility Management, Energy Forecast, Energy Storage, Energy Trading.

Abstract: The vision of the Smart Grid empowers a variety of innovative approaches for flexible energy management that fuse the business goals with the asset monitoring and control offered by the Internet of Things. The facility management domain can benefit from these advances by building upon Smart Grid energy services thereby realizing new business opportunities that make the best out of its assets. Due to the increasing integration of highly dynamic assets in future buildings, short-term deterministic behaviour is difficult. However with the availability of controlled variable storage, and futuristic services such as energy trading, errors in prediction can be absorbed internally or traded with the ultimate aim of "making the best" out of the assets and situations. The latter has the potential to enable facility managers to reach strategic objectives and potentially use assets more effectively by seizing new business opportunities. In this work we propose an architecture, describe its key components and depict in scenarios its usage with the goal of enabling facility management to take informed business decisions by following enterprise strategies as well as considering the volatility of the available energy excess or shortage.

1 MOTIVATION

The combination of deregulated energy markets and prevalence of modern Information and Communication Technologies (ICT) on the electricity infrastructure is paving the way towards the Smart Grid (European Commission, 2012; BDI, 2010). According to the Smart Grid vision (Yu et al., 2011), improved energy management may stem from the near real-time bidirectional communication between, and within, stakeholders. Today, several projects are under-way (Giordano et al., 2013) that apply innovative concepts to realize different aspects of this vision. The realisation of this vision heavily relies on the prevalence of the Internet of Things (International Telecommunication Union, 2005), which introduces intelligent networked devices (such as sensors and actuators) to everyday objects, house-hold appliances, industrial systems, etc. and leads to the fusion of the physical and virtual worlds (acatech, 2011).

Among ongoing research and development projects (Giordano et al., 2013), there are efforts towards better grid management, integration of smart-houses (Karnouskos, 2013) and smart-buildings, accommodation of intermittent energy resources including Electric Vehicles (EV), demand-response schemes (Mathieu et al., 2011), local energy markets for business interactions (Ilić et al., 2012), etc. Through the shift towards integration of small, highly-distributed, energy production and storage capabilities, not only will new stakeholders will (European Commission, 2012), but even the current ones may assume new roles. Combining advanced information-driven services (Karnouskos et al., 2012) with these new capabilities will give rise to new infrastructures (Karnouskos, 2011) eager for innovative business opportunities.

Future on-premise capabilities, such as on-site energy generation or EV fleets (Tomić and Kempton, 2007), will provide industrial facilities with new business and management opportunities (Kanchev et al., 2011). Since a typical industrial building can be seen as an ecosystem (Carosio et al., 2013), its internal (e.g. building infrastructure) as well as the new extended components (e.g. EVs, storage etc.) can cooperate to improve energy management (Palensky and Dietrich, 2011). This in turn can enable new forms of business interaction with other stakeholders that are either currently impossible, or incur high integration costs. Of particular interest is a facility's ability to keep-up with previously planned (Blank and Lehnhoff, 2013), or forecast (Vonk et al., 2012), levels of

energy consumption and/or production, and its flexibly in adjusting to new situations while trying to minimize costs, or increase revenue for its owners (Korpaas et al., 2003). By providing a reliable prediction, such a facility could generate revenue through effective participation in, for instance, local energy markets (Goncalves Da Silva et al., 2014), or demand response programs (US DoE, 2006).

Forecasting the electricity consumption and/or production behaviour of a building will of course lead to errors (Mathieu et al., 2011) internally; however these may not need to be propagated to external stakeholders as it is done today. The challenge is on how to leverage the facility's capabilities (Teleke et al., 2009) and external interactions in order to benefit the enterprise. More specifically, how the existing and new assets that are under the control of the facility management can be empowered with Smart Grid technologies and services, and be effectively used to address any energy shortage or excess caused by the on-site prediction errors (Pinson et al., 2009).

To address this problem, we propose a system that takes advantage of existing (including temporal) assets and Smart Grid services, and enables facility management to actively adjust its energy consumption/production behaviour as seen by external stakeholders, while adhering to its internal goals and strategies. The proposed system considers a stakeholder with variable storage and energy trading capabilities, which may be the norm in the years to come. We describe several management strategies that can be realized with this system to demonstrate its capabilities. Although individual aspects may exist in ongoing research work, the proposed system combines several of them together i.e. forecasting, storage and trading, with clear applications in facility management (i.e. buildings) and with a down to earth design that may enable it to be productively used in the short-term.

2 SYSTEM ARCHITECTURE

2.1 Overview

The proposed system is modular and designed to empower the collaboration of the independently operating sub-systems, as well as the homogenization of their functionalities in a mash-up end-user application. As depicted in FMC notation (www.fmc-modeling.org) in 1, we can distinguish the interactions of the end-user via the cockpit, the main systems involved in the back-end i.e. energy load forecast (ELF), variable energy storage (VES) and energy trading (ET), as well as the reliance on external parties such as an energy market or an external energy stakeholder.

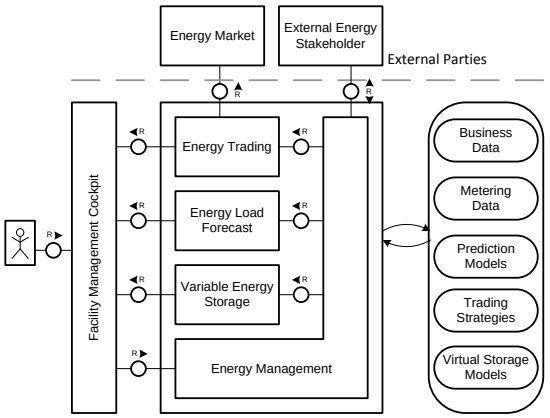


Figure 1: System architecture overview.

The *Energy Load Forecast (ELF)* is the system responsible for forecasting the energy signature based on historical smart metering data (residing in the metering system) as well as real-time data acquired by the infrastructure (Karnouskos et al., 2011). Its results form the basis for the decision making process of how to handle the excess or shortage of energy predicted.

The *Variable Energy Storage (VES)* consists of managing the available "storage" in the enterprise (Ilić et al., 2013). The latter may include static as well as dynamic energy storage (such as a fleet of EVs). The VES is also envisioned to have the capability of managing processes that could store or re-feed energy, such as, the rescheduling of a process.

The *Energy Trading (ET)* is able to trade energy on smart city marketplaces, that is, intelligently buying or selling energy depending on the needs of the overall system (Goncalves Da Silva et al., 2013).

The *Energy Management (EM)* is a coordinating entity which enables the collaboration among the different sub-systems, in our case ELF, VES and ET, while in parallel taking the decisions on the actions to be enforced. Based on the enterprise goals and strategies set by the facility manager, it may dynamically decide between the portions of energy that can be "stored" in the VES or traded by ET in an electricity market.

The *Cockpit* is the user interface (UI) that the end-user, i.e. the facility manager dealing with the energy related aspects, interacts with. The cockpit is envisioned as a mash-up application depicting key aspects of the status of the underlying infrastructure, including enterprise related key performance indicators. It can depict in real-time all information related to the utilization of the storage, the energy forecast-

ing as well as the achieved energy accuracy, the energy traded and related costs, the currently available and followed energy management strategies etc. The cockpit is considered to be easily realised as a web application hosted in the cloud, easily accessible via the browser e.g. of a mobile device or laptop.

Finally, we have to note that the envisioned system can communicate with external parties and services such as an *energy market* and *external energy stakeholders* in order to expand its capabilities. This also implies the role of being part of a larger ecosystem and the capability of being easily integrated in its business processes; for instance the goals pursued by the facility management could be adjusted to reflect dynamically changing enterprise needs.

2.2 Energy Load Forecast (ELF)

Forecasting is a well known component of every energy management system. Imbalances provoked due energy load forecast errors may result in a shortage or excess of energy that must be accommodated, e.g. in form of charging or discharging a battery. The ELF requires the availability of the actual energy load $y[n]$ of a stakeholder (an interval n of size T) in the past, i.e. its smart metering data and potentially other information such as weather data, asset specific behaviour or participation in processes, etc. With the availability of $y[n]$, an interval self-forecast $\dot{y}[n]$ can be reported with minimum offset of Δ, thus always reporting $\dot{y}[n-\Delta]$ at interval n. The reporting as such can be observed in 2.

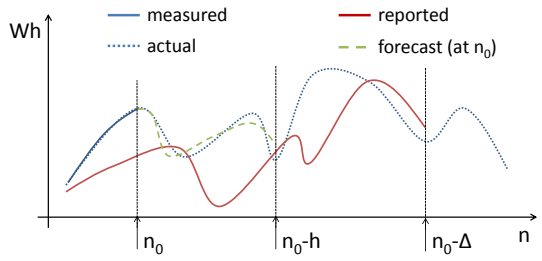


Figure 2: Forecasting on different horizons and intervals to improve the forecast accuracy.

ELF utilizes advanced forecasting algorithms that continuously provide accurate predictions $\hat{y}[n]$ over smaller horizons. Its accuracy depends on multiple conditions such as the applied forecast algorithm, the required horizon etc. In this work, ELF provides a forecast of the system for any horizon h in the future, so the continuous load forecast is done for an interval $\hat{y}[n-h]$. It is expected that many components of the system will require different horizons, as $h \approx \Delta$ might not be of interest. 2 depicts the accuracy of $\hat{y}[n]$ as being higher than $\dot{y}[n]$ (since $h < \Delta$). The ELF configuration is expected to be done internally based on historic accuracy of the achieved performance.

2.3 Variable Energy Storage (VES)

The VES component combines both static and dynamic storage into one (virtual) unit of capacity. A static storage has constant capacity if performance degradation is not considered. In contrast, dynamic storage is composed of multiple (potentially mobile) units that are at some point in time connected to the grid (e.g. EVs). While static storage can charge or discharge in dependence to its actual state of charge (SOC), these dynamic units are the actual energy-flexible components, when of course connected to the grid. This flexibility is gained by controlling the amount of energy that they charge or discharge as well as rescheduling such activities over an interval n of length T. As it will not always be possible to compensate the exact energy needed, e.g. due to technical restrictions, on every reschedule request, the error that should be absorbed $\dot{s}[n]$, is not expected to be fully addressed, but reduced to what is actually stored $s[n]$. This gap can be however addressed within the variable storage as a whole, since it is combined from its dynamic and its static part (which does not have the same temporal restrictions). A potential usage of the VES might be to use its dynamic part to compensate the closest value possible, while the static part can correct the uncompensated part of the error by charging or discharging the amount of energy needed. However, the exact usage may depend on various other technical or financial constraints, and is out of the scope of this work.

A stakeholder owned EV fleet (for which it is assumed that the facility management has full control over) is a good example of the dynamic part of a variable storage, while it is limited by scheduling and vehicle restrictions. For the rescheduling step, different priorities will need to be satisfied in order to ensure that these EVs are always within the fleet requirements. As such, any EV fleet can be used to calculate the maximal shiftable load to positive $\Delta s^{+}[n]$ and negative $\Delta s^{-}[n]$. For this calculation it has to be considered, that EVs can only vary their charging between the maximal and minimal power, or interrupt the charging completely. Within these limits, the fleet can react on energy shortage or surplus at stakeholder's premise, e.g. by interacting with an energy market or even compensating forecast errors by rescheduling or shifting loads in an interval n. Therefore in case of an energy demand change, discharging of EVs would be a secondary option, while reschedul-

ing has precedence, since no losses are made due to the storage efficiency.

2.4 Energy Trading (ET)

Local energy markets may emerge as a scalable methodology for controlling the levels of consumption and production on the grid (Ilić et al., 2012; Goncalves Da Silva et al., 2013), in particularly as a response to the increasing deployment of distributed energy resources (e.g. PV panels, wind farms, μCHP generators, etc.). Within the proposed architecture, a energy local market is considered as an opportunity for a stakeholder not only to maintain its predictability, but to also, in some cases, better utilize and capitalize on its storage facilities. With that in mind, the ET system component interfaces with the local market to buy/sell energy by applying different trading strategies, such as (Cliff and Bruten, 2000; Vytelingum et al., 2010).

The stakeholder calculates, on an interval basis, the energy trading target $\dot{\tau}[n]$ based on its internal strategies and goals. For instance, the trading targets could be based on the forecasting errors provided by the ELF. A limit price, $\tau_p[n]$,for either buying or selling is optionally set with each target to indicate the maximum (minimum) buying (selling) price for interval n. If the pricing information for a particular interval is undefined, the ET will trade aggressively on the market to ensure that the targets are met, so $\tau[n]$ presents the net quantity traded by the ET with the interval. Otherwise, each target can only be met within the bounds of the its pricing constraints.

Current targets can be updated as new information is made available to the stakeholder. In such cases, the ET updates its market position to meet the new targets. For instance, if the target is set to $\dot{\tau}[n] = 50\ Wh$, of which current trading is $\tau[n] = 20\ Wh$, when a new target of $-30\ Wh$ is received, the ET should then sell $\tau[n] = -50\ Wh$ to meet the new target. The performance of the ET can be tracked by requesting the total traded quantities $\tau[n]$. Furthermore, for purposes of a cockpit (thus assistance to an operator), the ET provides interfaces to access the overall market information, as prices $p[n]$ and trading volumes per time interval.

2.5 Energy Management (EM)

The facility manager, as illustrated in 1, interacts with the system via a cockpit. An example of such a cockpit and information it offers is depicted in 3. The facility manager can consume the (real-time) information depicted and by calibrating or setting the overall goals can exercise high-level control over the infrastructure. Such goals could be the optimization of the infrastructure reaction to the energy surplus or shortage reported by ELF towards economic objectives such as minimization of cost, or other corporate social responsibility related ones, e.g. maximization of usage of green electricity or even simpler ones such as making sure that the EVs of the employees are fully-charged by the end of their workday.

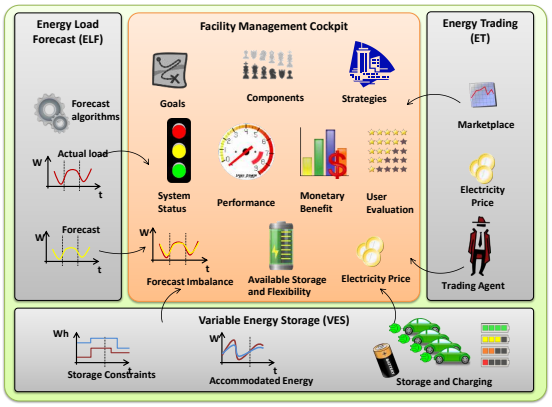


Figure 3: The envisioned system cockpit as a mash-up application.

The transformation of user goals (calibrated via the cockpit) to strategies are processed by the EM, which takes into consideration all other constraints of the system and takes the overall decision on the appropriate strategies to be followed. EM acts also as a communication broker among the different parts of the system as it holds the system-wide knowledge that is not available to the individual parts i.e. the ELF, ET, VES, enabling the latter scaling or extension of the system with other components or variations of the existing ones.

EM acts as the coordinator and decision engine, which communicates with ELF, ET and VES, and provides them with the operational context info. As an example, in a scenario where the EM is informed about the energy surplus available due to a forecast error, it may decide to redirect part of it towards charging the EVs while another part may be redirected to the ET (by charging schedule adjustment) in order to be traded to the market (because the price is high or can not be covered wholly by the VES). More example scenarios will be depicted in 3.

3 ENERGY MANAGEMENT STRATEGIES

3.1 Overview

The system proposed, whose main components are illustrated in 1, is flexible enough to accommodate several envisioned scenarios, depending on the goals set by the user, the available at time capabilities, and actions to be enforced. The scenarios we will focus upon, are in no way exhaustive, but serve to provide some understanding of the potential strategies that could be followed by the facility management. Our aim is to showcase the system's flexibility, which is a key part of realizing agile enterprises in the future.

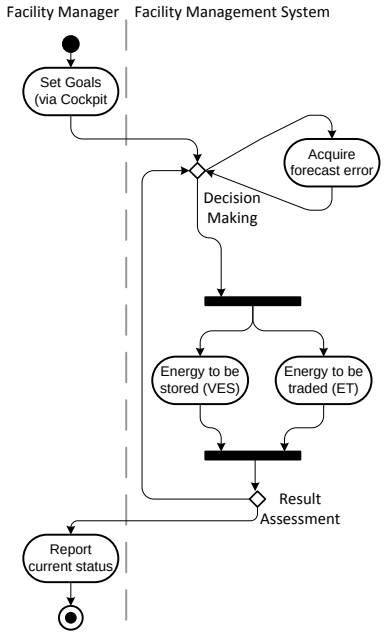


Figure 4: General view of the activity involving the architecture components.

A general view of the workflow is depicted in 4. The user input is acquired, which together with the forecast error and the underlying status and constraints of the subsystems, are used to reach a decision for either trading or storing of energy (or both). Some key strategies will be discussed in more detail i.e. 3.2, 3.3, and 3.4.

Generally, each envisioned strategy may not involve all parts of the system, as this depends on the actual constraints imposed at the time of the decision making. This also signals that an organization does not have to wait until all of the architecture parts are deployed and become operational to start realising (a limited set of) energy management strategies. As an example, the ELF and the VES could be realized today, while the ET could be realized some years later when energy markets are available at smart city level and it makes economic sense for the facility managers to participate in them. Hence, the system architecture accommodates the "migration" i.e. incremental evolution of the infrastructure towards the fully-fledged Smart Grid vision.

3.2 Storing Energy not Traded by ET

The decision making process (as depicted in 4) may consider a strategy that is described as follows: *after the estimation of the energy error within an interval by the ELF, try to trade the difference via the ET and differ any non-traded energy to the VES for storage*. The workflow of such strategy is illustrated in 5. ET accommodated $\tau[n]$ for the interval in question (potentially even at different prices p), and VES is contacted in order to absorb the remaining $\dot{s}[n]$.

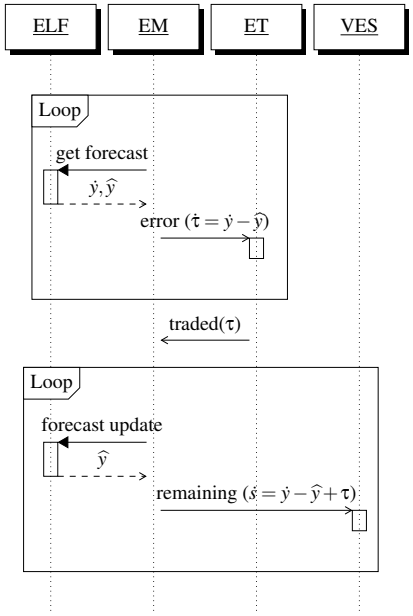


Figure 5: Strategy activity: 3.2.

The actual outcome of the trading done by ET depends on the real-market conditions (law of demand and supply) and hence strategy adaptation might be needed over time e.g. acting alone or as part of a larger group (Goncalves Da Silva et al., 2014). As the ET might not be able to fully trade the energy needed to balance the forecast error $\dot{\tau}[n] = \dot{y}[n] - \widehat{y}[n]$, a part of it remained non-traded. The traded quantity $\tau[n]$ is then communicated back to the EM, which instructs VES to accommodate the remaining $\dot{s}[n] = \dot{y}[n] - y[n] + \tau[n]$ energy. This process leads to a new

state where the error is minimized as a "best effort" procedure is followed by ET (interaction with external stakeholders) and VES (internal stakeholder) to minimize its impact.

Depending on the business motivation, this strategy may be followed when the return of investment (ROI) by selling the energy on the marketplace is high. This may be a result of high prices on the energy market, inability or no need of storing the energy internally, etc. The actual decision-making process will be dynamic and the exact fine-tuning is not considered here.

3.3 Trading Energy not Accommodated by VES

In compliance with the decision making process depicted in 4, here we focus on a strategy that can be described as follows: *after calculation of the energy due to the incurring error by ELF, try to accommodate the excess or shortage of energy via the VES (by charging/discharging) and for the remaining part not accommodated by the VES, use the ET*. In this strategy, the ET acts as a mitigating agent for any part of the error that could not be absorbed by the VES, which is shown in 6. In detail, the EM acquires the forecasting error ($\dot{s} = \dot{y} - \widehat{y}$) from the ELF and informs the VES, which attempts to accommodate the imbalances introduced by the errors, and informs the EM of any amount that could not be accommodated due to its internal constraints (s). These amounts are then given to the ET to be mitigated on the market ($\dot{\tau} = \dot{y} - y + s$).

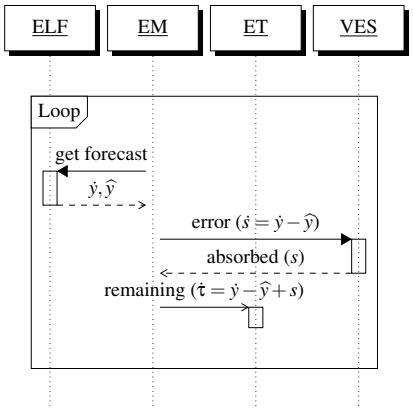


Figure 6: Strategy activity: 3.3.

This strategy is expected to be used when the enterprise has the capability to store energy extensively for its own use. For instance a significant number of EVs at the disposal of facility management, means that the VES can rely on storing energy there and acquiring it back again when needed. Even if the energy is not needed during the day for tackling imbalances, the EVs are charged and the energy can be used for the enterprise's processes in the future; an action that enhances better planning of energy-relevant actions. If a local marketplace is available, the ET tries to trade the remaining energy (or acquire in case of shortage) in order to make ends meet.

3.4 Trading Available VES Capacity

Independent of the strategies followed by the facility management, the available assets might not be fully utilized. Hence additional actions can be run, in compliance to the decision making process as depicted in 4 and in parallel to the existing strategies. As an example, consider a strategy that is described as follows: *check the available of VES flexibility and trade the additional shiftable energy with the help of the ET in the local energy market*.

This example goes beyond the traditional process of trying to cover the energy imbalances and targets clearly the optimization area of the available assets. The VES might be underutilized while trying to cover the occurring imbalances, and that "unused" capacity could be transformed into economic benefit for the company. The VES may have its own models for estimating capacity that will not be used, and hence can "release" it for further usage. Then the EM may consider this capacity and buy or sell energy with the help of ET in order to generate additional revenue for the company. The system is flexible enough to accommodate such actions. However, to avoid conflicts or side-effects, additional analysis on the resource utilization is needed which is not part of the investigation presented here.

Since the VES is trying to compensate the error produced by the ELF, a certain state of charge (SOC) will be achieved. Based on the actual flexibility levels with consideration of SOC, the VES can offer a certain capacity within an interval n for charging/discharging in order to increase the enterprise's revenue. Instead of only offering the capacity which is left from the error compensation, the VES may calculate the maximal and minimal shiftable energy $\Delta s^{+}[n]$ and $\Delta s^{-}[n]$. This offered capacity can be then traded and benefit from current price p. In another twist, the VES may decide that the economic benefits of trading the capacity are greater than that of being used a storage and act accordingly, which is blending the borders of the other two strategies discussed.

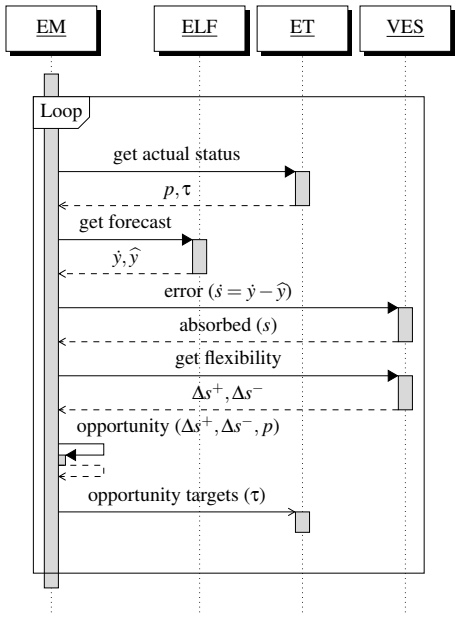


Figure 7: Strategy activity: 3.4.

4 DISCUSSION

Several considerations on the main components i.e. ELF, VES, ET need to be adequately addressed. Forecasting done by the ELF, cannot only be based solely on historical data, but needs to include real-time information. To this end, the Internet of Things coupled with the Cloud (Curry et al., 2013; Karnouskos, 2013) and the vast resources for analytics will help. Additionally, more specific knowledge of the processes involved, their scheduling at enterprise level, as well as their potential interdependencies may lead to better forecasting and planning. For our environment this assumes access to the building processes per se, the impact of the employee usage of its facilities (which extends to the EV usage), as well as potentially external factors such as weather conditions etc. The appropriate combination of such intelligent algorithms with (real-time) fine-grained data may enable the better adjustment of the infrastructure behaviour prediction.

Another key part of the system, the VES, demonstrates that the temporal storage availability e.g. coming from an EV fleet, can be used to acquire additional benefits for the enterprise. Although charging/discharging EV batteries or even rescheduling their charging may sound promising, at the moment few, if any, companies have fleets large enough for these envisioned concepts to be practically applicable. Furthermore, the communication protocols of the EVs or the charging stations might also pose challenges as they might not allow a secondary actor to set the charging schedule for them and always try to charge as fast as possible.

Such constrains would tremendously lower the possibility of interaction with other components in a smart way. The latter gives some indication that company-controlled fleets are the right target group for such concepts as the one presented here. Even then, due to constraints (physical or otherwise), fleets might not always provide the exact flexibility that is needed. The latter can me mitigated through the addition of static storage, or another buffer-like component, that can compensate the missing flexibility.

The ET demonstrates how interacting with other local stakeholders can not only aid the facility in reducing its forecast error, but also create additional opportunities though energy and storage capacity trading. Although local energy markets are a hot topic (Ilić et al., 2012; Lamparter et al., 2010; Ding et al., 2013) in Smart Grid research, how to effectively make use and interact with them is still unclear. As no such market currently exists, operational assumptions were made; however in a real-world assessment the underlying trading behaviour must be anchored in a clear understanding of the market's rules and protocols. Additionally, in order for the ET to meet the a wide range of strategies, such as the ones described in 3, it must be able to adequately handle dynamically changing trading goals in conjunction with market-forecasts and enterprise's needs.

Generally, we consider that there is added value if such systems are operational and would assist towards informed and automated decision-making processes in facility management domain. Their realization however, will need to be assessed and fine-tuned in real-world trials once the necessary Smart Grid services envisioned are mainstream.

5 CONCLUSION

The ability to capitalize on new business opportunities is vital for the survival of modern enterprises. To that extent, fully utilizing all the capabilities offered by its assets is pivotal. In the Smart Grid era, the facility management can take sophisticated decisions related to energy management, by including innovative technologies and concepts. The system we have presented builds upon the orchestration (by the the EM) of three key independent components (i.e. ELF, VES, ET). We have provided insights on its basic components, their operation as well as their usage in a variety of strategies. In the latter we have also discussed the benefits for the enterprise as well as the roadblocks that might hinder their realization. Ultimately, the proposed sys-

tem enables on-the-fly decision-making that empowers the facility managers to better meet their goals in the emerging Smart Grid era.

ACKNOWLEDGEMENTS

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The Experiment Has Shown
Set Your Own Goal and save Electricity!

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Keywords: Electricity Saving, Energy Feedback, Energy Visualization, Smart Energy Use.

Abstract: This study describes the final results from so-called "The Experiment - Swedish largest energy saving experiment" carried out by E.ON Sweden. The purpose of the Experiment was to investigate whether visualization of electricity consumption in real time would lead to a reduced electricity use. Almost 10,000 customers participated in the project and received displays where they could observe their electricity use. Over 50% of the participants made an actual electricity saving; for these customers the mean electricity saving became 8%. At the beginning of the Experiment, participants could set a saving goal and about 22% of the customers managed to achieve the target. This group saved about 15% of electricity. All the participants in total had made a saving of 0.7% compared to a control group that had increased their use by 1.5% during the same period. The impact of different factors on the final result was investigated in four segmentations after space heating type, family composition, level of education and bidding area. Four surveys were sent out to all participants to investigate their opinions and views on the Experiment. The interest for possible changes in the service and the willingness to pay for it was also investigated.

1 INTRODUCTION

Power company E.ON Sweden launched, as they called, "The Experiment - Swedish largest energy saving experiment" where 10,000 customers participated and tried on energy feedback technique called 100Koll. The main question of this experiment was weather the involved households could save electricity by getting their usage visualized and by setting up clear saving goals, which was a new way that has never before been tested in an experiment on the same scale. Furthermore, this experiment covered a full year, which is also rare for this type of investigations.

The Experiment started on February 1st, 2012 and lasted a whole year until January 31st, 2013. 10,000 grid customers of E.ON used home displays retrieving data from smart meters, giving possibility to follow household electricity consumption in real-time. Participants of the Experiment could also log into a website "My Account" and download a mobile application to monitor their daily electricity consumption.

A control group of 2,000 households was randomly chosen by the energy company among all the customers in the country (besides bidding area 1 in Northern Sweden - as for the experiment group), not participating in the Experiment and not being aware that they were included in the control group in order to evaluate their energy consumption change and compare it with the results from households participating in the Experiment.

1.1 Motivation Events

In order to increase participants' motivation to change their habits and achieve reduction of electricity use, five so-called "motivation events" were planned during the Experiment (E.ON, 2013). The aim of these actions was to generate interest in savings, in various ways, and to encourage participants to try to save even more electricity. Some of them were connected to TV-commercials, billboards and advertisements in newspapers all over the country. The results of these campaigns were evaluated in two surveys during the Experiment.

The first period started with the motivation case called "Balance". The participants could download an application to their smart phones to track the electricity usage of the households visualized in Swedish currency instead of kWh, see Figure 1.



Figure 1: Visualization of the Balance.

Second period was called "Neighbour Feud" and was a game between neighbours. 5 families in the neighbourhood could compete with each other to see who was able to save the most of electricity during the game, see Figure 2.



Figure 2: The “Neighbour Feud” on a smart phone display.

Then, the "Carrot" was a period during the Experiment where the households could send in their saving tips. The best of them were later rewarded with prizes and some saving tips were illustrated in a playful manner by cartoonist Henrik Lange (see Figure 3) and in humoristic TV-advertisements.



Figure 3: Example of energy saving tips from the motivation booster Carrot - The Anonymous Energy-holics. (Text: Change your behaviour! “Hej! My name is Gustav and I don’t turn the light off when I leave a room.”)

After that, during the autumn 2012, the fourth motivation case called “General” started. Through a special app, downloaded from the Experiment’s website, daily reminders were sent of things possible to do and with inspiration and challenge to do even more savings - much like a personal “energy coach”, see Figure 4.

Finally came the "Bongo", a small creature who appealed to the Experiment participants’ empathy being very sad and feeling sick if the family members did not save electricity, see Figure 5.

The boosting period that was most appreciated by the participants was the "Balance". They felt that it helped them the most with their electricity saving efforts.

The overall interest was quite low for all the motivation cases. During the interviews it was revealed that some people felt that motivation cases were a bit bizarre in an otherwise so important and serious subject as energy saving. One participant also pointed out the contradiction in messages in the game "Neighbour Feud". The more the family saved, the greater became the house and at last it could end up with a helipad on the roof of this already very spectacular building.



Figure 4: Motivation booster ”The General”. (Text on the display says: “Not bad! I’ve checked your electricity use and it’s sinking. Is there something more you can do to lower it further? Think really carefully now!”).



Figure 5: “Bongo” on a smart phone display.

2 METHODS OF EVALUATION

The scientific evaluation of the whole Experiment was carried out at the Department of Energy Sciences at the Lund University and reported in three publications (Andersson and Larsson, 2012), (Taimor and Hols, 2013), (Uggmark, 2013).

Electricity consumption during one calendar year (Feb 1, 2012 - Jan 31, 2013) was compared with equivalent period 2011-2012. Monthly electricity consumption data was collected and analysed for each household showing how the electricity consumption had changed compared to previous year. For electrically heated households the data was corrected for outdoor temperature variations.

A particular methodology was developed by the authors to calculate electricity savings. The percentage of electricity used for space heating was calculated as a difference between electricity use during winter (October -April) and summer (June-August) months. Degree-days values were obtained from the energy company and processed before they were allotted to the households.

Four web-based surveys and an interview study with limited amount of households were conducted during the Experiment in order to examine how the participants experienced different aspects of the Experiment - from technology to engagement. The content and structure of each survey was designed in cooperation with representatives from the energy company. The responses from the questionnaires and the facts about participants of the Experiment were put together to enable the segmentation of different test groups. Statistical tests were then performed to ensure that any differences between groups were significant and not just a coincidence.

Some specific conditions for participation in the Experiment were required:

1. the household should be a customer of E.ON;
2. the participants lived in single-family houses;
3. the electricity use was at least 10,000 kWh per year (which usually means for Swedish conditions that electricity is used both for space heating and household needs).
4. the household should decide an electricity saving target for the coming year (from 1 to 25%).

Totally, over 8.000 households participated actively in the Experiment. Unfortunately, as the analyses showed later, about 800 of them had electricity use below 10,000 kWh per year.

Annual electricity consumption (between February 1, 2012 and January 31, 2013) was compared with equivalent period year before (February 2011 - January 2012).

Because of the weather-related changes in heat demand, the evaluation of electricity savings from one year to another has to consider how the outdoor temperature differ between the two years. The space heating data was corrected for outdoor temperature

variations for all electrically heated households (direct resistive heating, electric furnaces or heat pumps).

In this way, the electricity savings were defined as temperature corrected difference between the year of the Experiment and the year before.

The methodology used for temperature correction was developed by one of the authors and is presented in detail in the final report (Uggmark, 2013).

The method used was based on degree-days for each geographical location and on the assumption that the electricity use during the summer months (June to August) might represent the use of electricity for household purposes and tap hot water preparation. This electricity was assumed as constant over the year. In this way the energy consumption was only adjusted for the part of electricity used for space heating.

Four web-based surveys were conducted during the Experiment with responses according to a 6-grade Likert´s scale. The content and structure of each survey was designed in cooperation with the staff from the energy company. The responses from the questionnaires and the facts about households were put together to enable the segmentation of different experiment groups. Each question was evaluated and the level of "belief" or "scepticism" was calculated.

Statistical tests were then performed to ensure that any differences between groups were significant and not just a coincidence. Kruskal-Wallis test and Chi2-test were used to examine the significance of the response results (significance level 0.05).

3 RESULTS

3.1 Electricity Savings

The final result of the Experiment is based on 8,040 participating households. At the beginning of the Experiment, the participants were asked to decide the electricity saving target during the coming year. Of these who actively participated, about 23% achieved or exceeded their stated energy saving targets. This group saved about 15% of electricity.

Of the remaining active households, about 34% saved electricity but stayed below their saving targets. About 43% of the households even raised their consumption, in some cases as much as by 70%.

Somewhat over 50% of the households who participated in the Experiment made some electricity savings (>0) compared to the year before. Their average savings were of 8%.

The group "Active households" comprises households participating actively in the Experiment by answering surveys (3985 households). This group as a whole saved 1.68% of power. In this group, totally 2,203 households saved 8.40% of the electricity. Those who reached their targets within this "active" group (886 households) saved 14.88%, see Table 1.

The analysis made with the same criteria for the Control group (2,000 households) showed that this group, on average, increased its use of electricity by 1.50% during the same period.

The fairly similar result was identified for those participants of the Experiment who did not put up the saving targets (about 4,000 households) in the beginning of the Experiment. This group had also increased the electricity consumption by 0.2%.

Table 1: The final energy savings in the Experiment (Uggmark, 2013).

	Total electricity saving (+**values** = saving)	
	Experiment group	Control group
All households	**0.74%**	-1.50%
'Active' households	**1.68%**	-1.50%
'Active hh' who 'Saved power'	**8.40%**	**8.33%**
'Active hh' who 'Reached saving target'	**14.88%**	NA

To investigate closer whether different groups among the participants had better (or worse) electricity saving results compared to the others, four segmentations after "space heating type", "family composition", "level of education" and "bidding area" (there are 4 such areas in Sweden) were made.

The most noticeable result from the segmentations was that bidding area 4 (Malmö) in the south of Sweden, usually having higher electricity prices, had the highest saving of 2% and that bidding area 3 (Stockholm) made a significantly lower savings. Households within bidding area 2 (Sundsvall) actually increased their use of electricity with approximately 0.6%.

3.2 The Participants' Experiences

To collect and evaluate participants' opinions on the Experiment, four surveys and an interview study was made. Surveys were sent out to all participants to investigate their own opinions on for example the

motivation cases and to study their views on the Experiment. The interest for possible changes was also investigated to see what could make the service more attractive and so was also the willingness to pay for the service. The survey ended with a question whether the respondents could consider participating in an interview. 18 respondents were later contacted for a short interview so that some questions could be investigated further.

It appeared that many participants were very positive about the Experiment. Most of the households felt that they would benefit from the equipment in the future and would be very disappointed if the service disappeared.

In addition, slightly more than half of the households were willing to pay for the service. Families with children and those who had reached their saving target were in slightly higher extent willing to pay. Not surprisingly - those who reached their electricity saving target probably had a more clear view of the benefits.

However, it was quite noticeable that many households participated in the Experiment not because of a possibility to save electricity and money. Many of them were also very interested in keeping an eye on their own everyday electricity use. For many households it was the most important argument. Another example of the reason to participate in the Experiment was the possibility to be able to see that the electricity bills were correct. Yet another one was, for example, the possibility to remotely watch that everything worked properly in the summerhouse.

The interest in the motivation cases was proved not to be very large however "The Balance" was considered to be the motivation case that had helped most participants to save electricity.

Finally, an inquiry was made to see how Facebook had been used during the Experiment and what kind of saving tips that had been submitted during the motivation case period "Saving tips". Most of all Facebook was used for technical support and other questions but the interest for this platform soon declined.

Technical Measures. The Experiment had influenced many participants to make small changes in their homes like switching lighting to more energy efficient but several families had also made major changes, such as changing heating systems or installing new white goods.

Approximately 66% of the participants answered that they had carried out different technical measures during the Experiment in order to save energy (Taimor and Hols, 2013).

The responses also indicated that performing technical measures was preferred rather than change of the behaviour. Participants also seemed to use the real-time display 100Koll a lot to ensure that the measures they had undertaken really resulted in energy savings.

Behavioural Changes. About 73% of the participants said in the surveys that they had changed their behaviour as a way of achieving energy savings during the Experiment (Taimor & Hols, 2013).

Again, the answers indicated that the participants made bigger steps in behavioural adaptation than they would if they were not involved in the Experiment.

The survey answers indicated also that the behavioural changes in the households did not affect the indoor comfort or family's living standard. Some respondents mentioned however that the most negative impact of the measures was reduction of the indoor temperature.

Respondents also indicated that both their partners and children often changed their energy related behaviour during the Experiment.

Usability of the System. Although one-third of survey respondents strongly agreed with the statement that they only had few problems with the feedback system during the Experiment, many households used the opportunity to submit open answers about the problems they experienced. At least one-third of these comments indicated that the equipment did not work correctly. Sensors reading electricity consumption often lost contact with the display. This means that nearly 20% of the households had this problem. This might also have affected the results of electricity savings shown on the website because the estimation of electricity consumption made by the company was based on these readings.

Many participants stated that their knowledge about household electricity consumption increased due to the visualization and feedback.

Possible Improvements. Some improvements and new options added to the service would, according to the participants, additionally increase the value of the service:

- better contact between devices,
- automatic updating of electricity price,
- more smart plugs for measuring individual outlets,
- possibility of measuring the consumption of fixed appliances e.g. heat pump,

- better information about possible functions,
- comparison with 'normal' values,
- lighting of the display,
- warning system for the temperature level - too high or too low,
- possibility of deciding saving targets
- warning system for if the consumption is too high for the goal to be achieved.

3.3 Future

There is a clear possibility that the participants discovered some "electricity thieves" during the Experiment and have started some major investments to reduce their electricity consumption during the next heating season (2013-2014).

Many households were very interested to keep the equipment after the end of the Experiment, which promises well. Whether the participants will continue to save electricity or will return to their old habits, remains to be seen. A possible follow-up after the winter 2013-2014 might give some indication of the duration of electricity savings for each group.

4 CONCLUSIONS

The following conslusions have been drawn from the study:

- Just over 50% of the participants made electricity savings during the experiment compared with the previous year; this group of customers saved an average of 8% electricity.
- Just over 22% of participants with a set energy saving goal managed to reach the target; this group saved an average of 15% electricity.
- All the participants together made a saving of 0.7%.
- All the customers from the control group increased electricity consumption by 1.5 %.
- 30% of the households believed they had reached their goals, while 55% did not know if they done it or not.
- Most people would benefit from the equipment and the service in the future and would be disappointed if it disappeared.
- Most people were not afraid that it would be a problem of privacy or integrity with company's access to the information about their electricity consumption.
- Slightly more than half of the households would be willing to pay for a similar service in the future.
- Families with children were more willing to pay for the service and more than others used the consumption data to check the situation at home.
- Those who achieved their electricity saving target were willing to pay more for the service than the others.
- Many of the participants interviewed had made some smaller or bigger modifications of the heating systems.
- Many of the participants interviewed had made some small changes at homes like converting light bulbs to more energy efficient.
- Participants used Facebook but focused on technical problems and issues.
- E.ON used Facebook primarily to spread out information about the Experiment and its homepage.
- The number of posts from participants dropped sharply during the Experiment.
- Almost 70% of the saving tips sent by the participants were serious.

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Beyond a Usage Threshold, NO Form of Energy is Sustainable or Green
We are Running Out of "Garbage Dump Space" To Dissipate "Used" Energy Into

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Keywords: Earth's Energy-dissipation-capacity, Green-energy, Sustainable-energy, Supply-side, Demand-side, Energy-conservation, Thermal-radiation-into-space.

Abstract: To date, almost all of the research on green/sustainable energy has been concerned with procurement of ever increasing amounts of energy for human consumption. This singular focus only on the supply-side of the problem completely overlooks what happens to the energy after we use it; thereby implicitly making the dangerously wrong assumption that the earth has unlimited capacity to dissipate energy.
In this position paper, we remind the reader that the earth can dissipate only a finite amount of even the greenest of the green forms of energy, while still maintaining thermal equilibria that have evolved over eons. Any long term sustainable energy solution therefore must include a curbing/limiting/controlling our ***demand*** for (and consequently, our ***consumption*** of) energy. Otherwise, even if and even after all the green-house-effects are fully eliminated, the earth still might eventually experience unnaturally large temperature increase because the amount of energy dissipated is too large.

1 INTRODUCTION

1.1 Background

It is not surprizing that the "supply" of sustainable energy has been investigated in great depth by a large number of researchers, for instance, see (Mackay, 2009) for an excellent exposition on all issues related to the potential sources (i.e., supply) of sustainable energy. This is natural since finding a sustainable supply of energy is essential for long term prosperity (and potentially even the survival) of humanity.

However, this singular focus on the supply-side alone is not sufficient. An equally careful analysis of whether the consumption of ever increasing amount of energy is sustainable; is just as critical for long term survival and prosperity of humanity. In this paper, we point out that the earth has a finite capacity do dissipate energy. The implication is straightforward: even if an unlimited supply of a totally green form of energy were to magically become available, we are not free to use it without restrictions on the surface of planet Earth[2]

[2]Steadily increasing number of scientists are concurring that "Earth" seems to be a misnomer, our planet should be called planet "Ocean", because the existence of water in liquid state is what sets us apart from a gazillion other planets.

1.1.1 What is "Green" Energy? what is "Sustainable" Energy?

In the literature the identifiers "green" and "sustainable" are often used together. To add to the confusion, they are also used inter-changeably. For the sake of clarity, we define them separately.
(1) ***Green*** Energy is a form of energy whose generation and consumption does not cause harmful chemical or physical pollution of the environment; or does not lead to large-scale chemical or physical changes in the environment.
(2) ***Sustainable*** Energy is a form of energy whose supply can last for a very long time (or in other words, the supply can be sustained for a very long time). A good example is that of the hydrogen available to us as a constituent of the ocean-water. It can yield energy for a very long time if "cold-fusion" is achieved; or a method of controlling the nuclear fusion reaction can be realized.
(3) ***Renewable*** Energy is a form of energy that can be renewed/replenished, and is therefore also indefinitely sustainable. The prime example being sunlight that we receive on earth.

Note that energy generation from any given source could possess any of the 3 attributes above independently of each other; although keeping on using a sus-

tainable non-green fuel (if one were available) would cause destruction because of the chemical pollution or some large scale change in the environment.
In other words, a sustainable source of energy had better be green as well. However, for the purpose of this article, such constraints are not crucial.

Turning to fuels we use today, burning coal not only produces Carbon-di-oxide (CO_2), it also releases mercury and Sulfur-di-oxide (SO_2), into the atmosphere. Both of these pollutants eventually rain back down on earth. The first one, mercury finds its way into our food-chain through the rain-water. The latter (SO_2), dissolves in rain-water (to various degrees), creating sulfuric acid which causes the "acid-rain" phenomenon.

Burning Petroleum and its derivatives might free us from the mercury and sulfur pollution, but it does generate a substantial amount of CO_2, which is a greenhouse gas.

Note that almost all living organisms that have evolved on earth appear to derive the energy that they require for living from a carbon-based cycle. The entire life on earth includes one element in a high degree of concentration: viz., Carbon. For this reason, "Organic Chemistry" which is a traditional name for the branch of chemistry that studies compounds found within and related to living organisms is also known as "Carbon Chemistry".

It is therefore not surprizing that pretty much any fossilized fuel that we know of, is primarily made-up of Carbon. Burning fossil fuels therefore generates CO_2, which in-turn helps exacerbate the greenhouse effect. Moreover, none of the fossil fuels (coal, oil, ...) are replenishable, since they can be used (burned) only once.

Fossil fuels are therefore neither green, nor sustainable and neither renewable (definitely not renewable at the current consumption rates).

Nuclear energy comes from fission and fusion processes. The only form we can harness right now is fission; fusion cannot be harnessed for energy production yet. Obviously nuclear energy is not "renewable" or replenishable; the nuclear material can be used only once. Fission generates extremely toxic waste products. However, they are in a solid state and therefore can be sequestered (at least in principle) for a long time. Nonetheless, fission is not considered "green".
Finally, the supply of fissile material on earth is not unlimited. Hence, Nuclear fission cannot considered sustainable in the long run; it is considered to be the least-destructive, potentially inevitable "bridge-fuel" until humans figure out something which is sustainable longer and is greener.

1.1.2 Sunlight/Solar Radiation is the Best Known Green, Renewable and Sustainable Form of Energy

In contrast to all prior forms of energy, sunlight, in every sense, is the ultimate form of green and sustainable energy. It is as renewable an energy form as we can think of today or even in the future. (note that burning fossil fuels simply gives back the small fraction of solar energy stored by life-forms on earth a long time ago).

Most other forms of renewable energy (for example hydroelectric generation from dams or wind farms) go back to solar energy (because sunlight causes the water-vapor and the rain that fills-up the dam. Likewise, sunlight is primarily responsible for heating/cooling the earth unevenly, thereby creating winds).

2 LET US GO COMPLETELY "GREEN"

2.1 Consider only using Sunlight

Since sunlight is the most clean, green and sustainable form of energy, we should only use sunlight as far as possible.
But there are a few problems with sunlight. The most important one being that it is inherently highly distributed. The energy-density of sunlight is considerably lower than the energy density delivered by the chemical bonds in fossil fuels or the nuclear bonds in fissile material. Therefore, a substantial amount of aggregation over a nontrivial amount of geographical area is required to effectively harness solar energy.

2.1.1 A Hypothetical Question: Suppose Humans were to Become Capable of Creating Huge, Ultra-ultra Thin Artificial Spheres/Mirrors in Space (Call them "mirroons") to Reflect more Sunlight onto the Earth. Should We Put up those "mirroons" to Get More Solar Energy?

Let us think for a moment as to what happens to the energy that we use. In high-school physics, everyone learns that:
① ***Energy cannot be created or destroyed,***[3] ***it only changes form***

[3]Except in nuclear reactions where mass gets converted into energy

② Moreover, all known processes that consume or produce energy are known to conform to the ***fundamental laws of Thermodynamics***. In particular ***At an abstract level, every single process that involves energy-exchange can be modeled as a Carnot Cycle and therefore must dump at least some portion of the input energy, as the "unused" portion into a "low temperature reservoir"***

But there is ***only one low temperature reservoir*** that we know of, (which we all also happen to share), viz., the ***surface of planet Earth/Ocean.***

Therefore it can be seen that ***all the energy that is used*** for every single action (from breathing, to the fuel used to run cars, airplanes, ships, and all energy used for heating/cooling, all electricity we produce,...) ***eventually gets transformed into entropy/disorder/ waste-heat on the earth's surface.***

For example, consider transportation: first and foremost, assuming that all objects involved in transportation are at rest before and after the transport operation, the kinetic energy of motion is zero at both the start and the end. In other words, there is no net change or net gain in the kinetic energy of any component of a transportation system. Typically, there is no chemical change in the objects being transported which means that energy does not get converted into/saved as chemical energy. Likewise, electric charge, temperature and other attributes of the objects being transported are not expected to and do not change much as a result of the trip.

That only leaves a consideration of "potential energy". Here, we first observe that most trips we undertake are "round trips", wherein, since the starting and ending place is the same, there is no net change in potential energy. Even when the trip is not necessarily a "round trip" (for example, when raw materials, finished goods are transported at various stages of industrial production), there is no known preferential bias toward moving objects upwards against gravity (in which case, they gain potential energy). Therefore, there is no net gain in "potential energy" as a result of any/all of our transportation activities. There are extremely few exceptions to this: rarely do we lift huge things and put them permanently on top of mountains or sky-scrapers.

It is therefore clear that all the energy used for transportation must eventually dissipate as friction (of some sort, including electric "resistance") against the transport conduit (which is typically a road surface when the transporter is a terrestrial vehicle; water-drag in case of ships and friction created by collisions against air molecules in case of airplanes). Friction eventually coverts all the kinetic energy of motion into waste-heat that cannot be further exploited in any other way.

Even if we "store" energy temporarily via regenerative breaking, and/or charging batteries, eventually, it gets used to move the same transporter again at a later time, or for lighting or heating/cooling on-board the transporter vehicle; and therefore must eventually dissipate as waste-heat/entropy.

We leave it to the reader as an exercise to show that energy used for heating or cooling also eventually dissipates as entropy/disorder/waste-heat.

2.1.2 Quality of Energy, Thermodynamic Irreversibility

A clarification is in order here (more in-depth treatment of the following material can be found in textbooks such as (Moran, MJ, Shapiro, HN, et. al., 2010); or at university course-websites like (Greitzer et al., 2013; MIT staff, 2003); or on wikipedia (Wikipedia, 2010; Wikipedia, 2012)...,) The important word here is "waste-heat". It turns out that different forms of energy have different levels of "quality" associated with them (Wikipedia, 2010). Energy of a higher quality can be converted into another form of energy with a lower quality easily via spontaneous or naturally occurring processes. The degradation of quality can be measured by a thermodynamic metric known as "Irreversibility" (Greitzer et al., 2013; Wikipedia, 2012). As the name implies, energy of a lower quality cannot be converted into energy of a higher quality without spending (a substantial amount of) additional energy.

Electricity is one of the highest quality/form of energy (Wikipedia, 2010), and therefore it is easy to convert electricity into mechanical work (through electric motors) or heat (resistive heating) or light (via light bulbs). Kinetic Energy of motion is of lower quality than electricity, but higher quality than heat (Wikipedia, 2010), and therefore it can be easily converted into heat (by friction via braking). But to convert it into electricity requires a generator which has its own losses. Unfortunately, "heat" happens to be one of the lowest grade/form of energy (Wikipedia, 2010). The higher the temperature, the higher the quality of heat. Therefore by burning fossil fuels, or via nuclear fission, we can generate very high temperatures or in other words "heat" at a high temperature and then convert a small portion of it into mechanical work or electricity as per the Carnot-cycle (the most fundamental rule governing heat engines).

In view of the above, note that ideas such as "build huge antennas and radiate microwaves away to get

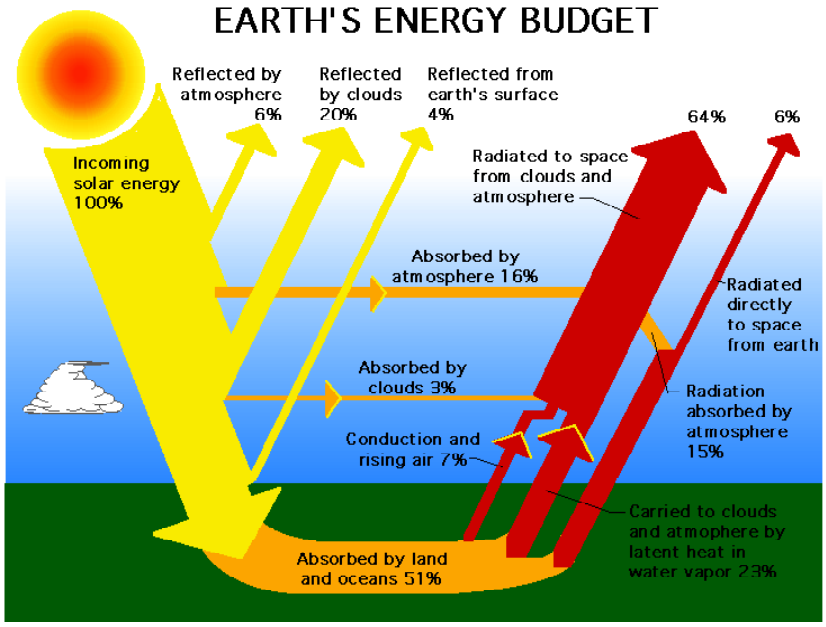


Figure 1: Graphic illustrating the balance of inbound and outbound energy flows (from Wikimedia, original by NASA).

rid of excess energy" or build "high power lasers to radiate excess energy away" are wrong and will not work for the following reasons: both Microwaves and Laser light are energy forms of higher quality. Accordingly, it requires a substantial amount of energy of lower quality to generate microwave radiation, and even more amount of energy to produce a powerful laser beam. A sizable portion of that energy (used to generate the microwaves or laser light) itself gets dissipated as waste heat, completely defeating the purpose.

It is therefore clear that once the heat has been dumped into the "low temperature reservoir" it is useless, it cannot be converted into other forms of energy without spending lots more energy, which would defeat the purpose of trying to get rid of that "wasted-heat".

Now that we have established that pretty much all energy used on earth eventually dissipates as waste-heat on the surface of the earth, the next question is why has the earth not already heated up by now?

3 ONLY WAY OUT: RADIATE TO SPACE

The answer is that the earth does lose a substantial amount of energy via thermal radiation, (also known as black-body radiation) into space. In fact this is the only way Earth is known to dissipate thermal energy out of it's system.

Since one half of the earth is always facing the sun all the time, the earth keeps getting solar energy input all the time. Yet, there is no runaway temperature increase observed on its surface. Rather, we are fortunate to be blessed with steady temperatures in the narrow range that is suitable for life. The (more or less or approximately) constant temperatures on the surface of the earth imply that there must be no "net" energy accumulation. Therefore the energy continually being input from the sun must be being dissipated to create a delicate thermal equilibrium.

3.1 Thermal Equilibrium on Earth

Figure 1 illustrates the Earth's energy budget. It was taken from Wikimedia (NASA staff, 2004), where it is available for download under the GNU public license (the wikipedia page also gives full credits, indicating that the original source was NASA)

In Figure 1, the sum of powers associated with all outbound arrows, which is the total power exiting the earth is

$$\begin{array}{rcll} \{\text{reflected power} & = & 30\% & = (6+20+4)\% \\ + & & + & + \\ \text{radiated power}\} & = & 70\% & = (64+6)\% \\ \hline \text{total outbound power} & = & 100\% & \approx \text{input-solar-power} \end{array}$$

3.1.1 Black-body Radiation: Quick Refresher (Wikipedia, 2013)

Thermal radiation power output of a black body is

given by the Stefan–Boltzmann law:

$$P = \sigma \cdot A \cdot T^4 \quad (1)$$

where the constant of proportionality σ is the Stefan–Boltzmann constant and A is the radiating surface area.

For surfaces which are not black bodies, the emissivity factor $\varepsilon(\nu)$ needs to be included (where ν is the frequency of the radiation emitted, and ε is a fraction). Approximating emissivity to be constant across the frequency spectrum (which holds true, especially around the peak emission wavelength), the formula for the power output becomes

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4 \quad (2)$$

This type of theoretical model, with frequency-independent emissivity lower than that of a perfect black body, is often known as a gray body.

From the above, it can be derived that the net power radiated out is proportional to the difference of fourth powers of the absolute temperatures T_b and T_s of the radiating body and the surroundings, respectively:

$$P \propto \left({T_b}^4 - {T_s}^4\right) \quad (3)$$

Therefore it is clear that the ***only way to dissipate excess heat via thermal radiation is by increasing the temperature T_b of the radiating body (which is the surface of the Earth in this analysis)***

4 DISCUSSION AND CONCLUDING REMARKS

Let $\mathscr{S}_E$ denote the total amount of solar-energy in Joules which the earth receives each year (it has been relatively steady across large time-spans and can be approximated to be a constant). We know for a fact the earth has been dissipating that much energy forever, creating a thermal equilibrium. It is therefore clear that as long as we keep our usage of energy to be a sufficiently small fraction of $\mathscr{S}_E$, we should not run into problems with thermal equilibria we've known forever. Therefore for the purpose of ensuing analysis, it is useful to focus on the ratio of the total energy used per year (denoted by U) to $\mathscr{S}_E$

4.0.1 How Close Are We to the Limit?

Using, data from The United States EIA (Energy Information Administration, an agency specifically created by the U.S. federal government to gather accurate energy consumption data and make forecasts) (EIA staff, 2013), in the year 2010, humanity consumed 524 quadrillion i.e., 524×10^{15} BTUs (British Thermal Units) of Energy. The solar energy input to the earth has been estimated to be about 173 Peta-Watts = 173×10^{15} Watts (NASA staff, 2004). Converting BTUs into Joules to obtain the amount of energy used annually and calculating the Joules received from the sun (by multiplying the wattage by the number of seconds in a year) and taking the ratio, we get the fraction:

$$f = \frac{U}{\mathscr{S}_E} = \frac{524 \times 10^{15} \times 1055.05585}{173 \times 10^{15} \times 365.2425 \times 86400} \approx 0.0001012664497 \quad (4)$$

note that

$$f > \frac{1}{10000} = 10^{-4} \quad (5)$$

4.0.2 Back-to the Question in Sec. 2.1.1

In light of the above facts, let us try to answer the hypothetical question raised in Section 2.1.1. as to whether or not we should try to divert extra sunlight toward the earth.

Note that if we (humans) were able to get even 1% extra energy from the sun (in addition to $\mathscr{S}_E$) each year, in 100 years we would have dissipated extra amount = ($2\,\mathscr{S}_E$). Such a continual accumulation (above the safe limit $\mathscr{S}_E$) is bound to cause a noticeable increase in the average temperature on the surface of the earth over several centuries.

Thus, even without the presence of greenhouse gasses, unlimited consumption of even the greenest forms of energy by itself would still lead to the same dreadful end result: runaway global warming with disastrous consequences (albeit more slowly as compared with the case where the generation and release of greenhouse gases is not controlled).

4.0.3 Let U Be Capped Well Below $\mathscr{S}_E$; Can We Use that Energy U without Restrictions?

Finally we address another interesting line-of-arguments that follows:
The earth gets a fixed amount of solar energy ($\mathscr{S}_E$). Independent of whether or not we turn it into electricity or other of forms energy in the interim, the original input energy is finally dissipated as waste-heat and is radiated away. Coupled with the assumption that the total amount of energy the sun gives us is way more than we need, we should be able exploit the incident sunlight without restrictions?

Our response is 3 fold:

1. This reasoning already admits what we set out to

demonstrate, viz., the total energy usage U cannot exceed a certain cap/threshold = $\{\tau \mathscr{S}_E : \tau \ll 1\}$. The only question that remains at this point concerns the distribution of the energy used (while satisfying the cap on the total amount used).

2. Note that the calculations above ignore the heat generated from uncertain events such as volcano eruptions, earthquakes (move tectonic plates against huge friction), large forest fires, ... etc. If those were to be accounted/provisioned for, then the "slack" available (i.e., the amount of energy we can safely consume while maintaining current thermal equilibria) might turn out to be even smaller.

3. Finally, besides the total amount of energy dissipated, ***the distribution of solar energy on earth is equally important***. For example, it is well known that about 2/3 of the input solar energy goes into creating the Weather and Ocean patterns that have evolved over eons. ***It is wrong to simply dismiss the light falling into the deserts as "wasted energy"***.

For a concrete example, suppose that the entire Gobi desert in Central Asia and the high and dry plateau of Tibet and other arid highlands on the rain-shadow side of Himalayas were to be covered with solar panels (to harness the supposedly "wasted" energy); and the energy aggregated (electricity) were to be used in cities far-away.

Such a big energy diversion could cause a failure of the monsoon-rains that sustain about 2 billion people in the Indian subcontinent and south-Asia, leading to droughts and related calamities on an unprecedented scale (because one of the main reasons for the regular occurrence of the monsoon in south Asia is the uneven heating of the above mentioned deserts and arid highlands, together with the northern plains of India; starting from early summer/spring in April each year. This causes a relatively low pressure area which sucks the air from "neighboring areas" that are mostly covered by the Indian Ocean. The air trying to rush-in is therefore richly moisture-laden. The high barrier presented by Himalayas helps squeeze out even more moisture, resulting in monsoon rains (between mid June through September)). These rains are essential to sustain about 1/3rd of world's population and a rich bio-diversity of flora and fauna in the tropical rain forests.

4.1 Conclusion

Only supply sided viewpoint completely misses these critical issues. Any long term solution must also include limiting the demand for (and as a result, the consumption of) energy. This could require ratcheting down human population and making our lifestyles less energy intensive, which may seem unrealistic at this point in time. However if these facts are ignored, we might perish in our own entropy. If we let that happen, then we cannot call ourselves "intelligent" species.

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An Optimization Model for the Aggregation of End-user Energy Management Systems in a Residential Setting

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Abstract: This paper proposes a model for an aggregator of energy management systems (energy box aggregator - EBAg) to operate as an intermediary between individual energy management systems (local energy boxes) and the System Operator / Energy Market capable of facilitating a "load follows supply" strategy in a Smart Grid context. The EBAg is aimed at using the flexibility provided by end-users of demand-side resources to respond to system service requirements, via contracts, involving lowering or increasing the energy consumption in each time slot. The aim is contributing to the balance between load and supply, avoiding peaks in the aggregate load diagram, and coping with the intermittency of renewable sources. For this purpose an optimization model for the EBAg has been developed, which is tackled using a genetic algorithm based approach to deal with the combinatorial characteristics of the model.

1 INTRODUCTION

The efforts to reduce greenhouse gases (GHG) emissions related to electricity generation have been leading to a fast increase in the deployment of renewable generation (European Commission, 2010). However, renewable sources present characteristics that differ from conventional energy sources. The power output is driven by environmental conditions, which are inherently variable and outside the control of generators and system operators. They cannot be reliably dispatched or perfectly forecast, and exhibit significant temporal variability. As a result, the proper integration of renewables into the electric grid presents a major challenge and new tools are required to ensure the grid reliability.

At the same time, the energy consumption in European Union (EU) households has been steadily growing due to the widespread utilization of new types of loads and the requirement of higher levels of comfort and services. The electricity consumption breakdown in EU households was recently characterized (de Almeida et al., 2001), recognizing that several end-use loads present some kind of flexibility; therefore, if properly controlled these loads can be used as a demand side resource capable of offering a responsive behaviour (Kowli et al., 2010).

As far as security of supply is concerned, the most severe problems due to power intermittence occur in peak load hours, since most system resources are already in use and a sudden reduction of power generation can have critical consequences on the system reliability. Thus, instead of acting on the supply side, Demand Response (DR) programs and technologies have the potential to contribute to optimize consumption and reduce peak loads, in (near) real-time. In this way, DR is an enabling strategy for the successful integration of renewable energy sources in the electric system, in a perspective of integrated energy resource management, involving controlling flexible loads according to (price and/or emergency) signals from the grid and end-users' preferences. In addition, DR can become a new source of revenue for entities that "aggregate" this load flexibility (Joo et al., 2007).

In a Smart Grid context, it is expected that the traditional end-user will become a *prosumer* (i.e., simultaneously producer and consumer) and dynamic (time-differentiated) electricity tariffs will be offered (Livengood and Larson, 2009). Therefore, an in-house demand responsive energy management system (Local Energy Box - LEB) is required, based on fully interactive Information and Communication Technologies (ICT), to help the end-user optimizing

the energy use without compromising comfort, achieving energy savings and satisfying constraints on the quality of the energy services provided. The LEB should also enable two-way communication, between the house and the grid in order to improve the global performance of the electric power system (Livengood and Larson, 2009); (Verschueren et al., 2010). Otherwise, in a scenario of a low price signal from the grid, all LEB devices would attempt to achieve benefits for the end-user engaging in similar actions (e.g., by shedding the same type of loads), eventually taking no notice of the instability that could impair the operation of the system, since the true impact of household consumption arises when it is summed up over a large number of houses (EU Comission Task Force for Smart Grid). In this context, a few recent studies have addressed the combination of demand and supply sides, to implement DR programs for the provision of system services, i.e. the balancing services that are provided by system operators for ensuring reliable system operations (EU Comission Task Force for Smart Grid). These services have been traditionally provided by generators, which are capable of adjusting their output rapidly in response to unanticipated imbalances between supply and demand. In the Smart Grid context, the provision of these services by aggregating electricity consumers using DR programs is becoming an attractive alternative (Agnetis et al., 2011).

In this context, an aggregator energy management system (Energy Box Aggregator - EBAg) is proposed, which is an intelligent mediator between the end-users (via LEB) and the grid (System Operator / Energy Market, SO/EM) allowing the coordination of a large-scale dissemination of in-house DR devices (Figure 1).

The main aim of the EBAg is to provide system service requirements, increasing the grid efficiency, ensuring the required levels of supply security, reliability and quality of service, taking into account inputs such as end-user flexibility of operation of demand-side resources and both grid and load technical constraints, thus contributing to the balance between load and supply coping with the intermittency of renewable sources and avoiding peaks in the load diagram, while minimizing overall electricity supply costs (Kowli et al., 2010).

The optimization problem faced by the EBAg consists in receiving requests from the grid to lower or increase electricity consumption and allocating these requests among clusters of LEB while satisfying technical and quality of service constraints, in order to maximize its profits. This is a combinatorial problem and an approach based on genetic algorithms (GA) has been developed, which combines features for handling discrete and continuous variables.

This paper is structured as follows. Section 2 introduces the problem formulation and the related key concepts, also referring to model and business strategy and the potential benefits for the end-user and the grid (SO/EM). Section 3 presents the optimization model and the algorithmic approach, which has been used in an experimental case study presented in section 4. The results of the simulations are briefly presented in section 5. Concluding remarks and future work are outlined in Section 6.

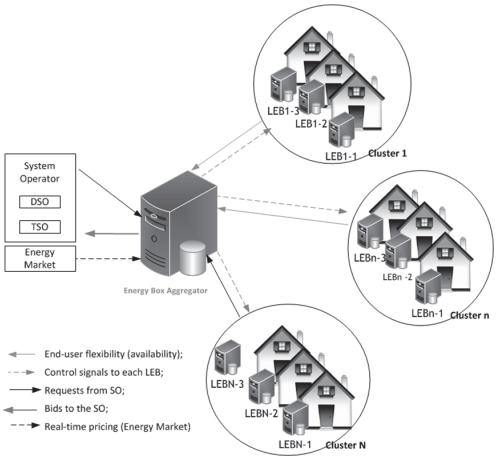


Figure 1: EBAg mediating the relation between LEB and the grid.

2 BUSINESS MODEL AND STRATEGY

This section presents a framework for analysing the EBAg role in the electric power system and the players involved. This comprises the information that is transmitted to/from the LEB, which interfaces the end-user directly with the EBAg, and the relation of the EBAg with the grid (SO/EM).

Nowadays the only direct relation between the grid and the end-user is with the retailer company, being associated through a contract for power supply with specific tariffs (power and energy prices). In such framework end-users are not generally aware of the existence of the energy market.

The energy consumption of domestic consumers presents some flexibility and end-use loads may be broadly characterized into four categories:

- Shiftable: loads that can be used in another period of time and therefore can have their

working cycle anticipated or postponed but not interrupted (e.g, dishwashers or laundry machines);
- Re-parameterizable: loads that can have their control parameters re-set (i.e., air conditioners);
- Interruptible: loads whose operation can be interrupted during a certain period of time (e.g., electric water heaters).
- Non-controllable: loads that cannot be the target of any type of demand response actions (e.g., computers, entertainment);

Based on this end-use load categorization, it is possible to exploit the load flexibility within each house. The large-scale deployment of LEB imposes an essential challenge concerning the coordination of grid and end-user objectives. I.e., requests from the grid should be weighed against the flexibility of end-use loads to be shifted, re-parameterized or interrupted in a certain period of time. The EBAg will gather this flexibility from the end-users by means of each LEB, asking them to adjust their load profile by offering a remuneration scheme specified in a contract, which is typically variable along the day with some relation with market prices.

Thereby, the EBAg is able to sell the flexibility gathered by making offers to the grid according to its requests in each time slot (i.e., increase or decrease a certain amount of load), with the aim of optimizing its own profits and offering benefits to all entities involved (increasing retail profits, decreasing consumption costs). Figure 1 and figure 2 depict the architecture adopted.

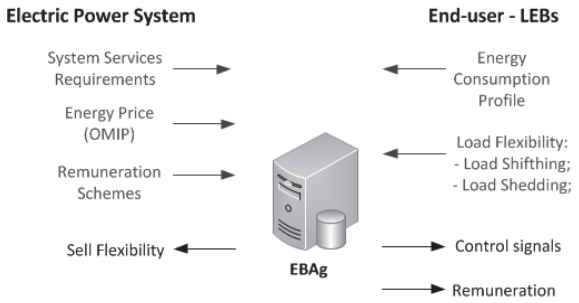


Figure 2: EBAg global architecture.

The EBAg sees its associated end-users grouped into clusters, which contain end-users with similar characteristics. The normal energy profile of the cluster, i.e. in the absence of a flexibility request, can be represented as a baseline load profile curve. The EBAg knows the baseline load profile of clusters as well as the possible load profile responses associated with each request.

The time variable remuneration schemes are known, i.e. the €/kW value paid by the grid to the EBAg and by the EBAg to the clusters. The incentive to remunerate the customer to participate in DR programs is a significant issue for the success of this type of programs (Quinn et al., 2010). An adequate EBAg business model should be designed to attract and maintain residential end-users under demand management contracts, in which end-users receive a reward to offer a certain amount of load flexibility to the EBAg. Customers sign up for programs depending on the benefits they derive in the form of upfront payments, i.e. when demand discounts and interruption payments exceed their perceived cost of interruption or consumption shifting (Fahrioglu and Alvarado, 2000).

The remuneration scheme presently implemented is based on the electricity price at OMIP (MIBEL - Iberian EM) (OMIP). The remuneration schemes are in place when the EBAg requests for consumption change are satisfied. The EBAg may be an Energy Service Company (ESCO) that buys and manages the end-user's flexible load and sells it to provide system services to the SO/EM.

Using the information gathered from the grid (SO/EM) and the individual LEB aggregated in clusters, a model to maximize the EBAg profits is developed that is then tackled using a GA approach.

3 OPTIMIZATION MODEL

The model aims at determining the best matching of the requests by the grid and the flexibility specified by the LEB. Binary variables denote whether or not the EBAg is able to gather load flexibility from the clusters and offer it to the grid, in each time slot. Continuous variables represent the corresponding amount of energy managed.

Indices:

c - 1,2, …C. Identifies the cluster, where C is the number of clusters associated with the EBAg. Each cluster gathers a set of end-users (LEB).

f - 0,1,… F. Identifies the request that the EBAg sends to cluster *c*; *f*=0 means that no request is sent by the EBAg. The EBAg congregates the flexibility offered by each cluster. A response function is associated with request *f*.

t = 1,2,…T. Identifies the time slot. A time resolution of 15 minutes is considered, thus having T=96 time slots in one day.

Coefficients:

E_t - Reward paid by the grid to the EBAg for the load flexibility provided, in each time slot *t*.

I_t - Reward paid by the EBAg to the clusters for the load flexibility provided, in each time slot *t*.

L_{ctf} - Load flexibility (kW) response function (i.e., consumption reduction) of cluster *c* in each time slot *t*, associated with request *f*.

$Lmax_{ct}$ - Maximum value of flexible load (kW) in each cluster *c*, in each time slot *t*.

$Pmin_t$ – Minimum amount of load (kW) the EBAg can offer to the grid, in time slot *t*.

R_t – Consumption reduction request from the grid (kW), in each time slot.

Decision variables:

$a_t \in \{0,1\}$. Represent the decision offers of the EBAg to the grid, in each time slot t. If $a_t = 1$ then the EBAg is able to present an offer to the grid in time slot *t*, according to the grid request R_t. Otherwise, $a_t = 0$.

P_t – Continuous variable representing the quantity of power (kW) that the EBAg is capable to offer to the grid, in each time slot *t*: $P_t > 0$ when $a_t = 1$.

$b_{ctf} \in \{0,1\}$. Represents the decision of sending an action/signal to each cluster *c* in time slot *t* responding to request *f*. If b_{ctf}=1 then the EBAg obtains the load flexibility response function L_{ctf}. Otherwise, b_{ctf}=0, $f = 0$ and the cluster is in the baseline load profile.

D_t – Continuous variable expressing the overall flexibility for all clusters *c* associated with the EBAg. It assumes only positive values since it represents a consumption reduction, in each time slot.

The objective function consists in maximizing overall EBAg profits.

$$max \sum_{t=1}^{T} P_t . E_t - \sum_{t=1}^{T} D_t . I_t$$

The first term accounts for the gains from selling the load flexibility to the grid, while the second term accounts for the cost that the EBAg has to pay to the clusters for their participation.

Subject to:

1. Only one action/signal request *f* for each cluster *c*, in each time slot *t*:

$$\sum_{f=0}^{F} b_{ctf} = 1, \forall_c, \forall_t$$

2. In each time slot, it is assumed that the load flexibility response function (L_{ctf}) has an upper bound of the maximum value of flexible load ($Lmax_{ct}$) in each cluster c. The overall load flexibility in each time period is obtained:

$$D_t = \sum_{c=1}^{C} \sum_{f=0}^{F} L_{ctf}\, b_{ctf}\ , \forall_t$$

3. The amount of power offered to the grid is bounded by a minimum offer and the overall load flexibility response gathered from all clusters, whenever the EBAg is able to present an offer to the grid (a_t=1):

$$Pmin_t\ a_t \leq P_t \leq D_t\ a_t, \forall_t$$

4. Whenever the EBAg receive a request from the grid, R_t, the offer to the grid, P_t, cannot exceed the requested flexible load in each time slot:

$$P_t \leq R_t, \forall_t$$

4 ALGORITHMIC APPROACH

A GA approach has been developed to tackle this model, namely to cope with its combinatorial nature. GAs efficiently exploit the search space using genetic operators (selection, crossover and mutation) to create new individuals (solutions) with expectedly improved performance. The evolutionary search process balances two main procedures: exploring the whole search space and exploiting the neighbourhoods of promising solutions. A GA for a particular problem has generally the following components: a representation (encoding) of potential solutions to the problem; a procedure to create an initial population of solutions, generally taking into account model constraints; a fitness function to evaluate the quality of solutions, possibly including a penalty term associated with constraint violations; genetic operators that make the solution population evolve, trying to preserve its diversity; values for the parameters (population size, probabilities of applying genetic operators, etc.).

The model and the GA approach have been implemented in Matlab. A problem-specific repairing process of infeasible solutions obtained in each generation has been designed. The size of the population is 100 individuals. Binary tournament has been used as the selection method. Elitism is considered by retaining the 3 individuals with better fitness, which go into the next generation population without being subject to the operators in order to guarantee that the best solutions are not lost. One-point crossover operators have been designed taking into account the binary/continuous nature of

decision variables. These operators ensure the consistency relations to be satisfied between the corresponding sets of binary and continuous variables. Mutation is a genetic operator used to maintain diversity in the population and promote the exploration of the search space. The mutation operator is also tailored to the binary and continuous variables ensuring their mutual consistency after mutation is carried out. For binary variables a bit flip is done with a certain probability, and for continuous variables a change is made within a given interval centered in the present value using a uniform distribution. After applying the mutation operator, infeasible solutions are subject to a repairing process. The evolutionary process ends after 100 generations, which has been set after experimentation.

5 CASE STUDY

Experiments have been carried out, based on real consumption data gathered through audits. These data provided a realistic basis to the specification of clusters, energy prices, baseline load profile, load flexibility response functions, bounds for load flexibility offered by each cluster, and bounds for the offers the EBAg can make to the grid.

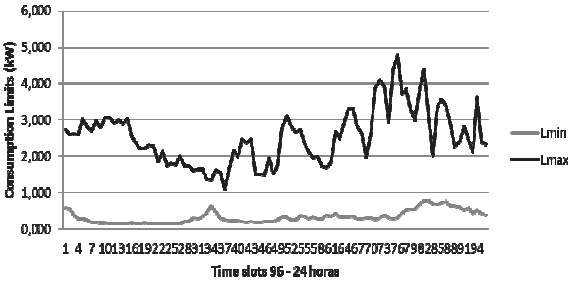


Figure 3: Maximum and minimum consumption of a cluster, in each time slot.

The data for these experiments have been obtained from a sample of 30 users of the Cloogy technology (CLOOGY), which is an energy management solution that allows monitoring and controlling energy consumptions in households. The energy consumption was monitored during one year, January 2012 to January 2013, with a time resolution of 15 minutes. An inquiry has then been made in order to create the house energy profile of each end-user (baseline load profile).

Clusters have been defined based on specific features of each house, namely geographical distribution, contracted power, number of inhabitants in the house, number and type of appliances and house typology (see table 1).

The experiments herein reported have been made with a reduced data set in order to moderate the computational effort. Each cluster is composed of 100 users (using the average of 30 end-users actually audited taking into account their consumption profile). Table 1 displays the daily consumption (kWh), the average power, the maximum power and the minimum power in each time slot for each cluster.

Table 1: Examples of clusters.

Clusters	Typology	Dweller	Consump. (kWh)	Ave. (kW)	Max. (kW)	Min. (kW)
C1	T0-T1	1-2	10,09	0,42	1,15	0,14
C2	T1-T2	2-3	12,22	0,51	1,21	0,25
C3	T2-T3	3-4	16,34	0,68	1,3	0,48
C4	+ T4	+4	33,45	1,4	3,1	0,18

The electrical signature of shiftable loads has been monitored for different machine (laundry and dishwashing) models and programs. These electrical signatures have been used to derive the load flexibility response functions associated with each cluster.

The evolution of the GA can be seen in figure 4, where the upper line displays the evolution of the best solution in the population, and the lower line displays the average performance of the population.

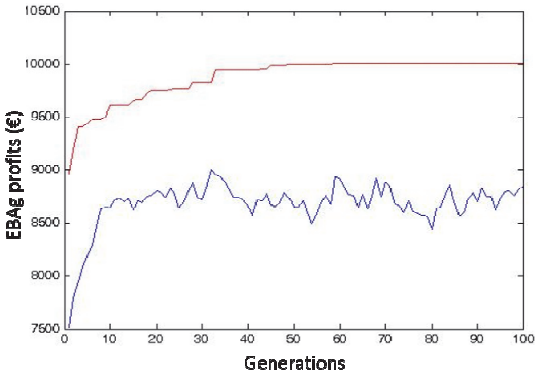


Figure 4: Representation of the GA performance, with 100 generations.

In general, after 60 generations the best solution is achieved. The best solution obtained gives an objective function value (EBAg profit) of 10.007€/day.

The load flexibility offered by each cluster to the EBAg is illustrated in Figure 5, and Figure 6 represents the load diagram of the cluster before

(baseline load profile) and after (flexible load diagram) the AG execution.

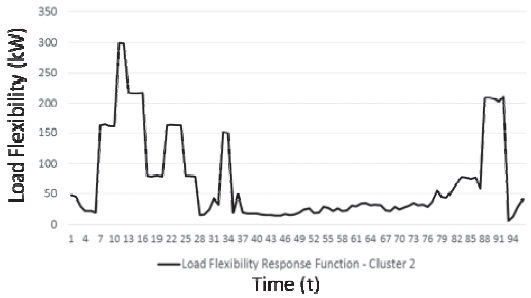


Figure 5: Representation of amount of load flexibility response function, in each time slot, provided by each cluster (example of Cluster 2).

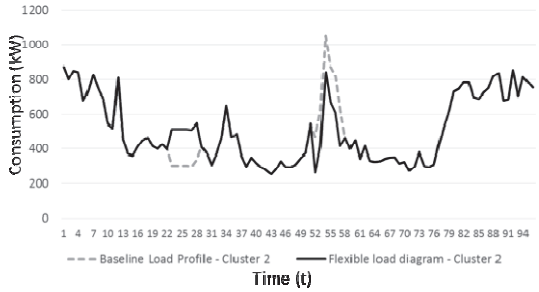


Figure 6: Representation of the baseline load profile and the flexible load diagram of the Cluster 2.

The global load flexibility provided by all clusters to the EBAg (*Dt*) is displayed in Figure 7.

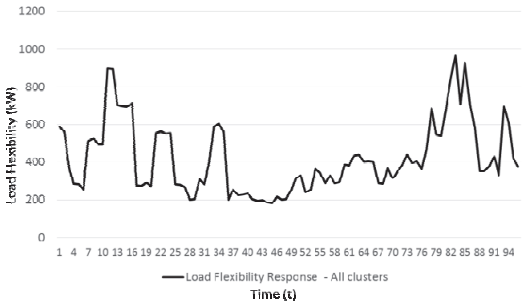


Figure 7: Representation of the amount of load flexibility offered by all clusters.

6 CONCLUSIONS

This paper presents the conceptual and operational framework of a model for a new entity - EBAg, that uses the load flexibility provided by each end-user (via LEBs), responding to the grid requests to facilitate a load follows supply strategy in a Smart Grid context, with potential benefits for all participants involved. The role of the EBAg is twofold: it makes the most of demand responsive loads according to in-house load flexibility and it provides system services that contribute to improve the system operation.

The optimization model from the EBAg perspective presents combinatorial characteristics and an approach based on GAs is proposed to deal with it. Work is underway to deal with the dynamic nature of the problem, uncertainty associated with several parameters, and multiple objectives (economic, quality of service, fairness).

ACKNOWLEDGEMENT

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A Study on Reliability Assessment for Offshore Wind Farm Configurations

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Keywords: Reliability Assessment, Offshore Wind Farm, Cost/Reliability Analysis, PNDR (Power Not Delivered Ratio), EEND (Expected Energy Not Delivered).

Abstract: Due to environment concern, fossil resource exhaustion issue and so forth, an attention on the use of renewable energy is being increased sustainably and various types of renewable energy are being developed. In particular, wind power plant is one of the most used resources among them. The recent trend in development of wind power is the large-scale offshore wind farm. However, the burden of investment for offshore wind power is still considerable so that comprehensive evaluation must be performed in the planning stage. For the evaluation, this paper introduces the concept and method to assess offshore wind farm according to their configurations, in the reliability aspect.

1 INTRODUCTION

Wind energy is one of the most used renewable energy resources. The related technology has advanced and a penetration of wind power has being increased sustainably. Furthermore, an installation capacity of a wind power plant has being increased.

There are two types of wind power developments according to the size. One is used as a small scale distributed generator, and the other is a large-scale wind farm. In addition, wind power plant can be developed at onshore or offshore. The recent trend is the offshore wind farm (OWF) which can gather more wind energy and avoid several problems that occur at onshore, such as noise pollution, destruction of the environment and concerns related with construction. However, compared with onshore, OWF has crucial disadvantages which are the more expensive investment and maintenance costs, and the fault effects lasted for a longer time due to a difficulty of geographical access. Therefore, OWF operator has a considerable burden on investment for OWF, so OWF operator has to determine a configuration and design for OWF comprehensively, in order to achieve the economic feasibility. The second one of disadvantages is evaluated by a cost through a reliability assessment, and the reliability and economic analysis can be performed using the result of the reliability assessment. For this, the following indices are redefined in order to represent the results of reliability assessment. PNDR is the power not delivered ratio, EEND is the expected energy not delivered. EENDC is the cost on EEND.

The rest of the paper is organized as follows; In section 2, basic compositions of OWF are described. In section 3, a method to evaluate a reliability of OWF according to wind power configurations is introduced. In section 4, brief case studies are performed in order to demonstrate the introduced method. Finally, section 5 contains a conclusion of this paper.

2 OFFSHORE WIND FARM

Basic composition of large scale offshore wind farm is represented in Fig.1, which consists of wind turbines, inner grid, offshore substations and external grid.

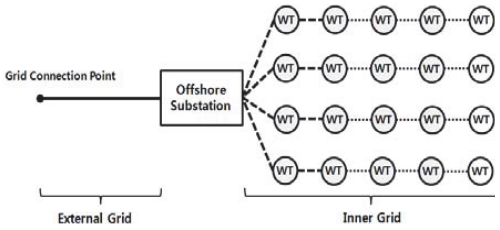


Figure 1: Basic Composition of OWF.

An electrical energy produced at wind turbines is aggregated thorough inner grid. And then, a voltage of the energy is made higher in order to transfer efficiently toward onshore at transformers in offshore substation. Finally, the energy is delivered toward onshore through external grid.

At the planning stage for OWF, the locations of wind turbines and offshore substations are preferentially decided considering a geographical condition, in order to gather more wind energy. And then, the design and configuration for inner grid, offshore substation and external grid are decided. There are diverse alternatives based on how to connect wind turbines and how to configure substation and external grid. Each alternative of OWF has had different performance on any failure in the OWF and it is indicated as the difference in results of reliability evaluation. When the planning for OWF is performed, considerations for each component are as follows.

In case of designing inner grid, there are the following considerations;

- the voltage of inner grid
- transfer capacity of cables
- the number of feeders(wind turbines per feeder)
- the layout for inner grid: the radial, star and ring types;

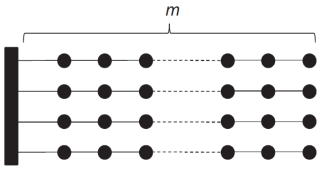


Figure 2: Layout of radial structure.



Figure 3: Layout of star structure.

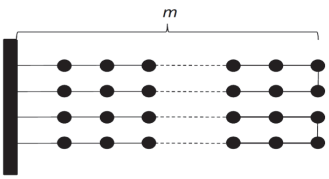


Figure 4: Layout of ring structure.

In case of offshore substation, the following factors are considered.

- the number of transformers
- a capacity of each transformer

In case of external grid, the factors to be considered are same with case of offshore substation.

- the number of transmission lines
- the capacity of each transmission lines

3 RELIABILITY ASSESSMENT ON OFFSHORE WIND FARM

In this paper, a quantitative reliability assessment is performed in viewpoint of OWF operator. Therefore, the goal of reliability assessment is to quantitate how much an expected energy is delivered to onshore from wind turbines considering interruptions in OWF. For this, the following indices are redefined. PNDR is defined as the ratio of a power not delivered by any failure to a power in non-failure state. EEND means the expected value of energy which is not delivered, reflecting all failure states defined at each component. At this time, the failures that may occur at any component, affect to the next component consecutively, so that failure states at any component should contain the failure states defined at the previous component. This fact is represented in Fig. 5.

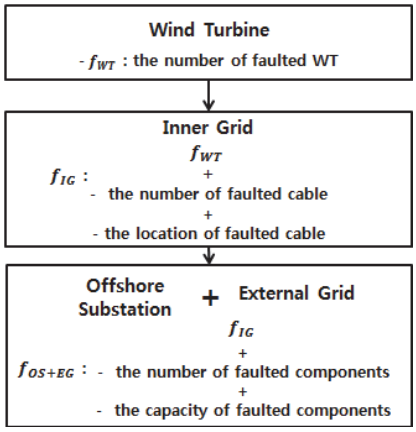


Figure 5: Failure States at each component.

3.1 PNDR at Wind Turbine

Although wind turbines are not related directly to the ability to transfer energy toward onshore, faulted wind turbines affect the transfer ability at next component. Therefore, ratio of energy not produced at wind turbine due to failure of wind turbines can be evaluated like PNDR at wind turbine. PNDR at wind turbine can be calculated as ratio of the number of faulted wind turbines to the total wind turbines.

3.2 PNDR at Inner Grid

PNDR at inner grid is influenced by sum of the number of faulted wind turbines and disconnected wind turbines according to locations where cable faults occur. Because of cable failure with a very low probability, two or more cable failures are ignored in this paper.

There are two different approaches to calculate PNDR at inner grid based on the layouts. In case of a layout of radial structure, PNDR is calculated by ratio of the net disconnected wind turbines to the total wind turbines, the net disconnected wind turbines mean the union set consisting of the faulted wind turbines and the disconnected ones. However, in case of a layout of ring structure which has the redundant cables, a more complex approach is applied. When a failure occurs at one among feeders composing a ring structure, power disconnected by the cable failure would detour through the other feeders in the ring structure. All the remained wind turbines in the ring structure, except for wind turbines connected normally toward offshore substation in the faulted feeder may be limited according to wind speed. If power to be delivered through non-faulted feeders is higher than their total rated capacity, the rated power of the wind turbines is restricted as shown in Fig. 6.

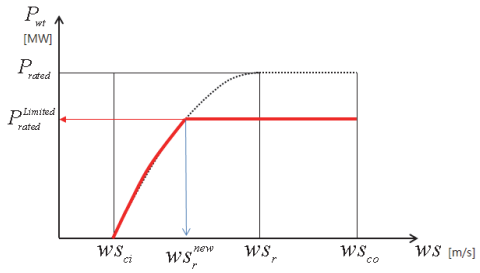


Figure 6: Normal/Restricted Output Characteristic of WT.

Therefore, in case of layout of ring structure, relationship between power delivered through non-faulted feeders and their total rated power is considered as well as the net number of disconnected wind turbines. Equation related to the limited rated power of wind turbine is represented by Eq (1).

$$P_{r,New}(f_{OS+EG}) = \begin{cases} P_r & \text{if) } P_r \le \dfrac{A\_Cap(f_{OS+EG})}{N_{WT} - n.n_{WT}(f_{IG})} \\ \dfrac{A\_Cap(f_{OS+EG})}{N_{WT} - n.n_{WT}(f_{IG})} & \text{if) } \dfrac{A\_Cap(f_{OS+EG})}{N_{WT} - n.n_{WT}(f_{IG})} < P_r \end{cases} \quad (1)$$

where, f_{OS+EG} means failure state at offshore substation and external grid and contains failure factors at formal components, $A\_Cap(f_{OS+EG})$ is total capacity of non-faulted feeders in a ring structure, P_r is the rated power of wind turbine, N_{WT} is the number of wind turbines and $n.n_{WT}$ is the number of the net disconnected wind turbines.

3.3 PNDR at Offshore Substation and External Grid

Failure factors considered at two components affect to PNDR of each component equally. Therefore, Failure factors at two components are handled together. Containing formal failure factors, failure states can be defined by combination of faulted transformers and external lines. If failures occur at transformers and/or external lines, all wind turbines may reduce their rated power only when power to be delivered toward onshore from inner grid is higher than the available capacity of offshore substation and external grid. This process for determining the limited rated power is same with case at inner grid composed by ring structure.

After obtaining all PNDR under predefined failure state at all components, an expected value of PNDR is calculated by multiplying each PNDR and the corresponding probability of failure state. And then, an expected PNDR is used in order to evaluate EEND. EEND is obtained by multiplying EPNDR and an expected energy produced by the entire OWF in non-failure state. This process is shown in Eq (2).

$$\begin{aligned} EPNDR &= \sum_{\forall f_{OS+EG}} PNDR(f_{OS+EG}) \cdot \Pr(f_{OS+EG}) \\ EEND &= EE_{OWF} \times EPNDR \\ EENDC &= EEND \times asp \end{aligned} \quad (2)$$

where, $\Pr(f_{OS+EG})$ is probability of that the failure state, f_{OS+EG} occurs. EE_{OWF} means an expected annual energy of OWF in non-failure state and asp is an average settlement price of electrical energy generated by wind turbine.

4 CASE STUDY

In the section, brief case studies are performed in order to demonstrate the proposed method. OWF is composed by 28 identical 5MW-wind turbines. Wind speed model is applied identically by historical data model obtained at the southwest coast in Korea. The expected annual energy of the entire OWF is 367,159.6MWh considering no failures.

Basic alternatives based on layouts of inner grid are represented by Fig. 7-9.

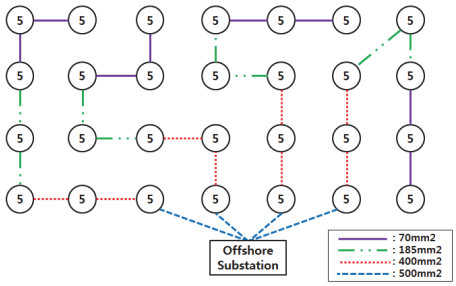


Figure 7: Basic Case 1.

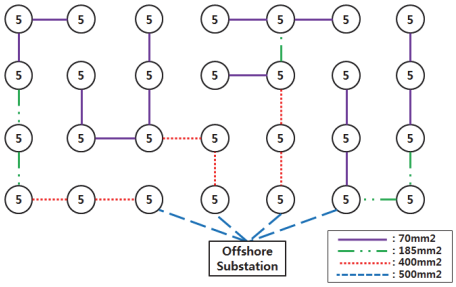


Figure 8: Base Case2.

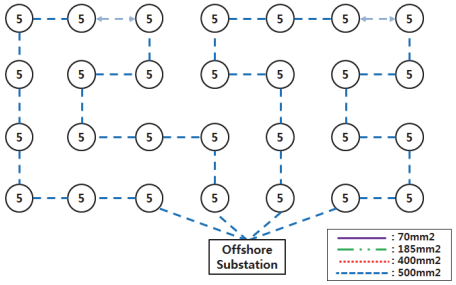


Figure 9: Base Case3.

Cable data in inner grid are represented in Table 1.

Table 1: Data for Cable in Inner Grid.

Cable type[mm2]	70	185	400	500
Available Capacity [MW]	13.0	21.5	31.5	35.5

Individual basic cases are also separated into the four sub-cases according to the number and capacity of transformers and external grid cables, as shown in Table 2.

Table 2: Data for sub cases.

No. Sub Case	-1	-2	-3	-4
Transformer	150MW x 1	75MW x 2	150MW x 1	75MW x 2
External Grid Cable	150MW x 1	150MW x 1	75MW x 2	75MW x 2

For the simplicity, it is assumed that reliability data for each component (Inner/External Cable, Transformer) is identical. The reliability data for individual components are shown in Table 3.

Table 3.

Components	WT	Inner Cable	Trans.	External Cable
Unavailability	0.016	0.00025	0.016	0.0025

The results for all cases are represented as the following Table 4-6, where 0.2$/kWh is applied as average settlement price of wind energy in order to calculate EENDC.

Table 4: Result of Case 1.

		Case 1			
No.Sub-		-1	-2	-3	-4
EPNDR [%]	WT	1.60			
	Inner Grid	1.70			
	OWF	3.51	2.17	3.30	1.95
EEND_OWF [MWh]		12,887.3	7,967.4	12,116.3	7,159.6
EENDC [10^6 $]		2.58	1.59	2.42	1.43

Table 5: Result of Case 2.

		Case 2			
No.Sub-		-1	-2	-3	-4
EPNDR [%]	WT	1.60			
	Inner Grid	1.68			
	OWF	3.50	2.15	3.29	1.94
EEND_OWF [MWh]		12,850.6	7,893.9	12,079.6	7,122.9
EENDC [10^6 $]		2.57	1.58	2.41	1.42

Compared with Case 1, Case 2 has less value of EPNDR and EENDC, respectively, due to a modified radial structure.

Table 6: Result of Case 3.

		Case 3			
No.Sub-		-1	-2	-3	-4
EPNDR [%]	WT	1.60			
	Inner Grid	1.60			
	OWF	3.41	2.06	3.20	1.85
EEND_OWF [MWh]		12,520.1	7,563.5	11,749.1	6,792.5
EENDC [10^6 $]		2.50	1.51	2.35	1.36

As shown in Table4-6, Case3-4 which has a layout of ring structure for inner grid and two transformers and external cables is the best alternative in terms of reliability aspect. On the other hand, Case 1-1 with a layout of typical radial structure and one transformer and external cable is the worst alternative. However, in particular, there is more investment cost for constructing inner grid which has ring structure. Therefore, the best alternative for offshore wind farm has to be determined considering not only reliability assessment, but also economic assessment.

5 CONCLUSIONS

In this paper, a method to perform the reliability analysis for offshore wind farm has been introduced. Basic components of offshore wind farm are divided into four components which are wind turbines, inner grid, offshore substation and external grid. According to a design or configuration for each component, there are diverse alternatives for offshore wind farm. The proposed method can evaluate reliability at each component level step by step, and then the results can be used for reliability and economic assessment to determine the best alternative for offshore wind farm.

As for future work, it is expected to study on how to design optimally inner grid using the suggested method in offshore wind farm.

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Towards Energy-aware IaaS-PaaS Co-design

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Abstract: The wide adoption of the cloud computing paradigm plays a crucial role in the ever-increasing demand for energy-efficient data centers. Driven by this requirement, cloud providers resort to a variety of techniques to improve energy usage at each level of the cloud computing stack. However, prior studies mostly consider resource-level energy optimizations in IaaS clouds, overlooking the workload-related information locked at higher levels, such as PaaS clouds. In this position paper, we argue that cross-layer cooperation in clouds is a key to achieving an optimized resource management, both performance and energy-wise. To this end, we claim there is a need for a cooperation API between IaaS and PaaS clouds, enabling each layer to share specific information and to trigger correlated decisions. We identify the drawbacks raised by such co-design objectives and discuss opportunities for energy usage optimizations. Moreover, we outline the design of a set of extension modules for Libcloud to serve as building blocks for cross-layer information sharing and cooperation.

1 INTRODUCTION

Energy efficiency is a major concern in large-scale cloud infrastructures. In 2010, data centers worldwide reportedly consumed 203.4 to 271.8 TWh, which accounted for 1.1% to 1.5% of the global electricity use. This number is expected to grow even further (Koomey, 2011). To help make the planet greener while reducing their energy-related costs, cloud operators use a variety of techniques such as workload consolidation and dynamic virtual machine (VM) resizing. These strategies are however fundamentally limited by the lack of knowledge by the data center infrastructure about the applications that generate the workload. If the data center infrastructure understood better the full software stack it supports, it would be able to use more aggressive consolidation policies and derive further energy savings.

Platform-as-a-Service (PaaS) environments deliver users complete runtime environments for building, deploying and hosting software applications, while dispensing them from the complexity of managing the underlying software and hardware required for their applications. PaaS systems rely on computational resources obtained on-demand from Infrastructure-as-a-Service (IaaS) clouds, by acting as clients that can create/remove, suspend/resume, shutdown/restart, or migrate VMs.

This position paper claims that significant energy gains could be obtained by creating a cooperation API between the IaaS layer (in charge of handling elementary computing resources) and the PaaS layer (in charge of hosting applications). We discuss two complementary approaches for establishing such cooperation:

Cross-layer Information Sharing. Each of the two layers contains information which is potentially relevant for the other in order to reduce the energy footprint of a given application. For example, an energy-aware IaaS may have an estimate of the energy footprint of individual virtual machine types, which may be useful for the PaaS to preferentially select energy-efficient VM instance types. Conversely, a PaaS layer may build short-term traffic predictions which constitute useful hints for IaaS-level consolidation algorithms.

Cross-layer Coordination. Both layers should coordinate their reconfiguration actions to reach a state where they help each other in achieving their goals rather than potentially take mutually detrimental decisions. For example, if the IaaS layer decides to migrate a specific VM, then the PaaS could in many cases temporarily reduce the load of the concerned

VM to facilitate its migration. Conversely, if the PaaS layer gives early warnings to the IaaS about future requests for creating/destroying resources, the IaaS layer can prepare in advance for these changes.

This paper proposes a research agenda towards the co-design of IaaS and PaaS layers. Section 2 first discusses the state of the art and motivation for this work. Section 3 details the issues created by the lack of IaaS-PaaS co-design. Then, Section 4 presents our early ideas about opportunities for improvement, while Section 5 outlines the design of interfaces to enable cross-layer cooperation in clouds. Finally, Section 6 concludes this work.

2 STATE OF THE ART

Many recent research works have been proposed to take into account the consumed energy in data centers. These works can be classified into two categories: (1) energy-aware systems and (2) energy efficient systems. The first category aims at informing cloud providers and users about the consumed energy for running their applications. For instance in (Singh et al., 2013), the authors propose a cloud-based customer-centric architecture that allows consumers to own and control access to their energy usage data and have it analyzed using algorithms of their choice. The second category aims at optimizing the consumed energy for running applications. Different techniques are used to achieve energy efficiency. In (Phan et al., 2012), the authors propose to increase the use of renewable energy by dynamically moving services across data centers. The works in (Jaiantilal et al., 2010; Takouna et al., 2011) propose to adjust CPU voltage and frequency according to the load for saving energy. In (Gadafi et al., 2010), the authors dynamically resize the active server set according to varying workload conditions. Workload consolidation on a limited number of servers is addressed in (Duy et al., 2010; Meisner et al., 2009), in order to allow idle servers to be switched off and save energy.

Other works have focused on analyzing the impact of various optimization techniques on energy consumption. For instance, in (Orgerie et al., 2010), the authors investigate the tradeoffs and limitations of existing energy models for large-scale systems.

3 ISSUES

3.1 Energy-awareness in IaaS and PaaS

PaaS frameworks provide application developers with runtime environments where applications can be easily deployed and managed in the cloud (Pierre and Stratan, 2012; Dib et al., 2013). They do not provide cloud resources directly, but rather make use of an underlying IaaS layer in charge of resource management. Consequently, PaaS does not have access to information about the underlying resources, while IaaS does not have access to information about the running applications. However, both IaaS and PaaS systems target multi-objective optimizations including primarily cost, performance and energy consumption. These parameters are intrinsically related, thus requiring complex trade-offs to be made between them.

Traditionally, energy-awareness and energy-efficiency have been addressed at the IaaS level with techniques presented in Section 2. To our knowledge, no research work has been targeting energy-efficiency or energy-awareness at the PaaS level. However, studies on real cloud infrastructures show that servers are considerably underutilized (Zhang et al., 2011), thus wasting large amounts of energy (Acc, 2010). This information about resource utilization is not available at the PaaS level, and nor is the energy consumption of resources. So, the PaaS layer has no means to provide energy-related metrics to users (e.g. energy-efficiency of their VMs, energy budget of their applications), and thus no way to increase their energy-awareness.

Conversely, the IaaS layer has no information about the applications and the users. As previously discussed, such knowledge would be useful to predict future resource utilization, thus leading to better energy-related decisions at the IaaS level.

3.2 The Case for IaaS-PaaS Co-design

We believe that the separation of the cloud stack in two distinct IaaS and PaaS layers, while having great advantages for portability and separation of concerns, is detrimental in terms of energy awareness. If each layer is allowed to take energy-related decisions independently, these uncoordinated actions can lead to significant resource waste and performance degradation, possibly negating the benefits of energy awareness altogether.

For instance, the IaaS layer can decide to migrate a virtual machine (VM) in order to perform a better consolidation for energy-efficiency purposes. Yet, this same VM may end a few seconds later because it

gets released by the PaaS layer. The decision to shutdown this VM may have been taken several minutes in advance by the PaaS layer. If this information is not communicated to the IaaS layer, we take the risk that IaaS will invest previous resources (for example by migrating the VM) without seeing any benefit from this action (because the VM gets shut down just after).

Conversely, the PaaS layer may help the IaaS layer in performing its VM management actions. For example, it is often easy at the PaaS level to temporarily redirect one VM's workload to another (by redefining load balancing parameters for example). Offloading a VM for just a few tens of seconds may greatly facilitate IaaS-level management tasks such as VM migration.

In order to avoid counterproductive independent optimizations, we believe that the IaaS and the PaaS should share their energy-related information and coordinate their reconfiguration actions. This coordination aims at allowing system-level optimizations and trade-offs.

4 OPPORTUNITIES

In order to design efficient cloud frameworks, both performance and energy-wise, it is essential to understand how the cloud stack layers can interact and cooperate. We argue that there is a need to extend the traditional boundaries of each class of cloud computing frameworks to ensure an effective management of resources, while delivering seamless application performance and SLA compliance to higher-level users. In this section we identify a set of design opportunities for both PaaS and IaaS providers to help address these goals. The research directions we investigate are twofold: first, we focus on the bidirectional information sharing opportunities between these cloud layers and the coordinated decisions they can trigger. Second, we discuss security concerns that arise from such interactions.

4.1 Workload-aware IaaS Frameworks

The emergence of a wide array of open-source IaaS solutions led to a gradual adoption of open standards and interfaces. This was a key incentive for enterprises to deploy private clouds in their data centers, allowing them to take advantage of the flexibility and performance of virtualized infrastructures, without the vendor lock-in shortcomings of proprietary solutions.

Most open IaaS cloud frameworks deliver similar services, typically focusing on resource management, VM lifecycle and on providing framework usage statistics. However, little has been done to achieve energy-efficient resource usage in such infrastructure clouds, despite the fact that lowering energy consumption is becoming a growing concern for data center management. This context provides a valuable opportunity for IaaS cloud providers to consider techniques that take into account the requirements of higher-level services, such as PaaS offerings, which traditionally build on infrastructure clouds. To this end, we believe that PaaS clouds can deliver a set of insights to the infrastructure level to guide its resource allocation and energy optimization decisions.

4.1.1 Passing Workload Information

VM allocation strategies typically rely on information concerning physical machine capabilities and their usage across the data center. Nevertheless, several factors may impact the performance of VMs, with critical side effects on application performance, user costs and power consumption. For instance, intensive network traffic between a few VMs may lower the available bandwidth across an entire cluster. On the other hand, PaaS virtual resource management services use the IaaS APIs to specify the number and type of VMs required upon application deployment. No information about the application class or its execution parameters is forwarded to the underlying infrastructure.

In this context, the answer to achieving better resource management at the infrastructure level is to enable IaaS schedulers to analyze and exploit a wider spectrum of parameters associated with the application behavior. Thus, as such workload properties are generally opaque to the underlying VM manager, a possible approach is to enable PaaS services to expose them to the infrastructure layer, as detailed below.

Resource Usage Patterns. The resource needs of VMs have a potentially heavy impact on the VM migration duration. As an example, it was shown that memory-bound VMs lead to very inefficient migration times (Liu et al., 2011). IaaS systems may avoid such operations by flagging affected VMs at deployment time. A more fine-grained approach may enable the PaaS services to trigger such flags dynamically, as the application enters a memory-intensive stage, and allow migration outside these intervals.

Execution Time. Cloud services can accommodate a large set of application types. For instance, web servers represent long-running jobs with specific access patterns. Oppositely, a short-lived VM, such as a MapReduce job, may raise specific scheduling constraints. Thus, as many MapReduce jobs run for short periods of time, migrating the VMs during ap-

plication execution may degrade their performance to unacceptable levels (e.g., migrating the VM may take longer than its actual runtime).

Elasticity needs. Unlike the infrastructure manager, the PaaS services may be able to estimate the application requirements in terms of workload peaks. As elasticity is one of the most appealing cloud features, anticipating application needs and passing them on to the IaaS layer may result in more timely workload adaptation mechanisms, which cannot be achieved by the PaaS services alone.

4.1.2 Using Workload Information to Reduce Energy Consumption

Such workload knowledge may allow IaaS providers not only to optimize resource allocation decisions, but also to improve the overall energy-consumption levels. This goal is typically achieved by adapting the number of used physical nodes to the workload and shutting down underutilized nodes (Orgerie et al., 2010). Taking into account additional PaaS-level aspects may lead to significant and accurate energy-saving decisions, as exemplified below.

Resource Scheduling. Resource allocation in IaaS clouds is generally based on the VM type and straightforward scheduling policies. Beyond the VM type in terms of required CPUs and memory, an essential parameter is represented by the association of VMs with a specific virtual cluster, and thus, a single application. By taking into account this type of hint made available by PaaS-level services, an IaaS provider may change the allocation process of similar VMs. For example, VMs belonging to the same job may be deployed on the same physical machines to benefit from data locality and avoid unnecessary and performance-degrading network traffic.

Node shutdown Policies. A widely studied mechanism to minimize energy consumption is shutting down unused nodes. However, resource managers usually lack any knowledge related to the type of workload or about the real-time evolution of resource requirements. Such information provided by higher-level services such as PaaS providers may allow for more aggressive shutdown policies, without incurring performance degradations. When the infrastructure manager is aware of the short-term evolution of its workload, it can adopt less conservative policies to reduce the powered-on resources and the total energy usage.

Management of Workload Peaks. Cloud services have developed on the premise that they can provide on-demand resource adaptation to workload bursts, relieving the client from the burden of over-provisioning resources to cope with unexpected workload fluctuations. Without any means to foresee the resource requirements of its scheduled jobs, an IaaS cloud is constrained to maintain a pool of unused running physical machines to accommodate possible workload peaks. To minimize the impact of such an approach on energy consumption, PaaS services may anticipate workload trends and, furthermore, forward them to the infrastructure level. Thus, IaaS schedulers can redirect small bursts to public clouds when the cost of switching nodes on is more important than the cost of obtaining remote VMs, both performance and energy-wise. When facing longer-duration workload peaks, the IaaS cloud can automatically adapt the pool of available physical machines, by enabling nodes in advance.

4.2 Optimizing PaaS Resource Management

Whereas advice from application-aware PaaS services may improve the efficiency of resource management decisions, PaaS frameworks can also benefit from infrastructure-level insights.

4.2.1 Exposing Low-level Knowledge to PaaS Clouds

Infrastructure Details. PaaS management services interact with the underlying infrastructure through the interfaces exposed by the IaaS provider, which typically hide low-level details from the user. As this information is provided in private clouds for administrative purposes, it can be also made available for higher-level entities, such as PaaS frameworks running on the infrastructure. For instance, knowledge about cluster utilization and node properties may allow the PaaS services to select the most suitable VM types to execute an application, enabling the use of large VMs when the infrastructure comprises high-performance physical machines.

Energy Awareness. The first step towards energy-efficient services at the platform level is user awareness, in particular if lowering the energy consumption is associated with monetary incentives. The user may be presented with several execution plans and the corresponding energy consumption estimations for the same application. He can thus choose the best execution schedule in terms of energy, regardless of a performance loss or a longer execution time. Nevertheless, the PaaS layer has no means to accurately estimate the energy consumption of a given application. It is at the IaaS level where such predictions can be made, based on the load of the infrastructure and the application requirements.

4.2.2 IaaS-PaaS Coordinated Decisions

Since PaaS services do not have full control over the management of their virtual resources, the key to an optimized resource usage and energy consumption lies in cross-layer coordination. Despite the fact that all VM allocation and placement decisions are taken at the infrastructure level, such a collaboration can lead to both improved scheduling mechanisms and a reduced incidence of conflicting actions.

Adaptive Resource Management. Equipped with detailed information about the user job, the IaaS layer can yield multiple scheduling options to handle it. According to user set thresholds, such as an execution deadline or a given energy budget, the IaaS resource manager may be extended to delay jobs according to the availability of energy-efficient or renewable energy sources (e.g., wind energy). PaaS may facilitate certain VM management actions as well. To reduce the time spent during VM migration, the PaaS can be instructed to temporarily decrease the load of the VM, which may entail performance and energy gains.

Preventing Conflicting Optimizations. Cloud cross-layer communication contributes to another unexpected, yet significant optimization angle for VM management, that is to prevent conflicting optimizations. As an example, the PaaS layer may detect an idle VM and redirect a slice of the job workload to it. Simultaneously, the infrastructure manager can decide to migrate the same idle VM, resulting in both an inefficient migration and a reduced performance for the PaaS application. To prevent such conflicting or counter-productive optimizations, it is essential to define a standardized interface and a set of parameters to be passed between the two layers, which can ensure portability and usability across cloud providers.

4.3 Privacy and Security Issues

As detailed before, cross-layer coordination can help increasing both energy awareness and energy efficiency of the entire cloud system. However, this coordination needs to be clearly defined as it can raise major concerns about the security and privacy of cloud providers and users. Indeed, it has been shown that having access to the energy consumption of a cloud server can allow people to guess with high probability what type of application (among various possible ones) is running in its virtual machines (Hlavacs et al., 2011). So, passing the information about energy consumption of servers is not possible for privacy's sake. It is therefore necessary to consider a coordination of these platforms that guarantees the privacy of the users and of the applications, while providing useful information to both layers in order to save energy. To do so, it is required to identify sensitive information that cannot be communicated between the two layers: energy consumption of physical servers, location of virtual machines (allowing users to target specific physical machines in order to be co-located with specific virtual machines). Moreover, the IaaS provider and the PaaS provider can be different, and they may not want to share sensitive information about the utilization of their platform.

5 PROPOSAL

To facilitate the interaction between cloud layers while preserving the separation and the interoperability across the cloud stack, we argue there is a need for an abstraction layer proposing coordination APIs. For instance, let us take the example of the Apache Libcloud (Libcloud, 2014) library. Libcloud consists of a set of Python libraries providing a unified abstraction across IaaS cloud APIs such as Amazon EC2, OpenStack or OpenNebula. It hides the differences between the various cloud providers by offering generic APIs for compute, storage, authentication, load balancers and DNS services. We believe such interfacing libraries can be the key of cross-layer interoperability in the cloud stack. The development of client libraries that expose APIs to promote collaborative decisions between IaaS clouds and higher-level frameworks may come as an incentive for cloud providers to exploit the potential benefits of inter-layer cooperation.

We aim at defining a set of APIs to complement existing Libcloud features with new mechanisms for designing IaaS-PaaS cooperation strategies. Our goal is twofold. First, we plan to enable IaaS clouds to expose extended infrastructure information to upper layers or applications. In this context, two sets of APIs are required to enable PaaS providers to optimize resource management, as detailed in Section 4.2. On the one hand, the IaaS provider can supply data about the infrastructure status, including cluster utilization and node properties, which can be accessed on-demand through the Libcloud API. On the other hand, the Libcloud suite may include a set of APIs dedicated to exposing infrastructure energy consumption at the higher levels, as the first step towards energy-aware PaaS and IaaS applications.

Our second goal is to add abstract triggers at the Libcloud level to enable PaaS managers to push workload-related information to the IaaS clouds. As the applications executed on VMs rented from IaaS

clouds are opaque to the infrastructure level, such APIs are essential to make application information available for the IaaS resource allocation and management mechanisms. Consequently, such APIs should allow PaaS managers to ask the IaaS provider to flag the activity of specific VMs or groups of VMs as CPU-, IO- or memory-intensive, to predict workload peaks or to provide hints regarding the execution time of groups of VMs that belong to the same job.

Such an API-driven approach to cross-layer cooperation achieves several benefits. First, each cloud provider may choose to implement only the required plugins according to the amount of information it intends to share. While private clouds may implement the whole set of energy-related and cooperation APIs, public providers may decide to share only non-sensitive data. Furthermore, an abstraction layer such as Libcloud fosters interoperability and portability between clouds, such that PaaS providers can make data available and collect infrastructure information according to predefined formats, while each IaaS cloud can provide its own interface implementation according to its internal structure and APIs.

6 CONCLUSION

The growing demand for "green" and energy-efficient data centers is a key driver in the design of cloud computing frameworks, which target not only performance, but also cost efficiency. In particular, designing virtualized environments for energy efficiency has led to a wide spectrum of optimization techniques, most of which are intended for IaaS cloud offerings. Whereas higher-level PaaS services hold key information related to workload properties and execution, they do not have direct control over the resource-management mechanisms that could trigger energy gains. In this work, we argue that there is a need for coordinated actions between IaaS and PaaS cloud layers. We believe that the conventional boundaries of the cloud stack layers can be extended to promote energy-awareness at higher levels, while enhancing low-level resource managers with detailed workload profiles to achieve fine-grained energy saving mechanisms.

We investigated a set of opportunities for both IaaS and PaaS providers to address these objectives and highlighted the tradeoffs of cross-layer information passing. As future work, our goal is to design the proposed API suite by extending Libcloud, in order to enable cross-layer cooperation between open-source IaaS and PaaS cloud implementations and to develop prototypes of cooperating cloud frameworks.

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SUSTAINABLE COMPUTING AND COMMUNICATIONS

FULL PAPERS

In-wall Thermoelectric Harvesting for Wireless Sensor Networks

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Abstract: We propose the use of embedded in-wall thermoelectric harvesters to power nodes of a wireless sensor network. We exploit the significant temperature differences between indoor and outdoor environments in cold climates. We use heat flow measurements of the exterior (outside-facing) wall of a number of apartments from the same apartment complex. We report on the degree of variability as well as on the seasonal changes that characterize the heat flow, and hence the potential for thermoelectric energy harvesting. We also examine whether the difference between indoor and outdoor air temperature is a good proxy for to the observed heat flow through the walls. Examples of data carrying capability of a particular harvester and sensor node combination are also provided.

1 INTRODUCTION

Wireless sensors are used to assist in structure maintenance (Vullers et al., 2010), to monitor human activity, to help prevent disasters like forest fires, and, in general, to collect data for scientific and business purposes. In the construction industry, sensors can be used to alert of dangerous situations, in cases where the infrastructure is critically compromised and to monitor wear and the "health" of buildings in general. For example, humidity sensors inside wall structures can provide advance warning of excess humidity which could lead to toxic mould growth, and strain dynamometers sensors can be used to determine the response of the building during earthquakes.

We consider the standard model for wireless sensor network (WSN) nodes, i.e., as consisting of a transceiver, the sensor, a microcontroller and an energy source, usually a battery. Generally, when the energy source for the WSN node is a battery, there exists a limit to how long the node can function without servicing, i.e., changing of batteries. With current technology, the node modules generally exhibit low energy consumption, therefore the lifetime limit that a battery imposes can be long enough that, depending on the situation, replacing batteries will not impose a significant cost. However, in particular situations, the sensors are inaccessible, i.e., embedded within structures, like walls, and the cost of replacing the energy source might be prohibitive.

There are three possible solutions for difficult–to-access sensor nodes. They can be either abandoned after they have performed their function for some time (with the hope that other, nearby, sensors will take over the task of measuring the same phenomenon), or they can be all connected to a wired power distribution subsystem. Finally, energy harvesting could be employed. Abandoning the sensors is an expensive option and possibly unacceptable. The wiring option is expensive in terms of labor cost and materials, exacerbated by the ever increasing price of copper, and wiring defeats the advantage of using wireless, since communication can be accomplished over the same wires that provide power. Wiring also results in a structure which is more complex and could be prone to faults (accidental puncture/cutting of the wires, problems with single points of failure, collection of RF energy by acting as low frequency antennas, etc.). In short, the ability of each node to power itself from energy harvesting leads to better node autonomy, and overall system resilience.

The solution adopted in this paper is to use thermoelectric energy harvesters to power each sensor node. Energy harvesters exploit the ambient energy of the environment to replenish the energy stored in the battery or the super capacitor. Photovoltaic harvesters have been studied extensively in previous works e.g., (Gorlatova et al., 2011). Buildings with good illumination can use photovoltaic energy to power sensor modules. Instead, in this paper we consider thermoelectric energy harvesting because (a) the potential for photovoltaic energy can be limited due to sub-optimal

placement, and because of long nights, as is the case at latitudes of northern continental climates, while, (b), during winter the indoor to outdoor temperature difference can reach as much as 60 degrees Celsius creating unparalleled opportunities for thermoelectric harvesting. More specifically, we take advantage of the difference between indoor and outdoor temperature in buildings in northern climates. To this end, we use data collected from an actual inhabited apartment complex in Fort McMurray, Alberta, Canada. The particular apartment complex has been constructed using modular construction techniques.

Placing thermoelectric harvesters inside walls serves the application of powering co-located sensors that monitor the wall and building behaviour. In climates like the one considered in our study, extreme weather conditions can cause events important to the integrity of a building, e.g., breakage of water pipes, more frequently occurring than in moderate climates. The ability to embed sensors in inaccessible locations that autonomously operate for several decades (i.e., as long as the building lasts), monitoring for such events, can currently only be supported using energy harvesting.

In terms of the methodology followed, we use the difference between indoor air and outdoor air temperature as the basis for the energy harvesting potential we report in this paper. Nevertheless, the energy harvesting specific to an apartment (and, more specifically, to a location on an exterior wall of an apartment) depends on a number of factors whose combined effect can be captured by the heat flow rate through specific locations of the exterior walls. We therefore study whether the difference between indoor and outdoor temperature at each apartment is a good proxy for the actual heat flow via the exterior walls. The heat flow is the real rate of energy transfer via the wall unit, i.e., the ground truth. Our study indicates among other things that, even though the difference between indoor and outdoor air temperature is a good (scaled) proxy for the average heat flow, there exists a high degree of variability of heat flow across apartments. Furthermore, the variability is smaller during certain times of the year. We comment on how these observations should guide the design of suitable network protocols.

The remaining of the paper is structured as follows. Section 2 briefly reviews some related work on the subject at hand, Section 3 has the description of the data set, and elements of the methodology we followed in interpreting them. Section 4 outlines the system model that we employ. Section 5 presents numerical performance results. We conclude with Section 6 summarizing our findings.

2 RELATED WORK

Energy harvesting for wireless networks and low power wireless sensor node architectures are areas of intense research activity. The use of energy harvesting for powering WSN nodes, with example applications, such as smart buildings and predictive maintenance of structures has been explored in the past (Vullers et al., 2010).

In this paper we narrow our focus to thermoelectric generators and specifically exploit the energy lost through walls in cold climates. We use a device model loosely based on (Mateu et al., 2006), in which energy harvesting from the human body was used, which is an idea explored by other researchers as well, (Ramadass and Chandrakasan, 2011; Wang et al., 2009). The devices proposed in previous works assume operation based on the difference of temperature between the human body and its environment, thus indirectly exploiting the temperature homeostasis of the human body.

In this paper, we are not concerned with the task of increasing the energy harvesters efficiency, a topic of intense activity anyway, e.g., (Hudak and Amatucci, 2008; Luber et al., 2013). We use off-the-shelf components and we do not even use a sensor platform optimized for energy efficiency. In other words, the results we present here are very close to representing a "worst case" scenario with respect to the devices employed.

In the field of energy harvesting for WSNs, a notable work is that of Gorlatova et al. (Gorlatova et al., 2009; Gorlatova et al., 2011) which focuses on how to use photovoltaic harvesting under diverse use scenarios, by proposing suitable optimization models. Another distinct property of their work is the study of photovoltaic harvesting in environments under the control of the users (depending on indoor illumination, or in the pocket of users), i.e., with idiosyncratic and sometimes unpredictable behaviour. They also consider elementary WSN applications, such as ID beacon transmission.

3 THE DATA SET

We use data collected over a period of a year, from 11 different apartments within a single apartment complex in Fort McMurray, Alberta, Canada. The data collected is comprehensive, including such aspects as water flow and temperature for the water used by radiators for heating, water flow and temperature for residential water, CO2 concentration, etc. For the purposes of this study we consider only the heat flow

through exterior (outside-facing) walls, the indoor air temperature, and the outdoor air temperature. The data collection was conducted in real–time and is still taking place, but we extract a one year period (8th of September of 2012 to the 8th of September of 2013) which is sufficient for the purposes of capturing seasonal variations.

In our data set, we obtain a separate indoor air temperature for each apartment but have a single outdoor air temperature, as acquired by the Building Automation System (BAS). It has to be noted that a single outdoor air temperature is, again, only an approximation of the locally specific outdoor wall temperature of each wall unit, since phenomena like convection can, depending on airspeed, result in different temperatures at different spots and orientations.

The heat flow measurements are obtained at two locations (one on a stud, and one on the insulation) of the exterior–facing wall of each apartment. Of the two heat flow measurements the one most relevant to our study, which we subsequently use, is the heat flow via the stud. Studs are necessary for the structure and proper framing of the walls but at the same time they are responsible for loss of heat as they represent a "bridge" of smaller thermal resistance (compared to the insulated area of the wall) between interior and exterior.

3.1 The Methodological Approach

The heat flow through a wall reflects the combined results of wall construction qualities (stud spacing, insulation, etc.), of human activity (e.g. the choice of thermostat setpoints, opening of windows, etc.), of weather phenomena (temperature, wind direction, etc.), the particular orientation and location of the apartment, and of course the exact location of the sensor in the wall. As we will see, the combination of the factors leads to a highly variable heat flow which nevertheless exhibits distinct seasonal characteristics.

We use heat flow data to describe the extent to which thermoelectric energy harvesting through the exterior walls is adequate to power (and to what degree) WSN nodes. Heat flow (measured in W/m^2 units) through exterior walls is directly related to the temperature difference between the two sides of the wall. Heat flow through an infinitesimally narrow slice of surface is defined as, $\vec{q} = -k\nabla T$ where $\vec{q}$ is the local heat flow, k is the materials heat conductivity and ∇T is the temperature gradient. We note that heat flow is a vector. We use the convention that a positive heat flow represents loss of heat (i.e., radiating from the interior side of the wall to the exterior side) while a negative indicates the reverse direction. Naturally, due to the climate characteristics in Fort McMurray, the latter case is infrequent, and occurs almost exclusively during the warmest summer months.

More precisely, if the wall is to be treated as a single homogeneous material of infinite area and thickness L the heat flow is inversely proportional to the thickness, that is, $\vec{q} = -kL^{-1}\nabla T$. In reality, the walls are more complex non-homogenous structures containing cavities, insulation, studs for wall support, studs for window framing, etc. impacting collectively on the heat flow magnitude and direction.

The thermoelectric harvesters are also dependent on the temperature differences to produce electricity and their output is governed by $-\nabla V = S\nabla T$ where S is the Seebeck coefficient of the material and ∇V is the electric potential between the two harvester terminals. In Section 5 we correlate the heat flux data (q_{hf}) with the air temperature difference between indoor and outdoor (ΔT_{air}).

After establishing a strong relation between q_{hf} and ΔT_{air}, we subsequently use ΔT_{air} as a proxy of the actual temperatures of the two (inside and outside) wall surfaces. This is primarily because the air temperature represents averages whereas q_{hf} is specific to the location of the wall where the heat flow sensor is mounted. However, our reasoning is that any thermal harvester installed in the wall will experience similar heat transfer behaviour as the heat flow sensors measure at the same location. Hence, whereas ΔT_{air} is a good basis for an overall estimate of energy harvesting potential, regardless of where the harvester is placed on the exterior wall, q_{hf} allows us to examine the highly idiosyncratic behaviour (captured by the standard deviation) due to the factors we listed at the beginning of this section.

Our interest in ΔT_{air} and q_{hf} and their relation is also motivated by the intention to use, in a future design, a thermoelectric harvester inside the wall whose two sides are in contact to the two wall surfaces via materials of high thermal conductivity, e.g., metal. This would allow the thermal harvester to be a low thermal resistance "bridge" and hence receive the full potential of the temperature difference of the two surfaces. However, such a design is future work because it needs to satisfy several other structural, mechanical, and safety constraints for in-wall embedding.

4 THE DEVICE MODEL

4.1 The Harvester Model

Our model is based on the performance of the TEC1-12703 Peltier module. The module has a surface area

of 16 cm^2. We carried out characterization experiments to determine the relation between ΔT and energy harvested. The setup was a small "refrigerator", using TEC1-12703 modules (see Figure 1), arranged such that, a constant ΔT was created and the resulting energy harvested measured. This refrigerator is made by using (top to bottom): (i) a heat sink, which is connected to a TEC1-12703, also connected to a power supply, to provide the hot side temperature for the harvester, (ii) the harvester, with its other side connected to, (iii) another TEC1-12703 module, again connected to the power supply to provide the cold side temperature. Lastly, another heat sink along with a small fan was used to help regulate the heat and stabilize ΔT. This setup was used to maintain constant ΔT ranging up to 40 degrees Celsius. The temperatures were sensed using thermistors, and a separate sensor module. Our findings indicate that the power output, W (in mW), of the particular harvester relates to ΔT (in Celsius) as $W = (2.57\ \Delta T^2 + 5.88\ \Delta T + 0.11) \cdot 10^{-3}$ (Least Squares fit with $R^2 = 0.9358$).

4.2 The Sensor Model

In order to develop a WSN node energy consumption model, we use the NanoZ-CC2530 device which employs the TI CC2530 microcontroller. We operate it with another node acting as data sink, communicating using the z-stack tool (ti.com, 2012) (Zigbee compliant). We carried out energy-exhaustion tests to determine for how long (how many bytes) of *payload* can be transmitted for the amount of energy accumulated to sufficiently charge a 1 Farad capacitor (rated at 5 V) up to 3.6 V. The packets transmitted followed the standard Zigbee data frame structure. We first conducted experiments using the TEC1-12703 harvester connected to a Texas Instruments BQ25504 Evaluation Board to regulate the voltage and to determine the ability of the harvester to charge the capacitor. After the success of the first step, and in the interest of accelerating the experiments, we used a standard power supply (GPC-3030) to charge the capacitor to the same 3.6 V. The capacitor was then connected to the NanoZ module and used to send data until exhaustion. From the measurements we concluded that it was possible to transmit an average of 4103.7 bytes of payload per Joule using messages of maximum payload size (90 bytes per packet). The sensor modules are not energy efficient, as we measured that they consume 0.49 mW in their sleep state when the processor is set to the sleep mode PM2 (only low-frequency oscillator operating), of which only approximately 6 μW is due to the processor consumption (as per the processor datasheet).

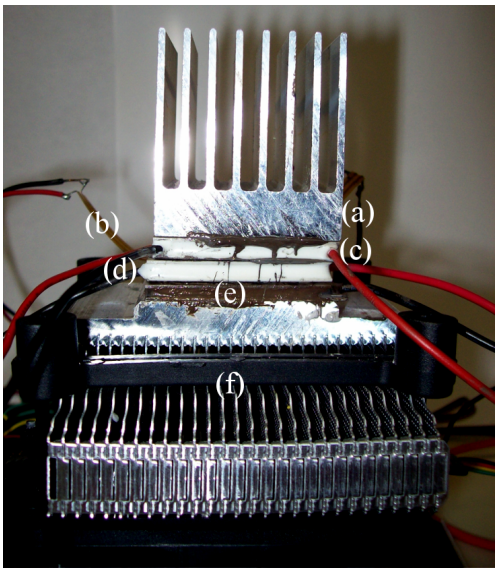


Figure 1: The harvester experimental setup. Shown in the figure are: (a) heat sink for temperature control of the "hot side", (b) thermistor for measuring the "hot side" temperature, (c) thermoelectric heater for the hot side, (d) the thermoelectric harvester, (e) the same as (c) but for generating the "cold side" temperature, (f) fan with heat sink for thermal control of the "cold side".

Table 1: Correlation of ΔT_{air} and q_{hf}.

Apartment	$corr(\Delta T_{air}, q_{hf})$
1	0.86
2	0.93
3	0.90
4	0.82
5	0.81
6	0.88
7	0.85
8	0.91
9	0.84
10	0.86
11	0.84

5 NUMERICAL RESULTS

We first consider the correlation of the ΔT_{air} and q_{hf} time series over the entire year and separately for each apartment. The time series represent hourly averages of the respective values. Table 1 demonstrates the overall strong correlation of the two time series but there exist differences (e.g. 0.93 for apartment 2 and 0.82 for apartment 4) that are ultimately related to the occupant(s) actions and behaviour. To illustrate the nature of differences consider the scatterplots of ΔT_{air} and q_{hf} in Figure 3 and 4 for the entire year, showing an overall strong correlation but with significant

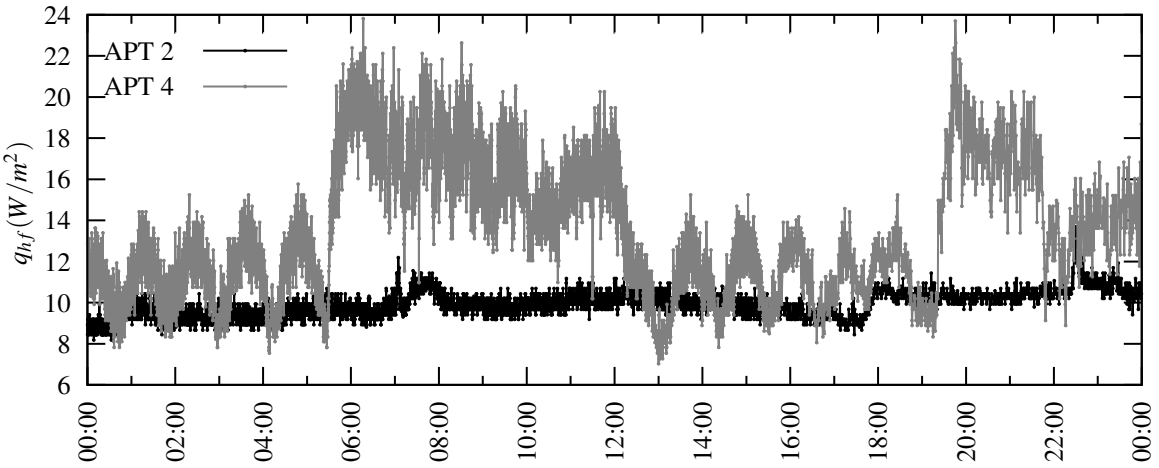


Figure 2: Intra-day q_{hf} in apartments 2 and 4.

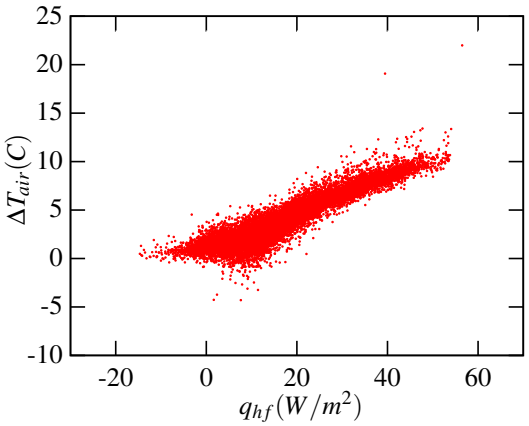


Figure 3: Apartment 2 ΔT_{air} vs. q_{hf}.

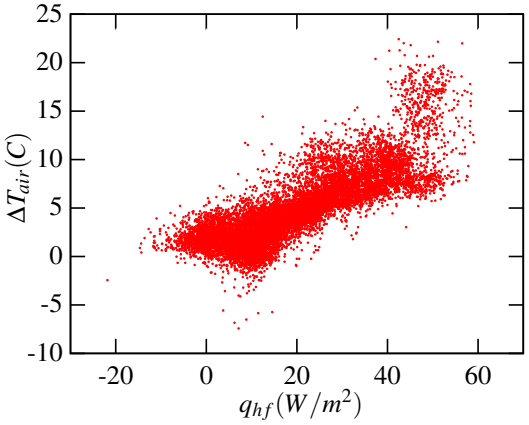


Figure 4: Apartment 4 ΔT_{air} vs. q_{hf}.

variance and occasional outlier points.

Without precisely knowing the inhabitants behaviour, one can only conjecture on several reasons for certain outliers (the resident could have been using an electrical radiator close to the location of the heat flow sensor, or touching the wall at the sensor location, or had the windows open, etc.). To illustrate the differences that might show up, consider Figure 2 showing the heat flow during a specific day (in mid-March of 2013) during which one of the two presented apartments had almost constant heat flow (possibly the apartment was vacant that day) while the other one had highly variable heat flow (the oscillations are probably due to the heating cycling around the thermostat setpoint, while higher setpoints and possible resident activity are evident from approximately 6am to 12pm and from approximately 8pm to 10pm).

We define $s^{(d)}_{avg}$, $s^{(d)}_{max}$, and $s^{(d)}_{min}$ as, respectively, the average, maximum, and minimum of daily q_{hf} standard deviation, calculated based on the hourly measurements of each day. Essentially we try to capture the statistics of variability of q_{hf} within the same day as they behave across the year. As can be seen from Table 2 the remarkable fact is that there exist days that almost every apartment shows a drastically small standard deviation. Apartments 3 and 4 exhibit a $s^{(d)}_{min}$ of 0.18 and even the apartment 11 which has the largest intra-day standard deviation of 8.37 still has low variability days as its $s^{(d)}_{min}$ of 0.37 illustrates. Our current conjecture is that the days of low variability represent days that the apartments were possibly vacant, and hence no resident–related influence was introduced apart from leaving the thermostat at a particular (and possibly low) setpoint.

Next, we try to capture the differences across groups of apartments based on the floor and their orientation. To this end, we define $\sigma^{(y)}_{avg}$, $\sigma^{(y)}_{max}$ and $\sigma^{(y)}_{min}$, representing, respectively, the average, maximum and

Table 2: q_{hf} and its standard deviation for various apartments, and potential harvesting output.

Apt.	$avg.q_{hf}$	$s^{(d)}_{avg}$	$s^{(d)}_{max}$	$s^{(d)}_{min}$	harvested (mW)	bytes/day
1	7.19	1.70	5.17	0.31	2.15	761864(588130)
2	5.91	0.98	2.76	0.19	1.74	617129(443395)
3	8.31	1.82	5.76	0.18	2.58	916274(742539)
4	6.80	2.06	6.42	0.18	2.06	730854(557119)
5	6.50	1.84	6.55	0.34	2.30	815768(642034)
6	8.25	2.64	7.20	0.41	2.23	790079(616345)
7	5.61	2.46	6.77	0.48	2.11	747428(573694)
8	8.07	1.40	4.15	0.26	2.45	870314(696580)
9	7.30	2.74	5.79	0.29	2.28	809130(635396)
10	6.85	3.24	7.99	0.42	2.06	730610(556876)
11	7.18	2.15	8.37	0.37	1.91	675688(501954)

minimum of the standard deviation of the daily averages of particular groupings of apartments across the entire year. Table 3 (ε stands for a quantity less than 0.005) provides some interesting results. As expected, by comparing to Table 2, the overall variability is less pronounced at the larger time scale of a year as it dilutes the effects of intra-day variance seen in Table 2. While the maximum variability, i.e., $\sigma^{(y)}_{max}$, can still reach significant levels, it is less than the one observed intra–day.

The minimum, $\sigma^{(y)}_{min}$, reaches a small value which occurs during summer days when the outdoor and indoor temperatures are almost equal and the temperature across all apartments is similar as well. Unfortunately, less variable days across apartments are also days of small harvesting potential because ΔT is small. Furthermore, due to the occupant behaviour, we encounter cases such as the average q_{hf} at floor 3 and 4 being quite different (6.66 vs. 7.41). The implication of this observation is that, should multi-hop forwarding be used in the sensor nodes, the bottleneck (in terms of nodes with least harvested energy) could assume undesirable topological characteristics, by restricting the paths that could be followed to collect the data to sink nodes. In this example, an entire floor may not have enough energy to forward traffic between adjacent floors, towards a sink node placed at the bottom floor.

Despite the variability, seasonal patterns are evident across all apartments. Consider for example Figure 5 which shows the differences of two apartments (number 2 and 4) over the entire year. Indeed, even though the differences on certain days can be significant, they follow identical seasonal trends. The trends are also similar to all the other apartments (not shown here for the sake of brevity).

Finally, we note that there exist relatively important differences in the heat flow, and hence on harvesting potential, between night and day. To put it differently, the amount of energy collected in the morning hours is generally different from what could be collected overnight. Therefore, the intra–day variability could be handled by collecting energy over an entire (and possibly more than one) day, modulo of course the seasonal variations. For the night vs. day differences, we present the, rather arbitrarily chosen, intervals of day (6am to 6pm) and night (6pm to 6am). Hence, each day represents two (average) measurements. When considered in groupings of weeks, and across all weeks of the year, we produce Table 4 where we can readily see the ratio between maximum and minimum standard deviation can be significant and it is not uncommon to find a 5-times difference (apartment 6 is a good example with maximum over a week of 4.09 and minimum over another week of 0.77). Extending the averaging over a longer time scale will naturally smooth the variability extremes. For example, in Table 5, each entire day is represented by its average value, and the standard deviation of the daily measurements over a month (defined as a sequence of 30 days) are reported, across the entire year. The maximum variability is tamed but the difference between minimum and maximum standard deviation of the same apartment can still be surprisingly large (apartment 6 has a maximum of 3.09 and a minimum of only 0.30).

Table 3: Average q_{hf} vs. orientation/elevation.

	$avg.q_{hf}$	$\sigma^{(y)}_{avg}$	$\sigma^{(y)}_{max}$	$\sigma^{(y)}_{min}$
Orientation				
North	7.00	0.95	3.08	0.17
South	7.14	0.78	3.04	0.24
Elevation				
1st floor	7.05	0.25	4.19	ε
2nd floor	7.22	0.78	3.57	0.11
3rd floor	6.66	0.74	3.02	0.03
4th floor	7.41	1.06	4.18	0.02

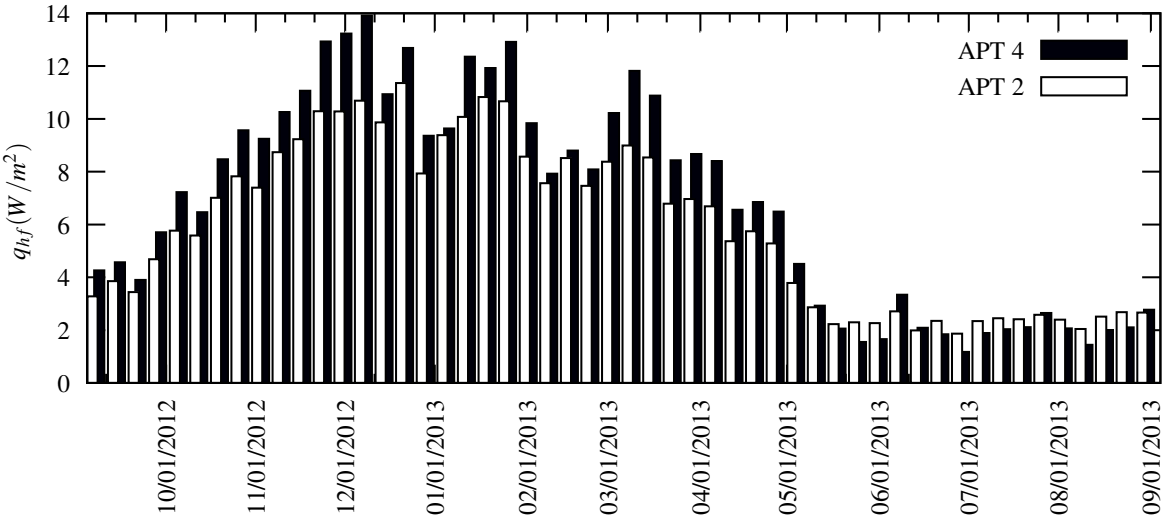


Figure 5: Daily average q_{hf} in apartments 2 and 4.

Table 4: Average, maximum and minimum weekly standard deviation of q_{hf}.

Apt.	$s^{(w)}_{avg}$	$s^{(w)}_{max}$	$s^{(w)}_{min}$
1	1.25	2.28	0.48
2	0.87	1.51	0.29
3	1.51	3.21	0.37
4	1.50	3.17	0.49
5	1.24	3.25	0.47
6	1.97	4.09	0.77
7	1.38	2.31	0.49
8	1.37	2.79	0.49
9	1.93	2.91	0.79
10	1.97	3.54	0.70
11	1.53	3.17	0.61

Table 5: Average, maximum and minimum monthly standard deviation of q_{hf}.

Apt.	$s^{(m)}_{avg}$	$s^{(m)}_{max}$	$s^{(m)}_{min}$
1	1.40	2.27	0.81
2	0.93	1.57	0.40
3	1.52	2.44	0.68
4	1.44	2.34	0.62
5	1.17	1.79	0.35
6	1.89	3.09	0.30
7	1.44	2.17	0.44
8	1.47	2.36	0.48
9	1.80	2.61	0.18
10	1.99	2.76	1.22
11	1.57	2.65	0.62

5.1 Data Transfer Capabilities

Let us return to Table 2 and notice the harvested power potential using ΔT_{air} and the model of the harvester noted earlier. The average power that can be harvested in the apartments exterior wall is $2.17\,mW$ with a standard deviation of $0.22\,mW$. The highest average is $2.58\,mW$, and the apartment producing the lowest could harvest $1.74\,mW$. Assuming we harvest energy to transmit once a day, each node could transmit an average of approximately 770 kbytes of payload per day. The per-apartment potential daily transfer volume can be seen in Table 2. The numbers in parentheses are the payload that could be transmitted per day assuming at all other times the sensor node idles as described in the node model, i.e., consuming $0.49\,mW$ in its sleep state. Admittedly, much better performance is possible with better designed nodes. However, even at 600 kbytes of payload per day, a sensor can adequately send samples of its own sensing (e.g.. slowly changing humidity values or accelerometer activity compressed to the interesting events only) and still have some energy capacity to perform multi-hop routing.

However, as Figure 5 indicates, during the summer there might not be enough power to send data without risking an outage. Specifically, apartment 11 during the week of 6/29 to 7/5 was able to harvest only an average power of $0.113\,mW$, that is not sufficient to even power the sensor module. The exact sensor node design is also important. For example, assuming that an external circuit duty-cycles the operation of the entire node, then the restarting (equivalent to a cold boot) of the particular nodes we employed takes around 2 seconds to complete during which time it consumes the same power as when transmitting, $84.51\,mW$. After those 2 seconds the device en-

ters sleep mode where it consumes $0.49\,mW$. Hence, power-up is a costly overhead of $\sim 169.02\,mJoule$, and a strategy of repeatedly powering up on-demand to gather data (not even transmitting) is probably unacceptable. Or, equivalently, the particular sensor would have to harvest energy for an average of 1497 seconds, to just cope with the 2 seconds startup energy cost before it performed any useful sampling, computation, and transmission (energy permitting), thus limiting the rate of sampling/sensing.

If the energy storage capacity is small to allow the longer term harvesting, outage is almost certain during summer months. The particular apartments do not have air-conditioning units for cooling, as they are rarely used in such northern climates. Thermoelectric harvesting during the summer occurs mostly at night when the outside temperature drops.

The good news is that due to the significant variability across apartments and throughout the day, a protocol to determine, at least locally, which node has (or has had in the recent past) the good fortune of harvesting more energy could be suitable for routing. In other words, there indeed exists diversity of opportunities to spend energy of another neighboring node because of the corresponding diversity in inhabitant behaviour. As a rule though, such routing strategies must become more conservative during the summer when the harvesting potential is reduced in both absolute numbers and in terms of variability across apartments. Our recommendation would therefore be in favour of "seasonally-aware" routing algorithms.

The potential of photovoltaic output from a cell of the same surface area ($16\,cm^2$) as the thermoelectric harvester used, at the same geographical location, and using off-the-shelf solar cells with efficiency 17% on a south-facing vertical wall is an average daily power of $88.739\,mW$ (according to data in Natural Resources Canada website (pv.nrcan.gc.ca, 2013). The average power from thermoelectric harvesting appears low by comparison. However, one has to consider that (1) the solar power favors the south facing side of the building, over the north facing ones, and (2) to harvest solar energy the placement of the photovoltaic cells is crucial and one has to consider problems of occlusion of the light source, compared to a fairly flexible placement of the thermoelectric harvesters. Finally, as a matter of aesthetics, a photovoltaic harvester requires that it be exposed to outside view, whereas a thermoelectric harvester can be embedded "out of sight" within the wall structures.

6 CONCLUSIONS

In anticipation of deploying in-wall wireless sensors for structure monitoring this paper reports measurements of temperature difference and heat flux taken in an apartment building at Fort McMurray, Alberta, to evaluate the feasibility of using thermoelectric energy harvesting in cold northern climates. We conclude that the use of such harvesters for wireless sensor modules is possible with current technology albeit not without some challenges.

First, even though the difference between indoor and outdoor air temperature is a good proxy for the potential energy harvesting, the exact behaviour of heat flow that ultimately governs the thermoelectric harvesting at particular points of the wall structure are subject to factors that are dependent on weather phenomena (e.g., convection phenomena on the wall surfaces) but, more importantly, on the behaviour patterns of the residents who are in control of not only the thermostat setpoints but also of objects attached to or close to the walls, extra forms of directional heat radiators (e.g. electric heaters), and so on.

Second, even though the heat flow follows, as expected, a seasonal pattern, its variability from one outside wall to another (one apartment to another) can be significant, especially when observed in small time scales, e.g., intra-day. Hence, despite the regularity of the harvesting potential, it is to be expected even within the same day, that the wall on some apartments can sustain higher volume of sensor data transfers than others. The implications of this behaviour to multi-hop routing are obvious. Short-term alternative routing paths would need to be considered.

Finally, the harvesting potential is reduced in the summer months and appears possible almost exclusively later in the day. Additionally, in the summer months, the variability of harvesting becomes smaller. Hence, sizing the energy storage (e.g., capacitance of a supercapacitor) necessary to sustain the sensor node operations, should be based on the worst case summer harvesting potential. One could argue that we need to consider complementing thermoelectric harvesting with photovoltaic harvesting which reaches its peak output during the summer months. Nevertheless, such a decision is dependent on a decision to expose the photovoltaic element which we try to completely avoid as we wish to deploy the sensors as inconspicuously as possible.

We are currently working towards a modular design for simple in-wall placement.

ACKNOWLEDGEMENTS

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Minimizing Environmental Footprints of Data Centers under Budget and Service Requirement Constraints

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Abstract: The energy consumption of data centers (DCs) has been increasing, which will continue due to the increase of Internet traffic and stringent service level agreements (SLAs). Analogously, the protection of global and local environments has also driven the regulation authorities to encourage energy consumers, especially corporate entities, for the usage of green energy sources. However, the green energy is usually more expensive (up to four to five times for some cases) than the traditional energy generated from coal and petroleum. One essential problem for managing DCs, according to the greenness tendency, is to minimize the environmental penalty (or equivalently to maximize the greenness) by dispatching the requests to proper DCs under the SLA and budget constraints. This paper presents optimization techniques for dynamic workload balancing for cloud-scale data center (DC) management. We present a model for commonly found electricity tariffs for green energy and provide an efficient heuristic algorithm to maximize its usage while incorporating its intermittent availability. We evaluate the presented solution with real-life traces of electricity prices and DC workloads. Extensive evaluations support our solution's potential to minimize the environmental penalty for Internet service providers under the budget while fulfilling their SLAs.

1 INTRODUCTION

The awareness towards the reduction of the emission of green house gases (GHG) is increasing for the protection of global and local environments. At present, the information technology (IT) sector consumes significant amount of energy. Specifically, according to a 2008 estimation, about 2% of world's GHG emissions come from this sector (Webb et al., 2008).

One way to control the GHG emissions is to use the greener form of energy obtained through renewable sources like wind and sun instead of coal, petroleum and nuclear. The de facto standards for such legislation have emerged to be *cap-and-trade* schemes. The essence of *cap-and-trade* schemes is that a regional 'cap' is set on the total amount of GHG emissions for all the businesses operating in the region. Within the cap, the businesses trade allowances (i.e. carbon credits) as needed. An example is Europe-wide EU-ETS (Commission, 2013) which is already in its third phase. Importantly, in *cap-and-trade* the brown energy cap is reduced over time so that total emissions are progressively reduced with an ultimate goal of having zero emissions (Commission, 2013). This approach is being followed by industry (Google, 2011). To this end, a logical optimization goal is to maximize the usage of green energy, within bugetry constraints - the focus of this paper.

The most common instrument for trading in *cap-and-trade* schemes are Renewable Energy Credits (RECs): each REC represents one MWh of renewable energy contributed to the power grid. The facilities that produce this energy can be based on wind or solar farms. Importantly, RECs are not the same as energy. Both of these, i.e. energy and RECs, can be sold and bought separately. When a wind or a solar farm produces energy, it is contributed to the power grid. Such energy can then be bought like other forms of energy. The RECs produced in this process can be bought separately. The term *green energy* is actually the sum of produced energy and RECs. Hence, it costs more than brown energy due to the addition of RECs (for details, see (Google, 2011)). Depending upon availabilities, the wind energy can be in the range of 6 to 16 cents per kWh. Similarly the solar energy per kWh can range from 25 cents on sunny days to 35 cents on cloudy days. In comparison, brown energy typically costs $3\sim4$ cents per kWh (SolarBuzz,

2013).

Data centers (DCs), being the biggest users of electricity in the IT sector (Paul Ontellini, 2011), have a significant environmental impact. One essential problem for managing DCs, according to the greenness tendency, is to minimize the environmental penalty by dispatching the requests to proper DCs under the service level agreements (SLAs) and budget constraints. There have been several results in the literature, e.g., (Zhang et al., 2011), (Shah et al., 2008), (Rao et al., 2010), (Le et al., 2010a), (Qureshi et al., 2009). Most of these researches ((Zhang et al., 2011), (Shah et al., 2008), (Rao et al., 2010), (Qureshi et al., 2009)) focus on the satisfying the average response time whereas actual SLAs often demand percentile guarantees. In (Le et al., 2010a), the percentile guarantees of SLAs are considered under the setting that the brown energy consumption is capped for each DC, whereas, a cap per enterprise is a more realistic model as discussed previously. In (Zhang et al., 2012), the authors consider the effect of DCs' demand on market prices of electricity. Detailed discussion about the related work follows in Section 8.

Our Contribution: This paper focuses on the minimization of the environmental footprint of DCs under the budget constraint and the generalized SLAs, including percentile and average response time guarantees. We present a software optimization strategy to dynamically dispatch the incoming requests from the central hub of an Internet service provider (such as Google or iTunes) to the distributed DCs. This optimization problem is multifaceted by considering many important aspects in such a setting, explained in detail in Section 2. In our approach, we divide the problem into subproblems to be solved individually by each DC and by the central dispatching hub. We present a practical solution that encompasses all the energy-consuming components in a DC. That includes the energy consumption from the infrastructure for networking, computation, and cooling devices. Our solution is flexible enough to be applicable to DCs consisting of heterogeneous servers as well as able to accommodate different SLAs. We evaluate this with real-world workload traces from Wikipedia (Urdaneta et al., 2009) and varying electricity prices from different regions in USA obtained from NYISO (NYISO, 2013). We show that this optimization problem can be effectively and efficiently solved with our greedy algorithm by relaxing the budget constraint and can be easily adopted in data centers.

2 BACKGROUND

This section presents the important aspects in achieving greenness in DCs.

Varying Price of Electricity. The price of both green and brown electricity vary temporally and geographically. Also, the variance in energy used for the requests, i.e., the active energy component, is a significant fraction of the total energy (Qureshi et al., 2009). Hence, an appropriate service placement can result in significant gains.

Multiple Services with Different SLAs. DCs are expected to offer more than one service to more than one client, under different SLAs and with different pricing. Majority of the previous work has focused on a single DC providing a single service. The impact of multiple SLAs and multiple services being offered by a group DCs has often not been considered.

Session-based Services. In the case of session-based services offered by DCs, not all requests can be arbitrarily routed to any DC. The requests belonging to one session must either be served by the same DC, or context transfer be quantified.

Communication Latency due to Geographical Distance. The geographical distance between the DCs and the front end causes additional delay in serving the routed requests (Qureshi et al., 2009). The effect of this delay on SLA should be considered when distributing requests.

Energy Cost of Sleep-wake Transitions. Putting a server in a DC to sleep or bringing it back for executing is not free in terms of energy consumption. Sleep-wake transitions incur additional energy costs that need to be catered when deciding to route the incoming load. By selecting a server that is already in operation, extra overhead caused by the transition can be saved.

Energy Consumption of Infrastructure. DCs do not only consist of servers. There are also other non-computing devices as well like networking switches, routers, cooling devices and lighting. The average energy consumed by these devices is almost the same as the energy consumption of processors (typical PUE=1.9 (Stansberry and Kudritzki, 2012)). These devices contribute substantially toward the environmental footprint of a data center and their effect must be considered.

Energy Sources and Caps. There are three basic sources of energy in each DC: (i) green energy harvested through the local resources (like a local wind farm), (ii) green energy bought in form of carbon credits and (iii) brown energy. Many DCs nowadays include some local facilities to produce green energy, e.g., (Apple Inc., 2012), (Upson, 2007). The energy

produced by the local facilities is audited and converted to carbon credits (NC-RETS, 2013) which can be used just as other credits bought at local market. The price for these credits has to be paid in the form of initial expenditure on the renewable energy facility. Local wind or solar farm can produce limited supply of green energy and its maximum production cannot exceed its rated output. This can be considered as a limit on availability.

3 SYSTEM MODEL

In this section we formalize the system model and discuss how we handle the the challenges discussed previously (Section 2).

We consider a network of N DCs as shown in Fig 1. A central dispatcher receives all the requests and dispatches them to the N DCs according to a *to-be-designed* dynamic load balancing strategy. The data centers share a common operational budget for a *budgeting period* (e.g. a month). The budgeting period is divided into smaller *control periods* (e.g. an hour). The network of data centers collaboratively provides the total required service Λ_b (the request rate) in a control period b.

Energy Sources. We consider that each DC has Z different energy sources to choose from. These can be different forms of green or brown energy sources. The cost to buy a unit ($ per kWh) from the jth energy source in DC i during control period b is $C_{b,i,j}$. We assume that $C_{b,i,j}$ is time varying. Importantly, fixed-cost energy contracts are just a special case of this more general setting. DCs with local green energy production facilities have to bear the initial investment and continuous management costs for such facilities. These costs, amortized over time, can be considered as the price of green energy.

When one unit of energy (kWh) is purchased from the jth energy source in DC i, the associated penalty is defined as $\phi_{i,j}$. In general, green energy sources have none, while brown energy source has a positive penalty.

The availability of renewable energy and carbon credits in the market depends on the weather conditions and the cap set by the legislation authorities. Availability affects the price of energy and the cap enforces an upper limit. We assume the jth energy source in all DCs is limited to maximum usage of L_j in the current budgeting period.

Service Level Agreements. DCs offer multiple services to multiple clients under different SLAs. This factor can be incorporated by dividing each DC into smaller cells to cover all the services that should be

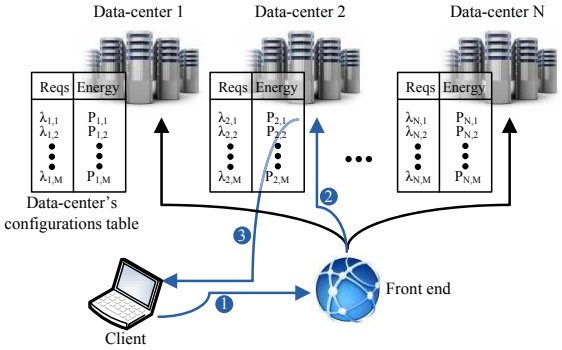


Figure 1: Arch. overview of a network of N data centers with a typical route for a request and its reply.

provided through the DCs. Each cell is considered as an individual DC. However, it is not that each DC cover all the services, due to the following reasons: (1) The overhead for maintaining the coherence of the states is larger than the performance gains (Le et al., 2010b). (2) Not all clients are geographically suitably located to be served by some of the DCs because the communication latency is correlated to the geographical distance (Qureshi et al., 2009). Therefore the clients can be statically assigned to a subset of DCs. Please note that SLAs that we consider are only within the premises of service providers. Our SLA can be combined with Internet QoS approaches to extend the guarantees all the way to the users' sites (Zhao et al., 2000). *For the rest of this paper, we only present how to deal with one SLA for the simplicity of presentation.*

Session-based Services. Incoming requests from the clients are distributed by a central dispatcher. We assume that once a request has been routed, the reply comes directly from the corresponding DC. If it is a session-based service, all the further correspondence is directly with the DC where the first request in the session was assigned to. We assume that the front end is not part of the routing process after the initial decision hence does not cause any additional latency.

DC Configuration Table. Every DC requires some energy as an input to provide some service as output. The required energy consumption depends upon the service requirements as well as the hardware and infrastructure configurations of the DC. This behavior can be captured in a table for energy requirement versus the maximum service (in terms of the request rate) in a DC under the specified SLA.

We consider DCs with discretized service levels, and each level has its required energy consumption in a control period. Every DC has up to M different energy usage levels (configurations) to choose from. Each energy consumption level corresponds to a particular maximum satisfiable service requirement. A

DC i, in its kth configuration uses $E_{i,k}$ kWh of energy to satisfy $\lambda_{i,k}$ service requirement, under the given SLA. Once these tables have been generated for all participating data centers, the energy requirement to satisfy the contracted SLA for a given workload can be simply looked up in this table.

Possible approaches for considering the energy consumption of the servers under an SLA for a DC can be found in the literature, e.g. the methodologies in (Guerra et al., 2008) or (Chen et al., 2011). The energy consumed by infrastructure is also part of the total energy consumption $E_{i,k}$. *The DC configuration table forms the basis of a very general solution*. It can include the energy spent on cooling, the energy consumption of network equipment, the hardware heterogeneity and various settings of SLAs. It can potentially capture most of the relevant aspects of a DC with selectable granularity.

Another important aspect is the energy cost for the off→on transitions of the servers in the DCs. We assume that the entries in a DC configuration table already include the worst-case energy requirement for such transitions. Hence, we do not explicitly include them in the model. Since the transition only occurs once (∼1 min (Le et al., 2010b)) per control period (1 hour in our model), i.e. turning the required servers on at the beginning of every control period, adding such worst-case energy requirements does not increase the actual energy consumption significantly.

For notational brevity, if the available energy configurations of data center i is m and $m < M$, we define $\lambda_{i,j} = \lambda_{i,m}$ and $E_{i,j} = E_{i,m}$ for $m < j \leq M$. Without loss of generality, with respect to k, we also assume that $\lambda_{i,k}$ is non-decreasing and $E_{i,k}$ is non-decreasing as well. We assume that the first entry $\lambda_{i,1}$ in the data center configuration table for DC i is 0. The corresponding energy consumption $E_{i,1}$ may be 0 when the infrastructure and the hardware does not consume any energy when the DC is not used in the control period. However, practically, $E_{i,1} > 0$ and represents the energy cost of network infrastructure and other equipment, e.g. lighting, etc. In essence, it is an offset that can be added to all the entries of the configuration table.

4 PROBLEM DEFINITION AND FUTURE PREDICTION

4.1 Problem Statement

The objective is to *minimize the total environmental penalty* in the current budgeting period while satisfying the *service requirement* with the quality of service (QoS) as contracted in the SLA, without exceeding the *total budget* S with the time varying energy prices. Each DC can choose a fraction of the total required energy in the period from any of the available sources. The optimization goal is to select an index k_i with $1 \leq k_i \leq M$ for DC i such that the total environmental penalty is minimized under the service requirement constraint $\sum_{i=1}^{N} \lambda_{i,k_i} \geq \Lambda_b \; \forall b$ and the budget constraint.
Summarizing this,

i, j, k, b	=	Indices for DCs, energy sources, configurations and control periods
N	=	Total number of DCs
M	=	Max number of configurations per DC
Z	=	Maximum type of energy sources
B	=	Max control periods in budgeting period
L_j	=	Maximum energy availability from j^{th} source for all DCs combined (kWh)
S	=	total allowed cost budget for all DCs ($)
$E_{b,i,k}$	=	Energy required at DC i for k^{th} confguration during b^{th} control period (kWh)
$\phi_{i,j}$	=	penalty associated with j^{th} energy source in i^{th} DC (kg of CO_2)
$C_{b,i,j}$	=	cost of jth energy source in i^{th} DC during the bth control period ($ per kWh)
Λ_b	=	total service required during the bth control period
$\lambda_{i,k}$	=	service provided at DC i's kth configuration
$x_{b,i,j}$	=	In i^{th} DC, portion of jth energy source to fulfill the energy requirement during the bth control period
$y_{b,i,k}$	$\in$	$\{0,1\}$ for all b,i,k. binary decision variables

With these symbols, the optimization problem can be formulated as follows:

$$\text{Minimize: } \sum_{b=1}^{B}\sum_{i=1}^{N}\sum_{j=1}^{Z}\sum_{k=1}^{M} y_{b,i,k}\cdot E_{b,i,k}\cdot x_{b,i,j}\cdot \phi_{i,j} \tag{1a}$$

$$\text{such that: } 0 \leq x_{b,i,j} \leq 1, \text{ for all } b,i,j \tag{1b}$$

$$\sum_{j=1}^{Z} x_{b,i,j} = 1, \text{ for all } b,i \tag{1c}$$

$$\sum_{i=1}^{N}\sum_{k=1}^{M} y_{b,i,k}\cdot \lambda_{i,k} \geq \Lambda_b, \text{ for all } b \tag{1d}$$

$$\sum_{b=1}^{B}\sum_{i=1}^{N}\sum_{k=1}^{M} y_{b,i,k}\cdot x_{b,i,j}\cdot E_{b,i,k} \leq L_j, \text{ for all } j \tag{1e}$$

$$\sum_{b=1}^{B}\sum_{i=1}^{N}\sum_{j=1}^{Z}\sum_{k=1}^{M} y_{b,i,k}\cdot E_{b,i,k}\cdot x_{b,i,j}\cdot C_{b,i,j} \leq S. \tag{1f}$$

These can be restated as:

1b: Usage of any energy source in a DC in any control period can not be more than total energy requirement for that data center in that control period.

1c: Sum of all the portions from all the energy sources should satisfy the energy requirements of the DC.

1d: Provided service should satisfy the required service for all control periods.

1e: Usage of any energy source cannot exceed its availability in the market.

1f: The sum of the costs occurring at the DCs should remain within the overall budget.

4.2 Infeasibility due to Unknown Future

A solution to the problem detailed in Equations (1a)-(1f) will result in the optimal reduction in environmental penalty. However, to solve this, we need Λ_b and $C_{b,i,j}$ for all future control periods. This is, however, not possible. Electricity prices change on hourly basis and the horizon for "certain" knowledge spans only an hour in future. Similarly, as service requests follow long term (monthly) and short term (hourly) trends (see Figure 3), good enough predictions are possible only for an hour in advance. Due to these factors we transform the problem to maximize the use green energy within a *single control period*. The problem can be modified as follows for a control period b, where $1 \leq b \leq B$: (with modified set of old symbols which belong only to a single control period)

$$\text{Minimize: } \sum_{i=1}^{N}\sum_{j=1}^{Z}\sum_{k=1}^{M} y_{i,k} \cdot E_{i,k} \cdot x_{i,j} \cdot \phi_{i,j}, \tag{2a}$$

$$\text{such that: } 0 \leq x_{i,j} \leq 1, \text{ for all } i,j \tag{2b}$$

$$\sum_{j=1}^{Z} x_{i,j} = 1, \text{ for all } i \tag{2c}$$

$$\sum_{i=1}^{N}\sum_{k=1}^{M} y_{i,k} \cdot \lambda_{i,k} \geq \Lambda, \tag{2d}$$

$$\sum_{i=1}^{N}\sum_{k=1}^{M} y_{i,k} \cdot x_{i,j} \cdot E_{i,k} \leq L_j - L_j^{b-1}, \text{ for all } j \tag{2e}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{Z}\sum_{k=1}^{M} y_{i,k} \cdot E_{i,k} \cdot x_{i,j} C_{i,j} \leq \psi(S - S^{b-1}). \tag{2f}$$

here,

- ψ = function for budget distribution. It must satisfy: $\psi(\Delta) \leq \Delta$. $\psi(\Delta)$ can be as simple as $\frac{\Delta}{B-b+1}$ or can be complex to include the predictions of traffic and pricing.
- L_j^{δ} = Used-up quota of energy availablilty for j^{th} type of energy upto δ control period, where $L_j^0 = 0$.
- S^{δ} = Budget consumed in the past for control periods upto δ with $S^0 = 0$.

Henceforth, we tackle the problem of greening the DCs as per Equations (2a)-(2f) i.e., according to the methodology shown in Figure 2. For every control period, we first calculate the budget on basis of traffic forecast. Predictions based on historical information or other prediction models, e.g., (Verma et al., 2010), (Box and Jenkins, 1994), can be adopted. In the second step a load balancing strategy has to be designed for the data centers under the calculated budget constraint and the Λ constraint with the specified SLA. The requests are dispatched to different DCs as a result of the second step. *The main focus of our methodology in this paper is the second step, i.e. load balancing.* We assume that dispatching overhead is negligible.

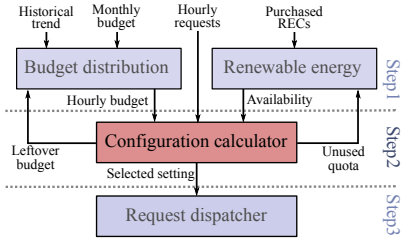


Figure 2: Outline for modified methodology.

Hardness. The problem formulated in Equations (2a)-(2f) is $\mathcal{NP}$-hard even for deriving a feasible solution. This can be proved by reducing from the decision version of the knapsack problem.

Proof. We reduce from the decision version of the knapsack problem. For an input instance of the knapsack problem, we are given N items and two constants W and V, in which each item i has a weight w_i and a value v_i. The objective of the knapsack problem is to select a subset of the N items such that the total weight of the selected items is less than or equal to W and their value is larger than or equal to V. The knapsack problem is $\mathcal{NP}$-complete (Johnson and Garey, 1979).

The reduction works as follows: We construct N DCs such that each DC has only two configurations for the performance and energy consumption. That is, for DC i, $\lambda_{i,1} = 0, E_{i,1} = 0, \lambda_{i,2} = v_i, E_{i,2} = w_i$. The performance requirement in current budgeting period b, $\lambda_{F,b}$ is set to V, while the budget is set to W. The cost to buy one unit from the brown energy source is set to 1 as well.

Therefore, there exists a feasible solution for the knapsack problem if and only if the reduced instance for the studied problem has a feasible solution. Hence, we conclude that deriving a feasible solution under budget and performance constraints for the studied problem is $\mathcal{NP}$-hard. □

5 OUR SOLUTION

The drawback of solving the optimization problem separately for each control period (Equations (2a)-(2f)), is that the global optimization is not guaranteed. I.e., the possibility to trade off expensive green energy in one control period against cheaper green energy in another control period might remain unutilized. We show this by solving this problem optimally within a control period through dynamic programming. After that we present a simple greedy algorithm that, by optimizing the budget distribution, produces better results in our simulations. Finally, we combine the positives of both approaches to form our final solution.

5.1 Dynamic Programming (DP)

5.1.1 Penalty Table for a DC

We first consider how to optimize for any DC i in a control period when the local budget S_i and the local service requirement Γ_i are given. According to the definition, we know that we should choose the least power-intensive configuration of the data center that fulfills the service requirement, i.e., k^* with $\lambda_{i,k^*} \geq \Gamma_i$.

Suppose that $x_{i,j}$ with $0 \leq x_{i,j} \leq \min\{1, \frac{L_j}{E_{i,k^*}}\}$ is the fraction of the total energy purchased from the jth energy source in DC i. It is now clear that the objective for this case is to minimize $E_{i,k^*} \sum_{j=1}^{Z} x_{i,j} \cdot \phi_{i,j}$ such that $\sum_{j=1}^{Z} x_{i,j} \cdot C_{i,j} \cdot E_{i,k^*} \leq S_i$ and $\sum_{j=1}^{Z} x_{i,j} = 1$. This can be solved by using the linear programming solver in general. Since, the green energy sources have zero environmental penalty, the above linear programming can be solved by a simple algebra calculation in $O(Z)$ time complexity given that energy sources are presorted for preference. We omit the details of algebra here.

By iterating all possible values of S_i and Γ_i, we can build the corresponding penalty table $p(i,\Gamma_i,S_i)$ to show the minimum penalty for DC i under the above configurations. If it is not feasible to support Γ_i under budget S_i, then, $p(i,\Gamma_i,S_i)$ will be set to ∞.

We remove the infeasible and dominated entries in the penalty p-table for DC i created above. An entry $p(i,\lambda,s)$ is dominated by another entry $p(i,\lambda',s')$ if $s \geq s'$, $\lambda \leq \lambda'$, and $p(i,\lambda,s) > p(i,\lambda',s')$.

Suppose that the p-table has Q_i entries for DC i after the above procedure. The p-table has to be generated in each control period because the penalty incurred depends on the time-varying energy prices which are not know a priori. For the kth entry in the p-table for DC i with $k \leq Q_i$, we denote

- $\ell_{i,k}$ as the service provided (request rates),
- $s_{i,k}$ as the allocated budget, and
- $\pi_{i,k}$ as the penalty stored in $p(i,\ell_{i,k},s_{i,k})$.

5.1.2 Building the Dynamic Programming Table

On the basis of the penalty tables (p-table) obtained for each data center in previous step we can now build a dynamic programming table to select the appropriate configuration of every DC to provide the total required service.

Suppose that $P(i,\lambda,s)$ is the minimum penalty for the *first* i DCs under the budget s to provide the service requirement (total request rate) λ. For brevity, when $\lambda < 0$ or $s < 0$, we define $P(i,\lambda,s)$ as ∞. Clearly, for $\lambda \geq 0$ and $s \geq 0$, we know that

$$P(1,\lambda,s) = p(1,\lambda,s). \tag{3}$$

Where p-table is from previous section.

For $i = 2,3,\ldots,N$, the following recursive formula can be adopted to minimize the total penalty P under budget $s \geq 0$ and service requirement $\lambda \geq 0$:

$$P(i,\lambda,s) = \min_{k=1,2,\ldots,Q_i} \{P(i-1,\lambda-\ell_{i,k},s-s_{i,k}) + \pi_{i,k}\}. \tag{4}$$

Clearly, $P(N,\Lambda,S)$ is the minimum penalty for distributing the requests and the budgets. The standard dynamic programming technique can be adopted and the solution can be obtained via backtracking from $P(N,\Lambda,S)$. The time complexity for calculating a single entry $P(i,\lambda,s)$ based on Equation (4) is $O(Q_i)$. To build the table correctly, we have to calculate $P(i,\lambda,s)$ from $i = 1,2,\ldots,N$ and from $\lambda = 0$ to Λ and from $s = 0$ to $s = S$ sequentially. This gives the overall time complexity $O(NS\Lambda Q_{\max})$, where $Q_{\max}$ is $\max_i Q_i$.

Optimality and Complexity. The above presented DP approach derives the optimal solution to minimize the environmental penalty for a control period. However, in the problem scale, some level of discretization in both budget and service is mandatory. Appropriate discretization results in a smaller global penalty table (P) and this reduces the computation complexity. The construction of the table P depends on how we discretize the values of λ from 0 to Λ and the values of s from 0 to S. The complexity can be reduced by rounding down $s_{i,k}$ and s to the nearest integer multiple of a given number, let's say, I_s. That is, $s'_{i,k}$ is $\left\lfloor \frac{s_{i,k}}{I_s} \right\rfloor I_s$. Similarly, we can also round down $\ell_{i,k}$ and λ to the

nearest integer multiple of a given number, let's say, I_λ. That is, $\ell'_{i,k}$ is $\left\lfloor \frac{\ell_{i,k}}{I_\lambda} \right\rfloor I_\lambda$. Then I_s and I_λ can serve as the discretization factors of budget S and Λ. This makes the time complexity to $O(N\frac{S}{I_s}\frac{\Lambda}{I_\lambda}Q_{\max})$.

5.2 Greedy Algorithm

We now present a heuristic algorithm based on a greedy strategy without building the penalty p-table constructed in Section 5.1.1. The two important factors to be considered are the penalty and the budget. These two factors are inversely related, i.e. to reduce penalty more budget has to be paid and vice versa. We devise a heuristic strategy which strives to minimize the weighted sum of both.

Suppose that the DC i has been decided to use the k_i^{th} configuration. That is, it will provide λ_{i,k_i} service with E_{i,k_i} energy consumption. Suppose that $x_{i,j}$ with $0 \le x_{i,j} \le \min\{1, \frac{L_j}{E_{i,k_i}}\}$ is the fraction of the total energy purchased from the jth energy source in DC i. If k_i is given for every DC i, the objective for this case is to

$$\text{minimize} \quad \sum_{i=1}^{N} E_{i,k_i} \sum_{j=1}^{Z} x_{i,j} \cdot \phi_{i,j} \tag{5a}$$

$$\text{such that} \quad \sum_{i=1}^{N} \sum_{j=1}^{Z} x_{i,j} \cdot E_{i,k_i} C_{i,j} \le S, \tag{5b}$$

$$\sum_{j=1}^{Z} x_{i,j} = 1, \quad \text{for all } i \tag{5c}$$

$$\sum_{i=1}^{N} E_{i,k_i} \cdot x_{i,j} \le L_j. \quad \text{for all } j \tag{5d}$$

The above linear programming can be solved optimally by using a linear programming solver or via linear algebraic calculation with less time complexity. We omit the details for the algebra due to the space limitation.

The algorithm works as follows: all the DCs are set to their lowest service setting, i.e. $k_i = 1$ and we check for feasibility of this setting in terms of budget and service by verifying the feasibility and solving the optimal solution for Equation (5a). If $\sum_{i=1}^{N} \lambda_{i,k_i}$ is no less than Λ, the algorithm terminates; otherwise it increases one DC i^* among the DCs to the next configuration $k_{i^*}+1$. The selection of i^* is as follows:

Suppose that the current solution has set k_i. By advancing only DC i to the configuration k_i+1, we can find the optimal setting in Equation (5a) for minimizing the penalty under this setting. Please note that the penalty is set to ∞ if there is no feasible solution for Equation (5a). By advancing the configuration of DC i, suppose that $\Delta_i^{service}$ is additional service, $\Delta_i^{penalty}$ is the additional penalty, and Δ_i^{budget} is the additional budget (this is none-zero when the budget has not yet been exhausted in the current solution).

Algorithm 1: The Greedy Algorithm.

Input: Data center configuration table for all DCs, Service requirement: Λ, Budget: S, weights: w_b, w_e
Output: Configuration for all DCs: k_i

```
k_i ⟵ 1 for each DC i;
while true do
    if Σ_{i=1}^{N} λ_{i,k_i} ≥ Λ then
        if Equation (5a) has a feasible solution then
            return the solution k_i for each DC i with
            the purchase plan by solving
            Equation (5a) optimally;
        else
            return the solution k_i for each DC i but
            with "over budgeting" by buying all
            energy from the cheapest brown source;
    for each DC i with k_i < M do
        Δ_i^service ⟵ λ_{i,k_i+1} − λ_{i,k_i};
        calculate Δ_i^budget, Δ_i^penalty based on
        Equation (5a);
    let i* be the minimum (Δ_{i*}^penalty / Δ_{i*}^service · w_b + Δ_{i*}^budget / Δ_{i*}^service · w_e);
    k_{i*} ⟵ k_{i*} + 1;
```

For a DC i, we define two terms: *brownness*, i.e. penalty caused per unit of provided service ($\frac{\Delta_i^{penalty}}{\Delta_i^{service}}$) and *economy*, i.e. budget spent per unit of provided service ($\frac{\Delta_i^{budget}}{\Delta_i^{service}}$). The heuristic that we use is $brownness \cdot w_b + economy \cdot w_e$. Where w_b and w_e are the weights that can be assigned to prefer brownness over economy or vice versa.

Algorithm 1 presents the pseudo-code of the above greedy algorithm. The worst-case number of combinations that we have to check for different k_i in this algorithm is $O(N^2M)$, as in each while loop in Algorithm 1 we consider up to N DCs and the number of iterations in the while loop is at most NM. For each combination, we have to solve Equation (5a). This can be sped up by starting based on the current solution. However, solving Equation (5a) by using linear programming solvers is already quite efficient. As we are not able to guarantee the budget satisfaction, over budgeting may be needed by borrowing from future invocations, as presented in pseudo-code.

5.3 Greedy + DP (G+D)

The greedy algorithm, when allowed over-budgeting, guarantees to find a feasible solution, if there exists

one. It keeps increasing the offered service progressively in search of a feasible solution. In the worst case, it configures all the DCs to run at maximum service setting. However, in the average case, it finds a feasible setting much earlier. Moreover, the heuristic used for the greedy algorithm does not buy overly expensive green energy, resulting in a efficient budget usage. In comparison, the DP method finds the optimal solution in terms of environmental penalty, even if the cost to reduce the environmental penalty is overly prohibitive.

We devise a method to combine both approaches to accumulate the benefits of both: for a given control period we execute the greedy algorithm to find a feasible solution. We analyze the budget requirement of this solution and set this as the maximum budget constraint for the DP method. Since the greedy algorithm optimizes for the budget as well, its solutions are more miserly in terms of budget usage. Setting this budget as upper limit for DP results in a reduced search space for dynamic programming approach. In this way we achieve a solution which incorporates the budget optimization of the greedy algorithm with the optimal search for minimal environmental penalty from DP approach.

As G+D uses greedy and DP sequentially, its worst case time complexity is $O(N^3 M \frac{S}{I_s} \frac{\Lambda}{I_\lambda} Q_{max})$, using the previously introduced symbols.

In the following sections we present our simulation setup and evaluation results.

6 SIMULATION SETUP

We adopt the settings from (Zhang et al., 2011) to evaluate the proposed solution by simulating the Google's setup for the location of DCs in the US. For these locations, we obtain the electricity pricing information from (NYISO, 2013). For our simulations, the following factors are important.

Non-varying Factors include the hardware capabilities of the DCs. These include server capabilities and cooling infrastructure. We consider four DCs, in which each data center is equipped with homogeneous servers, as detailed in Table 1. We use the method in (Wang et al., 2012) to build the DC configuration table, presented in Section 3, by considering 50 servers in each data center. The resulting table has at most 87 entries in each data center. Other methodologies like (Guerra et al., 2008) and (Chen et al., 2011) can also be adopted for calculating the DC configuration tables. Please note that the complexity of the presented solutions does not directly depend on the number of servers in DCs, but the number of entries in the DCs' configuration tables. Even when the servers in a DC increase, we can reduce the number of entries in the DC configuration tables by changing the management granularity.

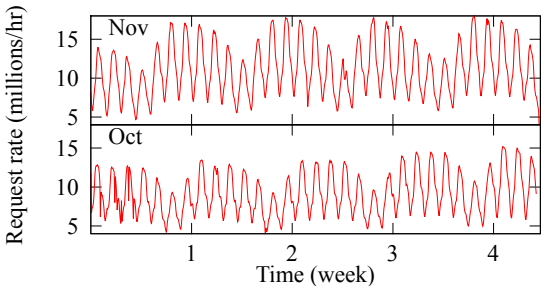


Figure 3: Wikipedia workload trace in Oct. and Nov. 2007.

The penalty for a green energy source is set to 0. The penalty for a brown energy source is set to 1. This multiplied by CO_2 kg generated per kWh gives actual environmental penalty.

Time-varying Factors include energy prices. The availability for both forms of energy does not vary. The fluctuation in the production of green energy due to environmental factors causes a shift in its price but the overall availability contracted by the suppliers in the form of RECs is fulfilled. Green energy has a higher price than brown energy as explained in the introduction (Section 1). In our simulation we assume a surcharge of 1.5 cents and 18.0 cents per kWh for wind and solar energy (SolarBuzz, 2013) respectively in addition to the brown energy price. For price trace of electricity, we use the data from NYISO(NYISO, 2013). Specifically, we use Day-Ahead price data for Nov'07 for four regions previously mentioned.

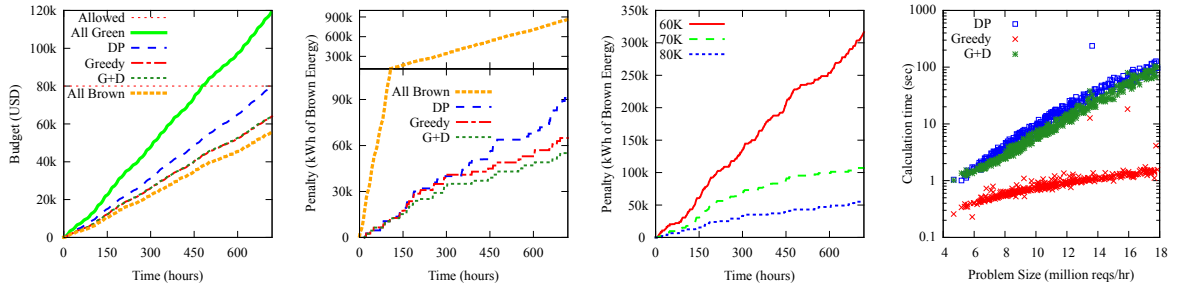
The other time varying factor is the total service requirement, Λ_b. It is a random variable but overall it follows a weekly recurring pattern (see Figure 3). We use the actual workload trace from Wikipedia (Urdaneta et al., 2009). We use Oct'07 for forecasting and the Nov'07 for the actual workload.

7 EVALUATION

In this section we present the results of our evaluations. We take a month as a budgeting period and an hour as a control period. For the greedy algorithm proposed in Section 5.2, we configure the heuristic weights as $w_b = 10$ and $w_e = 1$ in Algorithm 1. The presented algorithm (G+D) is evaluated for three main criteria, i.e. budget allocation and usage, environmental penalty minimization and computation time. We compare it with base line schemes of "All Green" and "All Brown" as well as DP approach (Section 5.1) and simple greedy (Section 5.2).

Table 1: Data center settings used for simulation (adopted from (Li et al., 2012)): Speed ratio is the ratio of the frequency by adopting dynamic voltage frequency scaling (DVFS) to the maximum frequency in the system.

	DC # 1			DC # 2			DC # 3			DC # 4		
Location	San Luis Valley, Colorado			Los Angeles, California			Oak Ridge, Tennesse			Lanai, Hawaii		
Processor	AMD Athlon			Pentium 4, 630			Pentium D950			AMD Athlon		
Max freq.	3.0 GHz			3.0 GHz			3.4 GHz			3.0 GHz		
Power settings	Speed ratio	Service (req/sec)	Power (W)	Speed ratio	Service (req/sec)	Power (W)	Speed ratio	Service (req/sec)	Power (W)	Speed ratio	Service (req/sec)	Power (W)
	1.00	750	174.09	1.00	750	93.99	1.0	850	194.00	1.00	750	174.09
	0.90	675	141.28	0.80	600	62.76	0.85	725	146.19	0.90	675	141.28
	0.66	500	88.88	0.50	375	37.99	0.64	550	102.13	0.66	500	88.88
	0.50	375	68.13	0.40	300	34.10	0.44	375	78.82	0.50	375	68.13
	0.26	200	55.29	0.30	250	32.37	0.29	250	71.20	0.26	200	55.29



(a) Budget usage. (b) Method comparison. (c) Budget vs. penalty (G+D). (d) Problem size vs. calculation time.

Figure 4: Evaluation Results.

7.1 Budget Allocation

The hourly budget is allocated as a weighted average of current monthly budget where the weights are calculated based on predictions. We adopt a simple prediction scheme that predicts the number of requests in the current control period based on the history. Any other prediction scheme, e.g., (You and Chandra, 1999; Cortez et al., 2006) can be used for better predictions.

The budget usage comparison is presented in Figure 4(a). The maximum allowed budget was set to USD 80k. As expected "All Brown" uses the minimum amount of budget at the cost of huge environmental penalty, whereas, "All Green" approach violates maximum budget constraint (see Figure 4(b)).

The proposed solution, G+D, follows the same budget allocation as the greedy algorithm. In comparison with the optimal budget allocating scheme, "All Brown", it uses only one eighth more budget but produces a 15 fold reduction in environmental penalty as shown in Figs. 4(a) and 4(b). In comparison with "All Green", G+D uses only half the budget.

Relaxing the budget constraint results in decreased environmental penalty for the presented solution. The result is shown in Figure 4(c). The effect is, however, non-linear. This is because increasing the monthly budget beyond a certain point makes the availability of green energy the limiting factor.

For minimizing the environmental penalty, among the presented schemes, G+D outperforms all others that follow the budgetry constraints as shown in Fig. 4(b).

The fundamental difference between G+D and the DP approach is the allocation of budget. Unlike DP, G+D tries to minimize the budget usage. This provides G+D a relaxed budget constraint progressively at subsequent control periods, as compared to the DP approach. DP produces the optimal results in terms of environmental penalty within a single control period. To this end, it sometime uses excessive budget for gaining a marginal reduction in penalty. This makes the budget constraint tighter in subsequent control periods, resulting in higher overall penalty for dynamic programming.

7.2 Computation Time

For the results to be useful, the maximum computation time must remain a negligible fraction of the length of the control period. This condition can be fulfilled by lengthening the control period. But, this, in turn, makes the prediction horizon longer for Λ_b and $C_{b,i,j}$. Irrespective of the prediction scheme, this results in deteriorated prediction quality hence affecting the solution quality.

One way to decrease computation time can be to compute the necessary tables offline. But, due to the time-varying factors like price and availability of en-

ergies, the offline tables will be huge and unpractical.

Online computation of solution at the beginning of every control period is the only viable option. Figure 4(d) presents the calculation time as a function of problem size for a single control period on a normal desktop machine (Intel i3, 6GB RAM, Linux). It is clear that the greedy algorithm is the fastest with majority of the computation times remaining within a second. However, G+D may take up to a minute in a few cases. This remains suitable for a control period of around an hour as necessitated by the electricity price horizon. With growing problem size, the computation times increases linearly for the greedy algorithm and exponentially for dynamic programming based solutions. This was expected as DP is pseudo-polynomial time algorithm. However, G+D, still fairs better than DP alone. The is because of the reduced search space due to the pruning by greedy algorithm.

8 RELATED WORK

DCs being major electricity consumers in the IT sector, have been focus of lot of research to make them environmental friendly. This can be divided into three main categories:

Energy Conservation: These studies aim to decrease the energy consumption of a DC, whereas decreased environmental footprint is a side product. Examples include (Chase et al., 2001), (Heo et al., 2007), (Wang et al., 2012). Mostly these aim to optimize a a single DC. For example Wang et al. (Wang et al., 2012) present a scheme to reduce power consumption while fulfilling the generalized SLAs within a single DC. The solution we present builds on top of these schemes as we aim for multiple DC optimization and single DC optimization is part of that.

Electricity Cost Management: These studies are more nearer to our approach. The key difference between this category and the previous one is that, here, multiple and geographically distributed DCs are considered. Examples in this category include (Qureshi et al., 2009), (Li et al., 2012), (Mathew et al., 2012), (Luo et al., 2013). Qureshi et al. (Qureshi et al., 2009) were the first to tackle the problem of cost minimization by exploiting the geographic variance of energy prices but they do not consider the carbon market dynamics. These are also not considered in (Li et al., 2012) and (Luo et al., 2013).

Utilizing the Green Energy: This is a relatively new direction with only few initial studies e.g (Zhang et al., 2011), (Shah et al., 2008), (Rao et al., 2010). Our approach falls in this category. (Zhang et al., 2011) present how to maximize the use of environmental friendly green energy to power the servers in DCs, while maintaining the average response time for incoming requests. However, since they use the queuing theory to model the service provision, it can not handle generalized SLAs, for instance, in the form of percentile guarantees. The same argument also applies to the limitations of the researches in (Rao et al., 2010), (Le et al., 2009), (Shah et al., 2008). Moreover, (Rao et al., 2010) and (Shah et al., 2008) do not consider time-varying workloads, multiple services, or market interactions. Stewart and Shen (Stewart et al., 2009) also focus on minimizing the environmental penalty by reducing the use of brown energy. They use a model in which Internet service providers own the renewable energy farm. *In contrast, we consider the more general case where the renewable energy can be locally produced or bought in form of RECs by the commercial producers and contributed to the grid.* Le et al. (Le et al., 2010a) is more thorough in their approach toward the problem. They focus on cost reduction by exploiting the distributed nature of DCs for dynamic request dispatching while maintaining SLAs. They are the first ones to consider carbon interactions. Our approach has two main differences from (Le et al., 2010a): Firstly, we aim to maximize the green energy usage within budgetary constraints as opposed to maximizing profits within brown energy cap. Secondly, in our solution, we divide the optimization problem to smaller parts: one to be solved by each data center and the other for the front end. This helps two folds (i) we can include more factors to model energy consumption, including the infrastructure for networking, computation, cooling devices, etc., and (ii) the optimization problem can be solved more frequently because of the reduced complexity at the front end. The latter also results in a shorter horizon for energy price and traffic predictions.

9 CONCLUSION

The environmental footprint of DCs is becoming significant. In this paper we formalized the problem of minimizing the environmental footprint of ISPs (or maximizing the green energy usage) while fulfilling the budgetary and service constraints. We showed that this problem is a $\mathcal{NP}$-hard problem and presented a viable greedy heuristic for optimization. The solution that we presented (1) is up to date, in that, it is based on current legislative and economic trends. (2) It is practical. By dividing the problem into two subproblems and solving them separately, it gives us the flexibility to add different kinds of SLAs and is also

valid for heterogeneous servers in a single DC. (3) It is wholistic in nature as it is cognizant of the energy usage for computation hardware, the networking hardware and also the cooling infrastructure of the DC.

The novelty of our approach lies in dividing the problem into two independent steps, that is, per DC optimization and a central optimization scheme. This forms the basis of general solution that can include factors like power consumption due to cooling infrastructure, power consumption of networking infrastructure, on-site renewable energy generation systems and multiple services with multiple SLAs.

We evaluated the presented solutions with traces of electricity prices and typical Internet workloads. Extensive evaluations based on real data for price, traffic and locations demonstrate efficacy of our approach.

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SHORT PAPERS

How Green Are Java Best Coding Practices?

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Abstract: This paper aims at explaining both how to measure energy consumption of Java source codes and what kind of conclusions can be drawn of these measures. This paper provides a formalization of best coding practices with a semantics based on quantitative metrics that correspond to the time, memory and energy saved while applying best coding practices. This paper also explains how to measure such source codes in order to provide repeatable and stable measures by combining both physical and logical sensors.

1 INTRODUCTION

Information and Communication Technologies accounted 2% of global carbon emissions in 2007 e.g. 830 MtCO2e according to (Webb, 2008) and is expected to growth to 1.430 MtCO2e. Rising energy costs of computers and mobile devices becomes a crucial issue and software has a major influence on these device consumption. In this paper, we target software developers and we propose to qualify energy savings applying the best coding practices. Best coding practices can be seen as a set of informal rules that the software development community has learned over time to improve the quality of applications, simplify their maintenance and increase their performance (Bloch, 2008). Defined as follows best coding practices should exactly cover that of eco-design. In fact, eco-design can be defined as an approach to design a product with considerations for its environmental impacts during its entire lifecycle. It aims at understanding our ecological footprint on the planet by searching for new building solutions that are environmentally friendly and leading to a reduction in the consumption of materials and energy. As improving code performance often has a positive effect on energy consumption: the latter decreases. This statement that best coding practices are eco-design rules as a matter of fact will be examined in this paper which focuses on Java best practices only as a starting point. But it also aims at measuring which are the best or the most green patterns among best coding practices.

However, it remains two issues to tackle. Firstly, as it has been defined previously, best coding practices are *informal* set of rules. This means that we should formalize them in order to assign them an energy semantics. Secondly, when best coding practices show examples of source code, this always involves very small pieces of code or codes without their context of use. As it has been pointed out by (Wilke et al., 2011a), works about software energy consumption actually consists in test scenarios (use cases) of whole applications but not on micro-benchmarking. It has to provide repeatable and stable measures from such small source codes that should be undertaken in very tiny laps of time with very little electrical power.

In this paper, we propose to deal with these two problems as follows. We formalize best coding practices by a pair of two executable source codes. One the green code corresponds to the model code that should be implemented for a given purpose, the other one the grey code corresponds to the code that should be replaced by the first one. Then, we assign a code semantics as a triple given by:

1. the time required by the code to be run,
2. the memory space used by the code while running,
3. the energy consumed by the code during its run.

Furthermore, this semantics is naturally prolonged to best coding practices as the rate respectively between the time, memory and energy of its green code over its grey one.

The second issue is tackled by setting up a measure system that manages codes, performs their measures and provides analysis results. It is composed of physical and logical sensors synchronized together by a main application. Logical sensors consist in programs that provide the time and the memory used by each code measure as well as its number of execu-

tions. The latter value is important in order to relate each metric to one execution of a given code. Moreover, the system involves a micro-benchmarking framework that prevents us from edge effects due to Java virtual machines. Physical sensor provide the energy consumed by each code measure. The main application manages sensors, code measures and stores their results.

2 RELATED WORK

Works undertaken on computer energetic consumption has evolved from hardware to software as the object of studies and from physical sensors to logical ones as measurement instruments. Moreover, energy analysis of software focus more and more on fine-grain code blocks and not even more on whole applications.

We follow this last path as well as we examine best coding practices from an energy point of view. However, at the same time, we defend a hybrid approach of physical and logical sensor systems. We argue that it still provides a better precision for our study cases. Effectively, the pieces of code that we analyze run in a few nano-seconds and consume few nano-Joules. Moreover, mixing measure values enables us to set up robust energy indicators and could certainly be extended to other data.

Nevertheless, the vision exposed in (Wilke et al., 2011b) sketches the future of energy consumption monitoring as reducing the energy it consumes. In fact, it aims at designing a static analysis method able to calculate energy consumption correctly. Although, its authors establish an abstract interpretation for software energy, we target an analysis based on waste density. Therefore, it requires determining the elementary energy waste or gaining throughout the compliance or not with best coding practices.

2.1 Software Energy Consumption

Two salient points have been very well explained in (Garrett, 2007). Firstly, we cannot afford to wait for technological breakthroughs in semiconductor technology for power savings. Secondly, as a consequence of the first point, we have to find a way to reduce energy consumption of our hardware devices by reducing those of our software. And more precisely throughout middleware components e.g. hardware devices and operating systems. This is possible as hardware provides power management systems such as processor frequency scaling or idle-power state management; however, as it is also exposed in (Saxe, 2010), this leads us to design energy efficient software.

Software doesn't consume energy directly! Components that require electrical power are hardware ones, not software. However, as hardware executes software instructions, it is meaningful to state that software consumes energy i.e. software makes hardware consume energy while the latter executes instructions of the former. It has been shown in (Wilke et al., 2011a) there exists 6 levels from hardware components to software ones that could rise energy consumption. Several works focus on different elements of different scales as for example, from databases in (Tsirogiannis et al., 2010) to data centers in (Poess and Nambiar, 2008); from programming languages in (Noureddine et al., 2012a) to one language operation codes in (Lafond and Lilius, 2006).

This leads us to elaborate an incremental testing plan of Java best coding practices. The latter consists in testing best practices in the same environment e.g. exactly the same hardware and software components. Then, we test again the same ideal practices within the same environment with two parameters: the processor and the Java virtual machine. By combination, it only represents Four different testing environments for Java best practices but it stands for the main components for leveraging energy consumption in the literature.

2.2 Software Energy Benchmarking

Software energy benchmarking can be divided into two sub-categories: the behavioral evaluations and the structural ones. Behavioral evaluations correspond to the fact that energy measures are related to a use case or scenario. It then consists in measuring energy consumption during an application carried out according to a scenario. These means of evaluations have been applied by (Wilke et al., 2012), for instance, on mobile applications in order to propose energy efficiency classes the same as for washing machines, dryers, refrigerators and freezers. In (Noureddine et al., 2012a), the energy efficiency of programming languages is estimated on several implementations of the game Tower of Hanoi. The latter corresponds to what we call a behavioral evaluations e.g. evaluations of the application main functionalities. This last study breaks a common belief that standard Java is not energy efficient as it shows that only the C implementation compiled with all options for optimization is more energy efficient. These sorts of evaluations are wide spread in energy benchmarking.

By structural evaluations, we conclude that energy measures are related to structural code blocks and not

to a scenario. For example, (Lafond and Lilius, 2006) elaborate a framework for estimating energy cost of Java applications by analyzing its byte code. It then consists in evaluating the Java virtual machine operation codes and in assigning them an energy cost in nano-Joules. Moreover, in (Seo et al., 2007), a framework is elaborated for estimating energy costs of Java applications either while designing or at runtime. They focus on a component based approach i.e. the total energy cost has been split into 3 sub-costs: computation, communication and infrastructure cost. These energy cost models concern Java components. In order to provide a static analysis, we cannot afford to analyze Java byte code suggested by (Lafond and Lilius, 2006). However, we aim at providing the same standard of results for Java best practices.

2.3 Power Instruments

Instruments for measuring energy consumption can be divided into 2 categories: the physical devices and the logical ones. The first ones, like watt-meters or power-meters, allow to keep defining the baseline of power measure precision. The second ones claim to be as accurate as physical measures but with the potential of being focused and portable. By focused, we mean that it can monitor a single process inside threads of processes whereas an external physical device could monitor all active threads at a given time. Effectively, (Noureddine et al., 2012b) states that a margin error of only 0.5% exists for their CPU power model between values provided by a power-meter and those drawn out from Power API (Boudon, 2013). Moreover, the PowerTOP tool (van de Ven and Accardi, 2013) is known for helping developers to fix power leaks in their source code. This is even more explicit for JouleUnit (Wilke et al., 2013) that itself provide the baseline results in the project of elaborating an abstract interpretation for energy consumption of mobile application (Wilke et al., 2011b). Other logical tools are discussed in (Noureddine et al., 2012a) but they only provide raw data, e.g. CPU frequency or utilized memory, but neither power nor energy information.

However, our own experiments with these tools did not provide the same accuracy as those claimed by their authors, the outcome turning out not to be relevant in our working context. We suggest that the reason lies in the fact that best practices involves too short carried out times required by these tools for retrieving input data to their software energy consumption models. In fact, they behave all in the same manner as they extract information of idle-power states or battery status from the operating system log files in order to estimate the processor energy consumption (for instance, by using the *procfs* library under Linux boxes). We then designed a hybrid instrument system for measuring time, memory and energy used by a software implementation (see section 4.1). Whereas the physical sensor we use was originally devoted for calibrating logical sensors, the ability of retrieving and handling its digital outputs makes it possible to employ it in the same way as a software component and to provide its results as a service.

3 JAVA BEST PRACTICES

This section aims at describing how to handle best coding practices for establishing or not their energy savings. Firstly, it is explained in the section 3.1 how to transform informal textual recommendations into occurrences of a formal definition as pairs of codes that are opposed throughout these best practices, explicitly or implicitly. Secondly, the section 3.2 explains the energy semantics of such best practices which relies on time, memory and energy consumed while running the codes involved in given best practices. Finally, the twenty Java best practices that will be analyzed below are presented in the section 3.3.

3.1 Best Practice Formalization

Java best coding practices are collections of suggestions and recommendations about the best code to produce according to a context or a coding goal as it is presented in (Bloch, 2008). Moreover, best practices could tackle either low-level design patterns as well as high-level ones. For instance, design by contracts[1] is addressed by a best practice whereas another one explains that developers should not use tab characters in the source code for indenting lines of code! These examples show that best coding practices scale from abstract to concrete layers of programming processes. Best practices aim at improving code implementations in different manners (Sestoft, 2005, bonus on performance):

Efficiency: some other best practices improve code performances in time and memory;

Maintainability: some best practices help developers to maintain pieces of code in ensuring the use of standards and uniform coding, in reducing oversight errors;

[1]Design by contracts is an approach for designing software with formal, precise and verifiable interface specifications for software components. This extends the ordinary definition of abstract data types with preconditions, postconditions and invariants.

Interoperability: other best practices reshape codes for running them throughout different environments.

Best coding practices could own samples of code or not. It could be explained by:

1. what should be done (*prefer-this* shape),
2. what should not be done (*avoid-that* shape),
3. both (*replace-this-by-that* shape).

We focus on best practices that reduce the code footprints as well as in time as in memory i.e. those of concerning time and memory efficiency in order to examine if they involve energy consumption rise. Secondly, we select or complete best practices in order to manage those with a *replace-this-by-that* shape. This means that best practices are formally defined by two codes: a green or clean one (the practice to prefer) and a dirty or grey one (the practice to avoid). Notice that these codes can be seen as unit test in the manner they are design (Koskela, 2013). Best practices are then formalized as follows by the means of this definition of *rule*:

Rule: a rule R is a pair composed of two source codes that are unit tests with exactly one test method.

Concretely, the figure 1 illustrates the best practice stating that it is preferable to initialize strings of characters literally e.g. without the use of a new constructor. This means that we have to complete every best practices without any code examples, to complete every *prefer-this* or *replace-that* shaped best practices in order to rewrite them accordingly to the *replace-that-by-this* shape.

3.2 Energy Model

The table 1 corresponds to the energy model of twenty rules i.e. formalized best practices. Effectively, there are 8 attributes per rule; four attributes by code as a rule is composed by two codes. These four attributes are:

Energy. This is the average measure of energy consumed by the green or grey code in nano-Joules;

Time. This is the average time taken by the green or grey code in nano-seconds;

Memory. This is the average memory space used by the green or the grey code;

StdDev. This is, for the green or grey code, the standard deviation rate of each energy measure against the energy average measure of this code.

Therefore, an energy interpretation of rules consists in comparisons, firstly, between the green energy and the grey one i.e. the energy of its green code and that of its grey one, between its green time and its grey one, between its green memory and its grey one as well as between the standard deviation of measures of its green code and standard deviation of measures of its grey one. The first two indicators precisely focused on energy savings. The following two indicators concerns impact factors on the previous one. As for the last indicator, it defines the confidence about measures that support these indicators. Finally, our energy model makes possible to state that a best practice is an eco-design rule if it provides absolute or relative energy gains. And the lowest are both of its green and grey standard deviations, the strongest this statement holds.

3.3 Study Cases

Twenty Java best practices are analyzed within the tables 5 and 1. These best practices can be dispatched into 5 groups.

A first set of four best practices focuses on FOR loops in Java. The first rule compares a loop of integers (the green code) between a loop of floats (the grey one) with exactly the same size of items and the same loop body. The second rule compares a loop of integers which the number of iterated items is provided by a method called once before the loop starts (the green code) and a loop of integers in which such method is called in the loop condition statement (the grey one). The third rule compares a decreasing loop of integers in which the condition statement is a comparison to zero (the green code) and an increasing loop of integers in which the condition statement is a comparison to the number of iterated items. The fourth and last rule compares a loop with two condition statements: the loop of the green code tests the most common condition first and the grey one tests the same most common condition at last.

The second group of best practices is composed 8 rules that corresponds to the same rule instantiated according to 8 Java types (strings, floats, integers, booleans, characters, doubles, longs and shorts). It is illustrated by the figure 1 for the Java type of strings. They compares initializations of variables either by a literal value, or by allocating a new object.

The third and fourth groups of best practices respectively focuses on how and when it is the best to set the size of string buffers and string builders. Both groups are composed of the same 3 rules. The first rule compares an initialization with the size set in parameter and an initialization without such setting. The second rule compares the invocation of the method that ensures the capacity of such structures against a

Listing 1: Example of Green Code.

```
public class StringValue {

  private String[] array;
  public void setUp() {
    array = new String[1000];
  }

  public void doRun() {
    for (int i = 0; i < 1000; i++) {
      array[i] = "abcdefg";
    }
  }

  public void tearDown() { }
}
```

Listing 2: Example of Grey Code.

```
public class StringObject {

  private String[] array;
  public void setUp() {
    array = new String[1000];
  }

  public void doRun() {
    for (int i = 0; i < 1000; i++) {
      array[i] = new String("abcdefg");
    }
  }

  public void tearDown() { }
}
```

Listing 3: Rule.

```
<rule id="prefer-string-value-initialization">
    <title>Prefer string value initialization</title>
    <description>
        Primitive type objects should be initialized literally
        e.g. with primitive values and without the use of any constructors.
    </description>
    <check green="codes.r96.StringValue" grey="codes.r96.StringObject" />
</rule>
```

Figure 1: Java Best Practice Example.

code that doesn't invoke such a method. The third rule compares the invocation of the method that set the length of such structures against a code that doesn't invoke such a method.

The fifth and last group of best practices gathers 2 rules that compares the use of Java primitive types against wrappers. The first rule compares a code in which variables have for type the primitive type *int* and the same code in which variables have for type the wrapper one *Integer*. The second rule compares a code in which variables have for type the primitive type *float* and the same code in which variables have for type the wrapper one *Float*.

4 MEASURE PROTOCOL

Measure protocol consists in a process described by the section 4.3. The latter consists in iterating a single measure task detailed in section 4.2. The measure instruments are previously described in the section 4.1.

4.1 Measure Instruments

The goal of our work consists in measuring the gains involved by applying a best coding practice. These gains correspond to performance gain e.g. the difference between the time required by the conducting of the grey code and the time required by that of the green code. It also corresponds to the memory gain e.g. the memory space used by the carrying out of the grey code against that of the green code. And the same for the energy gain e.g. the amount of energy saved by the carrying out of the green code with respect to that of the grey code. This is supposed to be able to manage fine-grained measures of codes: their short-time implementations and low energy consumptions. This also means to support the fact that measures have to be stable and repeatable.

We designed and implemented a digital power-meter made of two current probes and two differential probes connected together to one acquisition device that digitalised current and voltage values on 12 bits every 80 milliseconds. It is plugged to any computer by USB and controlled by a logger[2]. This logger

[2]It consists in the NI USB-6008 on 12 bits with a 10kHz frequency e.g. it makes possible to acquire 10.000 measures

provides a column-separated value (CSV) file with at least $n+1$ columns. The first one corresponds to the elapsed time from the moment the driver has been launched e.g. the first value starts at 0, the next starts at 80 and so on. The other n columns contain the power measured at the corresponding moment for a devoted couple of current and differential probes. Indeed, the CSV file can be seen as a group of functions $(p_1, \cdots, p_n)$ from an initial segment of the natural numbers (from 0 to a multiple of 80 ms). Each function p_i corresponds to the power $p_i(t_j)$ (in watts) required by the measured device at time t_j. The figure 2 presents a graphical view of this CSV file; it represents the power variation over the time for n devices as the first column of this CSV file corresponds to the x-axis and the n next columns are dispatched along the y-axis.

Therefore, the consumed energy is computed according to the trapezoidal rule by integrating the power over the time in order to estimate the area under each function pi, area that corresponds to the total consumed energy.

We use a Java agent for measuring object memory space[3]. It provides the memory space allocated by each unit tests. The latter is more precise than classical sensors that provide the maximum resident size as it doesn't take into account the memory footprint required by the Java virtual machine.

4.2 Measure Task

Our hybrid approach for measuring energy of Java code run concentrates on the measure task as the latter synchronizes the launch of both the physical and the logical sensors and as it merges their respective results. This task requires the identifier of the code to measure and the number of measures to plan. Then, it processes these following sub-tasks:

1. it calls the logical sensor service that warms up the given code;
2. it starts the physical sensor;
3. it waits 4 seconds and then calls to logical sensor service that executes the code;
4. it waits 3 seconds when the previous service responds and then stops the physical sensor;
5. it computes the consumed energy by the trapezoidal rule and stores it into a database.

per second. The logger is designed and implemented using LabView (www.ni.com/labview).

[3]This Java instrument is provided by the library ClassMexer (http://www.javamex.com/classmexer).

Such a measure task treats data provided both by the physical sensor (illustrated by the figure 2) and the logical one as follows:

- it computes the total consumed energy by the trapezoidal rule;
- it computes the average power at idleness e.g. during the first seconds and the last ones;
- it computes the consumed energy at idleness for the whole measure by the trapezoidal rule;
- it computes the difference between the total energy and the idle one in order to highlight the energy consumed by the code runs only;
- the code consumed energy is normalized according to the number of code runs provided by the logical sensor;
- the three values for time, memory space and consumed energy per code run is recorded into a database table which primary key is composed by the code identifier and the time stamp of this measure.

In fact, this measure task allows us to merge the energy indicator, computed from the physical sensor output, with those of time and space provided by the logical output. It ensures a very fine-grain precision when such measures tasks are carried out properly.

4.3 Measure Process

But not all measure tasks are correctly performed: third-party inconveniences can occur and then have side effects on the measure task results. The measure process aims at detecting measure task results that should be omitted for robust measure result sets.

Effectively, this measure process outcome consists in providing stable and repeatable measures for a given code in order to compare the green code and the grey one from a Java best coding practice and to ensure the amount of energy gain for applying this best practice. Moreover, this measure process automatizes thousands of measure launching, their planning and their cleansing until a quality extent has been reached.

This quality extent - or maturity - is composed of the number of measures made for a given code and their standard deviation against the average respective each time, space and energy values of measures. This process then iterates measure tasks until each code measure set reaches the quality extent and retains from these measure sets only those that match the cleansing rules (see section 5). The measurement process is itself composed of 6 sub-processes:

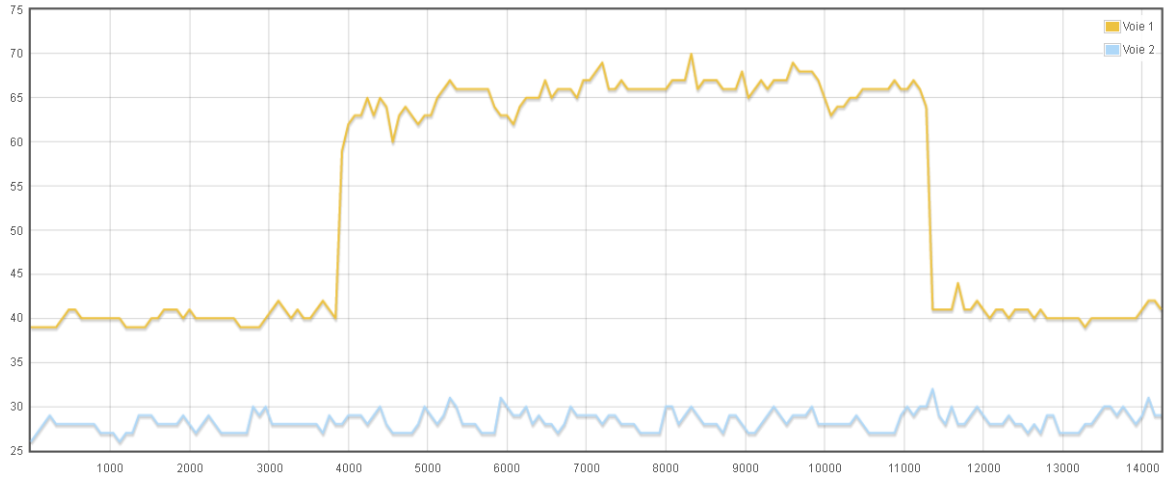


Figure 2: Measure Task Result.

1. the sub-process *retrieve* consists in retrieving (hence the name) the code identifiers available on the logical sensor side;
2. the sub-process *clean* detects measures that should be enabled or disabled for all available codes (see section 5);
3. the sub-process *embedd* just updates measure database according to the previous results;
4. the sub-process *plan* plans measures for codes which enabled measure set does not reach the defined quality extent;
5. the sub-process *launch* starts the measurement task if some measures have been planned and then iterates from sub-process 2 to sub-process 5, or exits to sub-process 6 otherwise;
6. the sub-process *send* reports the results.

In fact, the crucial sub-process is the clean as it removes from the final average values measures either that should be removed.

5 CODE MEASURE CLEANSING

There are 3 main reasons for removing a measure. The first one corresponds to the fact that a measure task has been launched while another third-part process was running after the physical sensor start and before the code run. This case is the left line chart of the figure 3. And this leads to overestimation of average power at idle, and then to overestimation of the consumed energy at idle and therefore to under estimate the code consumed energy.

The second reason, that is illustrated by the right line chart of the figure 3, corresponds to the fact that another third-part process was running before the physical sensor stop but after the code run has finished. This leads to overestimate the total energy and thus to overestimate the code energy (as the idle energy should correctly be estimated in this case). The last reason for a measure not to be clean corresponds to the fact that a third-part process was running between the beginning and the end of the code run. This leads therefore to overestimate the code energy.

5.1 Cleansing Rules

Technically, the measure cleansing sub-process consists in a 3-filter process:

- Dirty measures issued from first two reasons are filtered out by checking the idle periods (e.g. the first 4 seconds of the measure and the last 3 seconds) in order to detect power values out of an allowed scope of values.
- Dirty measures issued from the last reason are firstly filtered out by a mere rule drawn out from the measurement protocol: as it waits 4 seconds before, as it runs a code for 10 seconds and as it waits 3 seconds afterwards, measures which time value provided by the physical sensor does not exactly match 17 seconds are filtered out. whereas this could lead to filtered out acceptable measures i.e. false positive measures (see section 5). this filter does not keep unacceptable measures i.e. true negative ones.
- Dirty measures are also filtered out by statistical means in order to only keep homogeneous measures. A split-and-merge algorithm (also know as RamerDouglasPeucker algorithm (Douglas and Peucker, 1973)) is used allowing us a similar pre-

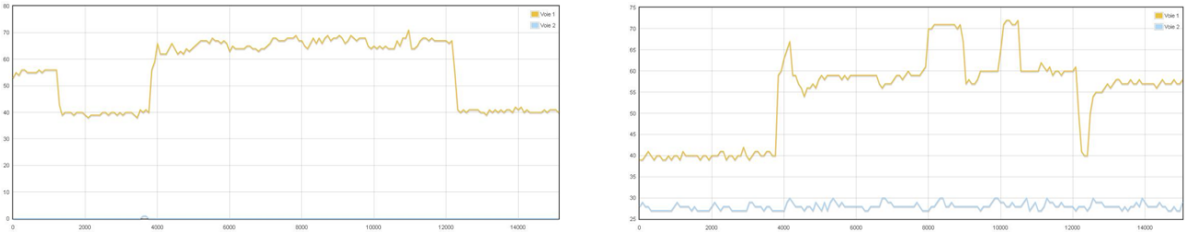


Figure 3: Wrong Measure Examples.

cision than the quartile methods but ensuring us a perfect recall (the quartile methods do not).

5.2 Cleansing Evaluation

The cleansing algorithm has a major role in our measure process as it removes measures and tasks which have not been performed correctly. Rules implemented and described in section 5 are evaluated in terms of precision and recall(Witten et al., 2011, p. 175-176) against a set of 200 measures manually annotated by 3 experts. Each expert assigns a Boolean value to each measure: true if the given measure is judged correct and false otherwise. Then, an inter-annotator agreement is computed by the means of Fleisss kappa(Fleiss, 1981, p. 38-46). Annotators disagree on 4 measures only (2% of all measures) for a Fleisss kappa of 0.94 which means an almost perfect agreement between experts; thus, having a good precision rate for an algorithm means in this context that this algorithm does not disable measures that have been annotated correct. And, having a good recall rate means that it does disable measures that have been annotated incorrect.

We challenge our algorithm against a statistical baseline: the quartile method. The latter has a precision of 0.953, a recall of 0.911 for an overall F-score of 0.931. As for our cleansing algorithm, it provides a lower precision of 0.941 but a perfect recall of 1.0 for a better overall F-score of 0.970. This means that our algorithm disables more measures that are annotated correct than the quartile method but it disables all measures that have been annotated incorrect whereas the quartile method does not. Thats why we keep using this *ad hoc* algorithm as it perfectly matches our requirements.

5.3 Code Measure Maturity

Another major issue concerns the number of measures required for a given code. As a measure performs in 17 seconds, we cannot afford to plan too many measures per code. On the other hand, we shall provide results that have to be repeatable in the same environment and provide minimal but stable result sets.

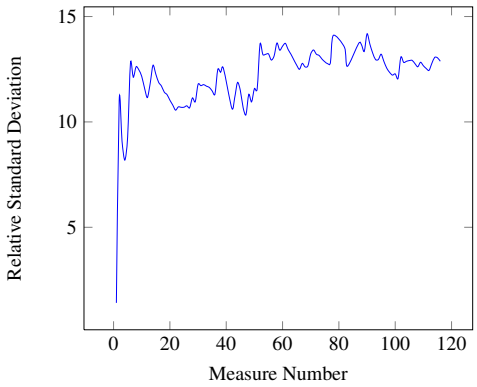


Figure 4: Evolution of the relative standard deviation according to the number of measures.

Tthe figure 4 sketches the average relative standard deviation between clean measures for every green and grey codes. This points out that one hundred of clean measures are not required in order to provide a stable set of measures, e.g. which standard deviation is low. Effectively, it shows that standard deviations range between 10% and 15% from the twentieth one. It leads us to fix an absolute threshold of at least 25 clean measures which standard deviation is less than 10%. The measure set of a given code is stated mature if and only if it matches these two constraints.

6 RESULT ANALYSIS

Results are presented both in the table 5 as well as in the table 1. The latter contains the energy model defined in the section 3.2 for the twenty Java best practices described int the section 3.3. Data of the table 5 are build on those of the table 1 as, firstly, it reminds the energy consumed at runtime by the green code and the grey one and, secondly, it computes the following two indicators:

Absolute Gain. This consists in the difference between the grey code energy and that of the green code. A positive absolute gain means that the best coding practice could be stated as an eco-design

Java Best Coding Practices	Green Energy	Grey Energy	Absolute Gain	Relative Gain
Prefer integer loop counters	82	98	16	16.32%
Avoid method loop conditions	8376	8602	226	2.62%
Prefer comparison-to-0 conditions	89	284	195	68.66%
Prefer first common condition	97	100	3	3.00%
Prefer string literal initialization	697	7885	7188	91.16%
Prefer float literal initialization	10311	10448	137	1.31%
Prefer integer literal initialization	685	9575	8890	92.54%
Prefer boolean literal initialization	683	6267	5584	89.10%
Prefer char literal initialization	695	33067	32372	97.89%
Prefer double literal initialization	10003	10210	207	2.02%
Prefer long literal initialization	669	8236	7567	91.87%
Prefer short literal initialization	680	7819	7139	91.30%
Prefer StringBuffer capacity initialization	593	1053	460	43.68%
Set StringBuffer capacity	598	1053	455	43.20%
Set StringBuffer length	1211	1053	-158	-15.00%
Prefer StringBuilder capacity initialization	378	899	521	57.95%
Set StringBuilder capacity	429	899	470	52.28%
Set StringBuilder length	1043	899	-144	-16.01%
Prefer integer primitives than wrappers	1009	3357	2348	69.94%
Prefer float primitives than wrappers	1048	3449	2401	69.61%

Figure 5: Energy Gains of Java Best Coding Practices.

practice whereas negative absolute gain should not appear.

Relative Gain. This is the rate between the previous absolute gain and the grey code energy. It corresponds to the proportion of energy that can be saved in applying the best coding practice.

The latter represents eco-design indicators and have to be handle separately. In fact, a best practice which relative gain is low but which absolute one is consequent could truly leverage down energy consumption of a software in which there are a lot of occurrences that this best practice is not applied at all. In the opposite, a best practice which relative gain is high could not have a major influence on energy consumption of a software in which this best practice is applied only a few times. This leads us to manage these two indicators separately.

These results that are commented below should all present gains because these best practices have been selected as they claim to improve efficiency in time or memory and therefore in energy. Moreover, these results can be trusted as no code standard deviation exceeds 10%. However, as it can be noticed, some results are not always positive. In such cases, it couldn't be state that the involved best practice should be ignore or avoid: it could mean that our implementation of this best practice is wrong. In the opposite, best practices with positive gains can be declared as eco-design rules as it has been proved that one of its possible implements generates gains in a concrete environment. The following lessons can be drawn out from the analysis of these twenty rules, group by group:

Rules About Loops. Loops with a condition to zero generate substantial gains. Moreover, it is preferable to iterate using integer counters than float ones. The rule that states to avoid methods in loop condition statements should be specified because the test method has no parameters and we suppose that the Java virtual machine optimized tests in loops. The Java virtual machine should also have optimized codes of the rule which states that it is preferable to place the most common condition in the first place inside loop condition statements.

Rules about Literal Initialization. For most of the Java types, it is better to initialize objects with literal values than new objects. However, rules for the Java types *float* and *double* involve that no gains. This could due to an sort of JVM optimization for the floating-point unit. For these, it is interesting to observe that their green codes takes more time to run than the grey ones, memory footprints are exactly the same; nevertheless these rules still generate energy savings!

Table 1: Energy Measure Results of Java Best Coding Practices.

Java Best Coding Practices	Green Energy	Grey Energy	Green Time	Grey Time	Green Memory	Grey Memory	Green SidDev	Grey SidDev
Prefer integer loop counters	82	98	4744	5931	16	16	8.66%	7.46%
Avoid method loop conditions	8376	8602	6181	6364	20056	20056	3.83%	6.14%
Prefer comparison-to-0 conditions	89	284	4709	17367	16	16	5.09%	5.78%
Prefer first common condition	97	100	4934	5017	16	16	4.37%	4.60%
Prefer string literal initialization	697	7885	842	7827	4136	36104	4.40%	8.14%
Prefer float literal initialization	10311	10448	4736	4127	20032	20032	5.85%	6.58%
Prefer integer literal initialization	685	9575	833	4591	4048	20032	5.21%	6.51%
Prefer boolean literal initialization	683	6267	775	4741	4048	20032	4.77%	7.03%
Prefer char literal initialization	695	33067	840	4595	4048	20032	5.04%	4.65%
Prefer double literal initialization	10003	10210	5810	4270	28032	28032	5.58%	7.83%
Prefer long literal initialization	669	8236	807	6066	4056	28032	2.89%	5.32%
Prefer short literal initialization	680	7819	819	3846	4048	20031	4.87%	7.71%
Prefer StringBuffer capacity initialization	593	1053	38085	59111	52056	73784	7.11%	8.40%
Set StringBuffer capacity	598	1053	38495	59111	52056	73784	7.86%	8.40%
Set StringBuffer length	1211	1053	70765	59111	104064	73784	9.40%	8.40%
Prefer StringBuilder capacity initialization	378	899	19278	41088	52056	73784	8.27%	7.18%
Set StringBuilder capacity	429	899	20976	41088	52056	73784	6.01%	7.18%
Set StringBuilder length	1043	899	20976	41088	104064	73784	6.01%	7.18%
Prefer integer primitives than wrappers	1009	3357	70198	144021	608	1472	4.83%	8.48%
Prefer float primitives than wrappers	1048	3449	71636	133655	608	1472	4.48%	8.21%

Rules about String Buffers and Builders. It is preferable to ensure the capacity of string buffers or string builders either while initializing such objects with the corresponding parameter or by calling the appropriate method. Absolute and relative gains are so close enough to corroborate the fact that such structure constructors ensure the capacity of strings. However, it is not recommended to set the length of string buffers or string builders as it just modify an internal field of such structures without allocating memory space. Effectively, the *ensureCapacity* method is used to allocate memory space of strings whereas the *setLiength* method is for shorten the size of already allocated strings.

Rules About Primitive Types and Wrappers. If it is possible, it is preferable to manage primitive types than wrappers. However, this rule should be completed with other ones. In fact, once codes deal with collections, Java virtual machines automatically casts primitives types into wrappers as collections require wrappers. This is called auto-boxing and it also consumes energy; furthermore much more energy than directly using wrappers in collections.

7 CONCLUSION

This document investigates how to qualify energetic relevance of Java best coding practices. This has been achieved, firstly, using a formalism of best coding practices which semantics consists in the comparison between a model code of this best practice (the green code) and another as the opposite of the model code. Secondly, this has also been achieved using an original and robust hybrid sensor system for estimating time, memory and energy required by a code implementation. This has lead us to these silent conclusions: there is no need to carry out numerous measurement operations for to obtain a consistent measure set.

This work leads us to improve, firstly, our measurement platform and, secondly, our measurement protocol, these two perspectives with the aim to develop an energy model programs. Our current platform is the result of a bottom-up approach which aims at producing measures by the means of a predetermined set of sensors. We plan to develop a new platform from a top-down approach and focused on analysis along these axis: the hardware architecture, the operating system, the programming language , the runtime environment, the type of measure, the type of sensor and obviously the analyzed code. Such a platform would make possible to elaborate energy models of programs in different programming languages, in different runtime environneents. For example, the energy model a FOR loop should depend on the number of iterated items, the type of these items and the complexity of the loop body. Such a goal requires designing much more sophisticated measure protocols than simple comparisons as it is currently the case.

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Evaluation of Femtocell Technology Challenges and Its Power Control Methodologies for Green Heterogeneous Networks

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Keywords: Small Cells, Femtocell Technology, LTE, Hetnet.

Abstract: Femtocell technology brings extended low-power radio coverage directly in the indoor premises, where propagation loss is typically highest. It also enriches both macrocell wide-area and in-building solutions in terms of coverage & capacity. The integration of femtocells into heterogeneous cellular networks is foreseen as a low-power and low-cost solution to cope with the exponential growth of required data traffic volumes, offload the macro base stations and offer high performance mobile networks. However, the massive and unplanned deployment of femtocells and their uncoordinated operations may result in harmful co-channel interference and cause significant power waste in order to maintain an acceptable user performance. In this work, we survey the technical challenges of femtocells deployment and the available energy control techniques. Moreover, we look into adaptive mechanisms for femtocell technology to cover the way towards green-oriented mobile networks. Our intention is to examine how femtocell deployment can share the available radio resources efficiently in order to limit the average power consumption and mitigate co-channel interference. Besides the introduction of the basic ideas for optimizing the spectral and energy efficiency in femtocell networks, typical interference management techniques are discussed too, with a special emphasis on power control methodologies.

1 INTRODUCTION

Recent analysis has shown that wireless networks, not data centers, are the biggest energy drain in cloud services. This is because more and more people are accessing wireless networks with the prospect of being connected anywhere and anytime. Tablets, smartphones and laptops no longer need to connect to wireless networks via cable. Instead, WiFi or indoor/outdoor cellular solutions which are inherently energy inefficient and a heavy contributor to energy consumption are used (Bell Labs and University of Melbourne, 2013).

As shown in Figure 1, a femtocell is a cellular base station (BS) solution typically installed by the end-user and transmits with minimal transmission power to serve residential or small business environments. It connects to the service provider's network via broadband such as Digital Subscriber Lines (DSL) and typically supports only a few user equipments (UEs). Femtocells can be deployed in a variety of scenarios such as: Offices and residences (from single-family homes to high-rise buildings), public hotspots (shopping malls, airports, train/subway stations, stadiums) or outdoor public area sites.

Due to its advantages such as low cost and high energy efficiency, femtocell technology has been proposed and applied by the 3rd Generation Partnership Project (3GPP) in its Universal Mobile Telecommunications System (UMTS), Long-Term Evolution (LTE) networks and its Advancement (LTEA) (Knisely et al., 2009), (3GPP TR 36.814, 2010).

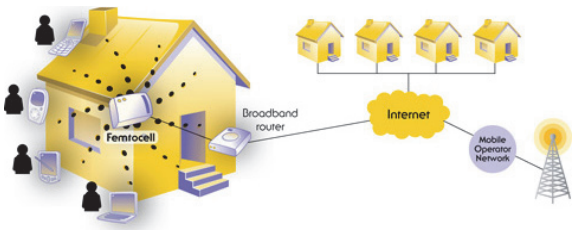


Figure 1: Basic Femtocell Network.

From the telecom provider's viewpoint, a significant amount of traffic can be moved from the macrocell networks to femtocell networks. Thus it reduces the number of macrocell BSs and equipments for backhaul transmission from macrocell BSs to their core network. This greatly

diminishes cost and power consumption. From the customer's viewpoint, the femtocells can be conveniently deployed as desired, providing sufficient radio signals to the UEs whilst consuming less power in indoor environments. It may also not be powered at all times for further energy savings. The typical power consumption of a femtocell is likely to be in the range of a few Watts, which is obviously much less than that of macrocell BSs. One other benefit of femtocells is that they help the user's battery last longer indoors where data rate requirements are often highest. This is because less power is required to transmit a signal over the short distance to the femtocell rather than over the long distance to a macrocell BS.

As femtocells are customer-deployed without proper network planning, their interference mitigation is more complicated than the traditional macro-level networks. Thus, interference problems in femtocell networks cannot be solved by existing schemes typically used for macrocell deployments. In (Kan et al., 2011), it's shown that the interference can be categorized in two types, the interference between macrocell and femtocell (i.e., inter-tier interference) occurs when femtocells utilize the spectrum already allocated to the macrocell and the interference between femtocells themselves (i.e., intra-tier interference).

Without proper interference management, significant power is likely to be wasted in order to maintain an acceptable user performance and quality of service. For example, usually the high transmit power is radiated by a macrocell BS to provide the services for outdoor UEs. If no proper downlink power control is applied at the macrocell BS, interference is possibly generated to indoor UEs connected to the femtocell BS in case the whole or a part of the frequency band is shared between the femtocell and macrocell. Therefore, the femtocell BS has to increase its transmission power to maintain the communication with its indoor UEs. In this case, the overall energy consumption becomes even worse after deploying the femtocells. Interference management is therefore a key issue to being able to capitalize on the potential energy efficiency in femtocell networks.

In this paper, we analyze some power control techniques related to femtocell technology to mitigate the happening interference and keep energy saved where possible.

2 WHY SMALL CELLS AND FEMTO TECHNOLOGY?

Studies on wireless usage show that more than 50% of all voice calls and more than 70% of data traffic originates indoors (ABI Research, Picochip, Airvana, IP.access, Gartner, Telefonica Espana, 2007). For indoor devices, propagation and penetration losses will make high signal quality and hence high data rates very difficult to achieve.

In this sense, femtocells are the ideal complement to the macro network. A better, faster user experience is delivered from a lower power and a lower cost site. Customer-close sites can be deployed and re-deployed as data demand ebbs and flows in the network (The Small Cell Forum, 2013).

Types of small cells include femtocells, picocells, metrocells and microcells based on increasing size from femtocells (the smallest) to microcells (the largest). Any or all of these small cells can be based on 'femtocell technology'— i.e., the collection of standards, software, open interfaces, chips and know-how that have powered the growth of femtocells. Small cells are low-power wireless access points that operate in licensed spectrum and are feature edge-based intelligence. Femtocells or Home Node Bs have been a hot topic for quite some time since they offer benefits such as:

Improved Cellular Coverage and Capacity: femtocells facilitate a new variety of mobile services that exploit the technology's ability to detect presence, connect and interact with existing networks. The enormous gains reaped from smaller cell sizes arise from efficient spatial reuse of spectrum. In addition to the full coverage and high speed transmission at home, they increase the area spectral efficiency (total number of active users per Hertz per unit area) (Alouini and Goldsmith, 1999).

Better Link Quality, Significantly Lower Transmit Power and Prolong Handset Battery Life: because of their short transmit-receive distance, femtocells can greatly lower transmit power, prolong handset battery life, and achieve a higher signal-to-interference-plus-noise ratio (SINR). These translate into improved quality. The lowered transit power will mitigate interference from neighboring macrocell and femtocell users due to outdoor propagation and penetration losses.

Improved Macrocell BSs Reliability: when a pre-authorized MS enters the coverage of a home BS (femtocell), it automatically switches affiliation from the serving macrocell BS to the femtocell. Hence, initiating as well as receiving calls and data

transmissions is performed as usual but through the femtocell network instead and over its IP backbone. This will enable the macrocell BS to redirect its resources towards providing better reception for mobile users and improve the service reliability and resource provisioning.

Offload Data Traffic from the Macrocell BSs: instead of deploying a lot of outdoor macrocell BSs, the heavy data traffic can be offloaded to femtocell networks. Offloading a fraction of the traffic to the femtocells will improve the macrocell BS capacity since it will have to handle less traffic.

Higher Performance and Customer Experience: weak in-building coverage causes customer dissatisfaction, encouraging customers to either switch operators or maintain a separate wired line whenever indoors. The enhanced home coverage provided by femtocells will improve customer satisfaction.

Cost-related Benefits: femtocell deployments reduce the operating and capital expenditure costs for network operators. The deployment of femtocells will reduce the need for adding macro BS towers. A recent study (Analysys Research Limited, 2007) shows that the operating expenses scale from $60K per year per macrocell to just $200 per year per femtocell. In addition, the end user will benefit too, for instance with special home-zone services— e.g., free calls, superior indoor coverage, and quality without changes in phones—and seamless services across all environments without dual or new hardware equipment.

3 FURTHER TECHNICAL FACTS ABOUT FEMTOCELL

The capacity potential of femtocells can be verified rapidly from Shannon's Channel Capacity law, which relates the wireless link capacity (bits/second) in a bandwidth to the Signal-to-Interference plus Noise ratio (SINR):

$$C = W \log2 \left(1 + \frac{S}{N}\right) \quad (1)$$

[Where W is the bandwidth of the channel in Hz, S is the signal power in watts and N is the total noise power of the channel watts]. We could increase the capacity by increasing the amount of spectrum, if possible, or we could also increase the number of antennas at the transmitter and receiver, as done with MIMO (multiple input multiple output):

$$C = n * W \log2 \left(1 + \frac{S}{N}\right) \quad (2)$$

[Where n here is # of antennas]. Another way to increase the capacity is to manipulate the SINR ratio. The SINR is a function of the transmission powers of the desired and interfering transmitters, path losses, fading and shadowing during terrestrial propagation. The transmitted signal is usually decomposed by Path losses. The simplest form of Path Loss is expressed in dB and can be calculated using the formula:

$$L = 10\, n \log10\, (d) + C \quad (3)$$

[Where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses]. The key to increase capacity is to enhance reception between intended transmitter-receiver pairs by minimizing d and n.

Reducing distance to end-user and lowering femtocell transmit power will improve the capacity through increased strength and reduced interference. In addition, deploying femtocells will enable more efficient usage of precious power and frequency resources. Of course, the assumption here is that the wired broadband provides sufficient QoS over the backhaul. Otherwise backhaul capacity limitations could reduce the indoor capacity gains provided by femtocells.

New telecommunication radio technology like the Long-Term Evolution (LTE) network is reaching the limits of Shannon's law, the spectrum available for mobile data applications is limited, and the only solution for increasing overall mobile network capacity is to increase the carrier-to-interference ratio while decreasing cell size and deploying small cell technologies like femtocells.

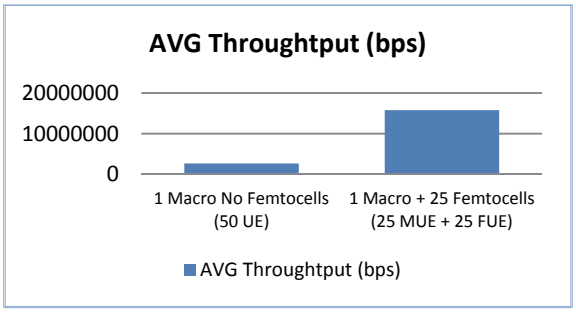


Figure 2: AVG. Throughput between UEs with/without femtocell deployment.

Example scenario - throughput as a function of macrocell / femtocell setup by using the simulator software in (Piro et al., 2011):

- Averaged Throughput, 1 macrocell deployment

without femtocell support, and 50 UEs (all of them are served by the macrocell alone).

- Averaged Throughput, 1 macrocell deployment with femtocell support, and 50 UEs (25 served by the macrocell + 25 by femtocells).

As illustrated in Figure 2, we can see that the throughput has dramatically improved after introducing femtocell to support the macrocell deployment.

Table 1: Simulation system parameters.

Parameter	Scenario Macro only	Scenario Macro and Femto
Apartment size	10m2	
Nr of apartment on a building	25	
Nr of buildings	1	
Building Type	5x5 grid	
Nr of Macrocell	1	
Nr of HeNB (Femtocell)	0	1 per apartment (25 per Building)
eNB power transmission	43 dBm, equally distributed among sub-channels	
HeNB power transmission	20 dBm, equally distributed among sub-channels	
Radius of Macrocell	1km	
Nr. of users/UEs	50	
Speed of UE	3 km/h	
Total bandwidth	20 MHz	
Flow Duration	10 Second	
Frequency reuse schema	N.A.	Reuse-1/4
Activity Factor	1	
Scheduler	Proportional Fair	
Traffic	(Best Effort Flows) Infinite Buffer	
Access Policy	Open Access	
Frame Structure	FDD	

4 GREEN FEMTOCELL TECHNOLOGY

It's discussed in (Bell Labs and University of Melbourne, 2013) that Mobile networks, and especially their radio access parts (frontend to user), are by far the dominant and most concerning drain on energy in the entire clouding system. The energy calculations show that by 2015 wireless cloud will consume up to 43 TWh in comparison to only 9.2 TWh in 2012. That is an increase of 460% which is in carbon footprint from 6 megatons of CO2 in 2012 up to 30 megatons of CO2 in 2015. Figure 3 shows up to 90% of this consumption is attributable to mobile and access networks (data centers account for only 9%).

Therefore, the focus should be on making cloud systems more energy-efficient by developing more energy-efficient radio access network technologies and specifically the upfront ones like small and femtocells.

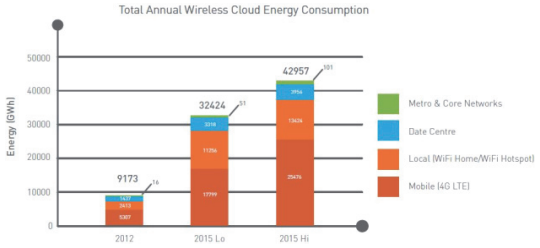


Figure 3: Estimate for annual energy consumption broken down into the various components of the wireless cloud ecosystem, 2012 and 2015 (Lo and Hi scenarios).

In (Al Haddad et al., 2012), a new indicator is introduced which enables us to calculate the consumed CO2 emission per kWh and enlighten the green effect of any technology based saved energy amount. The kWh is converted to kg of carbon saved. For instance, the conversion factor for the United States is 0.62747 kg CO2 saved for each kWh produced from a carbon free source.

The factor is based on the carbon emissions generated by the current United States' power stations per kWh generated. This factor includes other greenhouse gasses such as methane and nitrous oxide which are converted to their carbon dioxide equivalents so the value is really kg CO2 eq. per kWh. The CO2 consumption can be calculated as shown in the following equation:

$$\text{CO2 Power (Watt)} * \text{Conversion factor} \quad (4)$$

5 ANALYSIS OF FEMTOCELL DEPLOYMENT IN CELLULAR NETWORKS

In heterogeneous networks, where high data rates are desired, more dense deployment of femtocells is seen as an enabling solution. They are deployed with the macrocells in an overlay, overlapping or disjointed area in cellular networks. With such hyper-dense networks, the problem of interference comes between the macro cells and small cells as well as among the small cells themselves. The interference between macrocell and femtocell, i.e., inter-tier interference, arises from the fact that femtocells may utilize the spectrum already allocated to the macrocell. Without proper interference management, significant power is likely to be wasted in order to maintain an acceptable user performance.

Main challenges with femtocell Technology are

the Coordination between macrocells and ad-hoc femtocells, Interference mitigation with macrocells and femtocell deployment in a power-aware and green way. Further challenges to be considered with femto technology:

Tx Power Management: the RF environment is constantly changing and each femtocell needs to adapt its transmit power as other cells are being added, relocated or removed to maintain a continuous coverage and avoid interference.

Location Uncertainty: the location of femtocell is randomness and unpredictable, and as the owner likes.

Configuration Variation: some femtocells configuration parameters might be adjusted by the owners for operation and performance. The degree of uncertainty in the deployment increases if the femtocells configuration could be set differently for each femtocell.

Access and Security Control: OSG (Open Subscriber Group) or CSG (Closed Subscriber Group). Different access control mechanisms for femtocells may result in different interference environments much more complicated to control than that of the conventional wireless cellular networks.

Resource and Interference Management: femtocells can operate in their own dedicated channel or share a channel (co-channel) with the existing network cells. Femtocells deployed in co-channel manner as macro cells need to coordinate with macro cells to determine the optimal resource partitioning and maximize traffic offloading to femtocells.

Mobility Management: femtocells need to discover neighbors autonomously to facilitate UE handover.

Backhaul Management: bandwidth of customer backhaul cannot be guaranteed. When femtocells experience limitation in backhaul bandwidth, they should prioritize user classes or transferred packets.

All in all, Introducing femtocells should not significantly degrade the performance of other/prior deployed networks, therefore all the above listed challenges should be considered and solved.

6 INTERFERENCE MANAGEMENT TECHNIQUES FROM POWER CONTROL PROSPECTIVE

It is crucial to mitigate the interference which arises when femtocells are deployed in macrocell networks and ensure that the spectral efficiency is better than that of the macrocell only networks. Several interference management schemes for cellular networks with femtocells are presented.

- Optimization of Resource Allocation in case of coexisting femtocell and macrocell network (cognitive radio) like analyzed in (Femto Forum Working Group, 2009); (Boudec, 2012); (Luo and Yu, 2006) or by utilizing new features like “range expansion” that allows a User Equipment (UE) to be served by a cell with weaker received power (3GPP R4-092042, 2009) (RP – 111369, 2011).
- Radio resource coordination by allocating different resources between neighboring eNBs in the time or frequency domains as shown in (3GPP R4-093349, 2009).
- System/Design improvement by adding more resources like MIMO design as shown in (Cui et al., 2004).
- Dynamic Resource Management where new techniques like “opportunistic small cells” are introduced (Qualcomm, 2013), which dynamically turns the femtocell “ON” or “OFF” based on the need for capacity for instance proximity of users or traffic status e.g. idle status, to not only reduce interference but also lower energy consumption.
- Power Control (PC) which is necessary to mitigate the interference by manipulating the transmission power settings.

In this chapter we will go through the existing PC-related solutions only. There are Downlink and Uplink Power Control techniques for Interference Mitigation and Power Setting Tuning. In this section we try to summarize the most recent and important ones.

6.1 Uplink Power Control

In the uplink (UL), the interference from the outdoor Home UE to the macro eNB becomes a serious problem when the Home UE is located close to the macro eNB. In this case, the transmit power from Home UE has to be reduced in order to mitigate such interference. On the other hand, the indoor Home UE, which is close to its serving Home eNB and far from the macro eNB, can increase transmit power with a bit or even no interference to macro eNBs. Therefore, it is necessary to apply the uplink power control in femtocell networks.

The uplink power control for LTE as currently

defined in 3GPP standards (3GPP TS 36.213, 2013) is composed of open and closed loop components. The open loop power control (OLPC) is responsible for a rough setting of UE transmit power. It compensates slow changes of pathloss (including shadowing) in order to achieve a certain mean received signal power for all users. The closed loop power control (CLPC) is used for user specific adjustments of the power settings considering such factors as Modulation and Coding Scheme (MCS), measurement errors and rapid changes in radio conditions. It can be also used for further optimization of general network performance, as e.g. described in (Boussif, 2008); (Boussif, 2010). The equation defined in 3GPP for setting transmit power of Physical Uplink Shared Channel (PUSCH) is as follows (dB scale):

$$P = \min\left\{\begin{matrix}\mathrm{PMax}, 10\log_{10}(\mathrm{M}) + \mathrm{P0} + \alpha \cdot \mathrm{PL} + \\ \mathrm{deltaMCS} + \mathrm{f(deltai)}\end{matrix}\right\} \quad (5)$$

[Where PMax is the maximum allowed UE transmit power, M is the number of Physical Resource Blocks (PRB) scheduled for the given user in a time slot, P0 is parameter related to target mean received power (user or cell specific), α is pathloss compensation factor (cell specific), PL is the downlink pathloss measured by the UE (3GPP TS 25.814, 2006), deltaMCS is a parameter depending on the used MCS (user specific), and f(deltai) is a user specific CLPC correction]. In this case the cell specific parameters of the OLPC are considered (P0, α) as they have the main impact on the inter-cell interference.

If this simple power control method is applied in the uplink, a too strong signal transmitted from the outdoor Home UE possibly can cause interference to nearby macro eNB(s). In order to deal with this problem, the PL between Home UE and its nearest neighbor macro eNB has to be estimated for additional actions. Some well-known methods developed for uplink power control are:

- **Power Cap Based PC*:*** the maximum transmission power density (i.e., power cap) of the HUE is restricted in order to avoid heavy interference to macro eNB(s). The power cap of the HUE is calculated as a function of the estimated PL between HUE and its nearest neighbor macro eNB. Then, the HUE is power-controlled based on the PL from the HUE to its serving Home eNB, up to the level of the power cap (3GPP TS 36.104, 2007).
- **PL Difference based PC*:*** with the knowledge of the difference between the PL from the Home UE to its serving Home eNB and its nearest neighbor macro eNB, the Home eNB calculates the power offset as a non-decreasing function of the PL difference. Then, this offset value is sent to the Home UE via a radio resource control message to further adjust the uplink transmission power. Based on these facts, the Home UE transmit power can be adjusted accordingly (3GPP TS 36.104, 2007).
- **Adaptive Target Mean received po>Wer (Adaptive P0)*:*** the proposed solution in (Jacek, Pedersen, Szufarska and Strzyz, 2010) is to define the OLPC parameter P0 in equation (5) in a way that would reflect the distribution of interference levels within macrocell, e.g. as a function of pathloss towards closest macro-eNB:

$$\mathrm{P0} = \mathrm{round}\{\mathrm{APo} + \mathrm{BPo} \cdot \mathrm{PLLA_{WA}}\} \quad (6)$$

[Where P0 is the calculated OLPC parameter for a local area node, PLLA_WA is the downlink pathloss to the closest wide area node. APo and BPo are parameters of the function that can be e.g. operator or vendor specific]. The algorithm introduces two additional parameters (APo, BPo are the same for all Home eNBs) but it allows full individual configuration too. To achieve similar effect with the basic OLPC procedure, each local cell would have to be configured with an individual set of parameters.

- **Link Budget Analysis:** a link budget analysis is provided which enables simple and accurate performance insights in heterogeneous networks. In (Chandrasekhar, Andrews, Muharemovic, Shen, and Gatherer, 2009), a distributed utility-based SINR adaptation at femtocells is proposed in order to alleviate cross-tier interference at the macrocell from co-channel femtocells. The Foschini-Miljanic (FM) algorithm is a special case of the adaptation. Each femtocell maximizes their individual utility consisting of a SINR based reward less an incurred cost (interference to the macrocell). The radio link quality for a cellular user is determined, given a set of N transmitting femtocells with different SINR targets. Achieving higher SINR targets in one tier fundamentally constricts the highest SINRs obtainable in the other tier.

6.2 Downlink Power Control

Several interference mitigation schemes using femtocell BS power level setting in DL have been investigated:

- **Basic fixed Power Approach:** it is based on a preconfigured value which is common for all

femtocell BSs regardless of the surrounding RF conditions. Advantages of this scheme are its simplicity and ease of implementation. Disadvantages are its difficulty to adapt to the surrounding RF conditions and likeliness to cause large interference. If the fixed power level is too low, the femtocell BSs located close to the macrocell BS have poor coverage because the interference from the macrocell BS is high. On the other hand, if the fixed power level is too high, the femtocell BSs located at edge of the macrocell provide a large interference to the near macrocell MSs because the interference from the femtocell BSs to the macro MSs becomes high.

- **Self-configuration based on Macrocell BS Signal:** self-configuration of transmit power level based on the measured received signal level from the macrocell BS was developed by Claussen et al., (2008).
- **Self-optimization Approach based on SINR:** a self-optimization of coverage in accordance with the information on mobility events of passing and indoor users is used. Li et al., (2009) used downlink power control to achieve SINR for both macrocell and femtocell users.

Guidelines on how to control UMTS Home NodeB (HNB) and LTE Home eNodeB (Home eNB) interference by transmit power level setting are given in (3GPP TR 25.967, 2012) (3GPP TR 36.921, 2012). However, the previous techniques have not adequately accounted for the interference with neighboring macrocell users and surrounding conditions.

- **RSRP Approach:** the largest Reference Signal Received Power (RSRP) corresponding to the nearest macro eNB is used as one of the parameters for tuning downlink power control (3GPP R4-093557, 2009). As the RSRP decreases, which means that the Home eNB is located close to the edge of the macro cell, the transmit power should be small in order to mitigate the downlink interference to the macro UE. If a Home eNB is close to a macro UE, lower transmit power should be set to mitigate its interference to the macro UE. With the knowledge of the largest RSRP and power offset, the Home eNB selects the transmit power of the reference signal as the median values of the sum of the largest RSRP and power offset, the lower and the upper limit values of transmit power.
- **Adaptive power level setting approach:** two adaptive power level setting schemes are possible here as shown in (3GPP TR 36.814, 2010):

a) Adaptation based on DL Reception Power from MBS:

This technique is based on downlink co-channel reception power of the reference signal of the strongest macrocell BS. The femtocell BS measures the reception power at the initial configuration phase or in operational phase and adaptively set the transmit power level accordingly. This scheme corresponds to the measurement based self-configuration scheme given in (Morita, Matsunaga, and Hamabe, 2010). The femtocell BS sets the transmit power of the reference signal as:

$$P_{\_tx} = \text{MEDIAN}(P_m + P_{offset}, P_{\_tx\_upp}, P_{\_tx\_low}) \quad (7)$$

[Where the function MEDIAN() means the returned value is the median of all arguments. P_m[dBm] is the reception power of the reference signal from the nearest macrocell BS measured at the femtocell BS and is dependent on the path loss between the nearest macrocell BS and the femtocell BS which includes the penetration loss at the building wall. P_{offset}[dB] is the predetermined fixed power offset compensating for the indoor loss. $P_{\_tx\_upp}$ and $P_{\_tx\_low}$[dB] are the upper and the lower limit value of the transmit power. $P_{\_tx\_upp}$ is needed to limit the interference from the femtocell BS to the macrocell MS. $P_{_tx_low}$is also needed to guarantee a certain minimum performance for femtocell even if the surrounding macrocell cannot be detected].

A disadvantage of the schema is that it is not enough for only fixed power offset to compensate for the indoor path loss. Each building has different properties, such as the penetration loss at external walls and P_{offset} should be tuned accordingly.

b) Adaptation based on DL Reception Power from macrocell BS and UL Reception Power from macrocell MS:

This technique is based on downlink (DL) co-channel reception power of the reference signal of the strongest macrocell BS and uplink (UL) reception power from neighboring macrocell MSs. The femtocell BS adaptively measures the DL and UL reception power at self-configuration phase and then optimizes the transmit power during the self-optimization phase. The femtocell BS sets the transmit power of the reference signal as follows:

$$P_{\_tx} = \text{MEDIAN}(P_m + P_{\_offset\_o} + K * L_E, P_{\_tx\_upp}, P_{\_tx\_low}) \quad (8)$$

[Where P_m, $P_{\_tx\_upp}$, and $P_{\_tx\_low}$ have the same meaning as (7). $P_{\_offset\_o}$[dB] is a predetermined

power offset value compensating for the indoor path loss excluding the penetration loss. K is an adjustable positive factor and can be determined by the priority of the femtocell BS operation. L_E[dB] is the penetration loss which assumed to be ideally estimated]. A macrocell MS is assumed to be located in close proximity to a femtocell BS. This means the distance from the macrocell BS to the macrocell MS is nearly the same as that from the macrocell BS to the femtocell BS. The penetration loss L_E can be calculated as follows:

$$L_E = \frac{1}{2} * \left(P_{tx\_f} - P_{rx\_f} - L_a \right) \quad (9)$$

[Where P_{tx_f}[dBm] is the UL transmit power virtually calculated by the femtocell BS. P_{rx_f}[dBm] is the UL reception power from the macrocell MS measured at the femtocell BS. L_E [dB] is open - air propagation loss between the macrocell MS and the femtocell BS excluding the penetration loss]. L_E is a predetermined value and is assumed in advance so that the distance between the macrocell MS and the femtocell BS can be minimized under the conditions in which the interference from the macrocell MS to the femtocell BS is tolerable. When the path loss between the macrocell MS and the femtocell BS excluding the penetration loss is within La, the penetration loss in equation (9) is estimated to be smaller than its real value and the transmit power is suppressed. When the path loss is outside L_E, the penetration loss is estimated to larger than the real value and the transmit power is released. This power setting technique can resolve the problem of the last power setting schema.

- **Auto-tuning of DL Power of Femtocells Adaptive to Various Interference Conditions:** the power offset in previous introduced technique has not been adequately optimized for various interference conditions. In (Kan et al., 2011), the proposed scheme automatically tunes the power offset so that the femtocell throughput can increase while maintaining the macrocell throughput based on macrocell mobile stations' interference detection reports. In comparison to the last technique where the $\mathbf{P_{\_offset\_o}}$ is fixed, various interference conditions such as size of buildings where femtocell mobile stations exist and distance to a street where macro MSs exist are not sufficiently considered. The macrocell or femtocell throughput may degrade if the initial value is too large and too small compared with the conditions.

Therefore, (Kan et al., 2011) introduces different auto-tuning schemes using individual offset where the $P_{\_offset\_o}$ is tuned individually per femto BS or using common offset where the $P_{\_offset\_o}$ is tuned commonly among femto BSs in a macrocell with per-femtocell or per-macrocell measurement, respectively. This approach uses a stepwise tuning of $P_{_offset_o}$based on Interference Detection Ratio (IDR1) indicator, which is the ratio of the number of interference detection reports to the number of macro MSs that receive the measurement control message from the serving macro BS.

7 CONCLUSIONS

With the steadily increasing demand for mobile traffic, it is important that the telecom networks are modernized with all the capacity, quality and coverage extension technologies available and especially the energy efficient ones such as femtocell technology. In 3G networks, small cells are viewed as an offload technique whereas from 4G networks onwards, the principal of heterogeneous networks is introduced where the network is based on layers of small and large cells together. Whether it's a low indoor coverage, bad network performance in rural areas, required capacity increase and high data rates or qualified coverage guarantee in hard-to-cover areas, a cost-efficient way to address these issues is femtocell solutions.

There are no distinct standards to define the physical power transmission of a femtocell but only recommendations. This survey work provides an overview of the power control and saving methodologies with regard to femtocell technology. It also discusses its challenges and different potential ideas for improvements. The femtocell technology is still young and fertile research is still required here.

In our future research work, we will be further identifying the ability for femtocell technology to help with the green initiatives. For instance, future network releases need to support the coordination among femtocells and not only between macro and femto cells and take into account conditions of both surrounding environment and networks. In addition, other topics will be further investigated like enhancing existing power control methodologies, powering down small cells based on traffic situation, improvements on cell phone battery life and throttling small cell power down based on cell type and usage.

Future innovations and further research are strongly required to overcome the challenges coming with this immature technology.

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Assessment of the Environmental Impact of Applications in Federated Clouds

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Abstract: While in recent work the energy efficiency of cloud platforms has been emphasized and many approaches have been proposed to reduce the energy consumption in data centres, the evaluation of the environmental impact of applications running in cloud environments is still a research issue, as well as possible techniques to lower their environmental footprint. In the paper the approach taken in the ECO_2Clouds project towards assessment of environmental impact of applications and the evaluation of its potential reduction based on adaptive services is illustrated and discussed, including in the discussion the evaluation of alternative possible uses of eco-metrics towards reducing the environmental impact of applications.

1 INTRODUCTION

Energy consumption in large scale data centres and in clouds is a growing concern that has only recently received necessary attention. Several techniques have been developed to improve energy efficiency in data centre and cloud environments (e.g. Kolodziej et al., 2012); (Lindberg et al., 2012) and several metrics have been proposed to assess the obtained results (e.g. Kipp et al., 2012). In (Beloglazov et al., 2011) a comprehensive survey is provided on the existing approaches for achieving energy efficiency, with particular reference to dynamic power management approaches, both at the hardware and at the software level. At the software level, approaches range from management of workloads at the level of the single servers, to overall workload management at data centre and cloud level.

In cloud computing virtualization provides necessary basis for not only dynamic management of resources but also for making efficient use of available resources while guaranteeing quality of service. Lately research work in the area of cloud computing has been focusing on allocating virtual machines with the goal of improving energy efficiency in cloud infrastructure and reducing environmental impact of cloud computing [Kolodziej et al., 2012); (Lindberg et al., 2012); (Khosravi et al., 2013); (Wajid et al., 2013). On the other hand, to carry out assessment of energy efficiency techniques and approaches several metrics have been proposed (Kipp et al., 2012); (GreenPeace, 2012). In this respect, the GreenGrid Consortium has proposed a Data Center Maturity Model (DCMM) which, on the basis of computing, networking, infrastructure, and management variables enables users to determine the current performance of data centres and identify ways to achieve greater energy efficiency and sustainability (Singh et al., 2011). In this work strong emphasis is put on a better use of available resources based on parameters such as for instance the percentage of CPU usage, which, rather than being kept low in the average data centre, should be increased to reach 60% on the average to achieve desired outcome (envisioned by 2016).

Besides energy efficiency, a related stream of research focuses on evaluating and reducing the environmental impact of cloud computing by means of minimizing CO_2 emissions. From the point of view of environmental impact, many proposals are based on deriving from the consumed energy the equivalent estimation of CO_2 emissions. However, in a (GreenPeace, 2012) report, several other factors are highlighted that can also contribute towards environmental impact of cloud computing.

In this respect, reporting of the Carbon Utilization Effectiveness (CUE) is one of the parameters which is starting to be considered by

some of the public cloud providers. Another contribution of GreenPeace report is the clean energy index, which considers the energy mix for generation of the utilized energy, siting, the adoption of energy efficiency techniques, and reuse of energy in datacentre or cloud environments.

Notwithstanding the many proposals there is not a single agreed or standard metric or set of metrics that clearly allow the assessment of the environmental impact of cloud computing. In particular, while the above-mentioned work focus on the IT infrastructure (and in some cases also the facility management, which is out of the scope of this work), there is no clear indication on how energy efficiency and environmental impact should be evaluated at the level of application deployed or running on cloud.

If we focus on the assessment of non-functional parameters at application level, adaptive approaches have been proposed ((e.g. in the S-Cube network, (Papazoglou et al., 2010)) as a way to guarantee quality of service in service-based systems where services are provided in a distributed way to a variety of users and to other service providers. In such environments, a major emphasis is given to the ability of assessing the context of execution, in order to base adaptation on the available knowledge of the context. In (Bucchiarone et al., 2012) such an approach has been particularly studied for composed services, where service is provided through a combination of services to clients requesting it with agreed Quality of Service constraints.

In this paper we describe how in the EU funded ECO_2Clouds project the assessment of environmental impact of cloud applications is performed, and by virtue of this assessment we evaluate the potential benefit of an adaptive approach that we have developed and implemented in the project. The focus being on the IT components of federated clouds and efficiently running applications in the cloud, considering also the dynamically varying energy mix in the different sites, we show how such an approach could bring more than an order of magnitude of improvement in the environmental impact of cloud applications.

In addition to the discussion about the potential of adaptive and context-aware approaches, the goal of the paper is to put forward a discussion about the possible uses of indicators, not limited to techniques for automatically reducing absolute values of energy consumption and environmental impact.

In this position paper, first, in Section 2, we briefly introduce ECO_2Clouds project and discuss the assessment of environmental impact of applications as carried out in ECO_2Clouds and possible approaches for evaluating the assessment. This is followed by a brief description of adaptation techniques used in the ECO_2Clouds project for reducing the environmental impact.

In Section 3 we evaluate the potential of using adaptation techniques on experimental data while discussing possible options. Finally, in Section 4 we discuss possible approaches for assessing the environmental impact of applications and their potential for improvement.

The paper ends with summary remarks and acknowledgements.

2 ENERGY EFFICIENCY AND ENVIRONMENTAL IMPACT IN ECO_2CLOUDS

The ECO_2Clouds project (http://eco2clouds.eu) investigates strategies and develops mechanisms for environmentally aware cloud sourcing with the aim to reduce energy consumption and CO_2 emissions of cloud applications as well as of the underlying infrastructure.

In ECO_2Clouds, assessment of environmental impact of cloud computing is carried out by defining a set of layered metrics. The evaluation of the metrics is performed within an adaptive and context-aware application deployment and management approach discussed in the subsequent sections.

2.1 Metrics and Assessment

In ECO_2Clouds, three levels for evaluation of environmental impact are considered: physical, virtualization, and application level. While it is not the goal of the paper to provide details on all metrics concerning each of the three levels (described in detail in ECO_2Clouds D3.1, 2013), we focus here only on the evaluation of energy and CO_2 emissions related parameters. In ECO_2Clouds assessment and improvements concerning these parameters relies on the management of IT component of the cloud infrastructure, and in particular on the computing components.

In ECO_2Clouds energy is evaluated at physical level of cloud infrastructure, based on measurements from PDU (Power Distribution Units), for each site of the federated cloud. From these measures, energy consumption is evaluated for each server or host of each cloud site. From measurements at host level, considering the running virtual machines and their

CPU usage, the energy consumption is mapped and evaluated for each virtual machine.

A third level introduced in ECO_2Clouds concerns the actual use of VM by applications. We assume that one or more applications (or service) can be executed on a VM, and, based on their execution parameters, such as start and termination times and CPU usage for each service, power level and energy consumption are evaluated for each running service.

ECO_2Clouds utilises a federated cloud infrastructure composed of three geographically distributed cloud sites located in Germany, France, and UK (details of the characteristics of the sites are provided in the ECO_2Clouds web site), where the energy mix (i.e. proportion of coal, nuclear, hydro etc.) is known for each site. Such energy mix can vary based on the time of the day and of the year. Using the energy mix information alongside energy consumption measure the CO_2e (Carbon dioxide equivalent) emissions can be evaluated, for all three levels, i.e., physical, VM, and applications as a measure for environmental impact of the underlying cloud infrastructure and applications. In this way, it is possible to give to users a rather precise evaluation of the environmental impact of their cloud applications based on above-mentioned data.

2.2 Adaptation Actions

Based on the defined metrics, their evaluation can be the basis for establishing an adaptive control system for reducing the environmental impact of cloud computing.

As mentioned above, several approaches have been proposed in the existing literature for improving energy efficiency in the cloud (for example, as discussed in (Beloglazov et al., 2011) and (Lindberg et al., 2012).

In ECO_2Clouds, the problem of energy consumption and CO_2 emissions is addressed at the software level, assuming that optimization at the server and operating system level is not under control of the cloud platform or the users.

In this respect, actions that can be applied within the context of ECO_2Clouds are at two levels i.e. VM level and application level. This limitation is primarily based on the use of BonFIRE platform (BonFIRE, 2013) and its functionalities that are made available for usage and experimentation in the ECO_2Clouds project.

Further actions could be envisioned in other platforms; however, we briefly mention here the principal two types of actions under consideration, as a basis for the following discussion:

- VM level: here the main goal is scheduling of VMs on available cloud resources with a focus on consolidation, to be able to save energy by possibly switching off unused machines, and freeing less used computing resources for other uses.
- Application level: actions inspired by dynamic service composition approaches, VM reconfiguration and usage management of long running applications (such as the ones described in (Cappiello et al., 2013)), starting, freezing, reactivating, and terminating one or multiple VMs on which the application is running based on the applications' internal and execution context information.

3 POTENTIAL OF ADAPTATION

A first approach for a general evaluation of the environmental impact is to evaluate the total energy consumption and consequent CO_2 emissions over a given period of time.

In ECO_2Clouds, the Zabbix monitoring solution used in BonFIRE has been extended with the defined eco-metrics, since each cloud site in the BonFIRE federated cloud already provides a Zabbix server which uses Zabbix client agents to capture the cloud resource utilization data at host and VM levels. These Zabbix agents can be used to retrieve energy consumption and CO_2 related data for two of these layers: physical and virtual resources (Tenschert and Gienger, 2013).

Application level metrics are evaluated within the application deployment environment. The general architecture is shown in Fig 1. Three cloud sites are considered as testbeds in ECO_2Clouds.

An example of display of power metrics is shown in Figure. 2. In addition to the graphical interface and exports in spreadsheets, a REST interface for interacting with the application level control environment has been developed.

In this section we base our discussion on an analysis from the experimental data, starting from the assumption that in the beginning there is no VM management.

For an evaluation of the potential of considering the execution context of applications for their dynamic management, we consider for a rough evaluation an average CO_2e conversion factor for each given site. A further improvement could be gained considering also daily and seasonal variations in the energy mix, but we do not consider this in this paper to simplify the presentation, with the goal of

giving an approximate estimation of the possible gains. However, the energy composition is actually available as a monitored parameter within Zabbix, together with the other eco-metrics defined in ECO_2Clouds project.

We assume to run applications initially on 10 separate physical servers, running with an average power of 133 W. Due to the different energy mix in the three countries, as reported in (ECO_2Clouds, D3.1, 2013) we can assume an average value of 85 gCO2e/kWh for France, 706 gCO2e/kWh for Germany, and 567.17 gCO2e/kWh for UK.

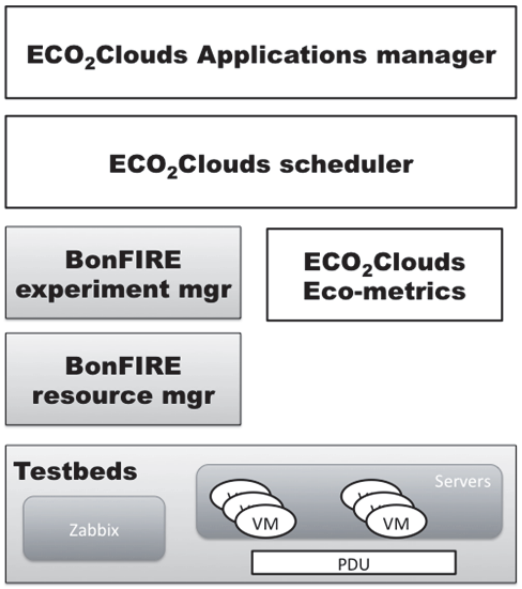


Figure 1: ECO_2Clouds architecture.

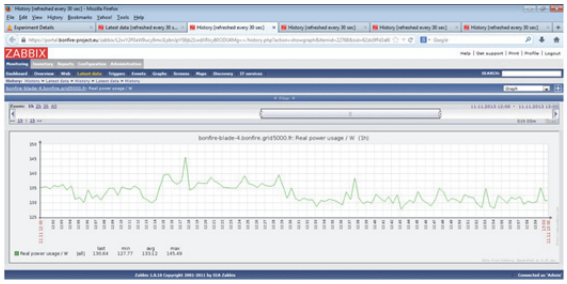


Figure 2: Monitored eco-metric (courtesy of INRIA).

Due to the application of VM consolidation techniques, based on the target goals of DCMM (GreenGrid, 2011), we can assume that the load of the servers can raise from 20% to 60%, owing to activating and deactivating the VMs as needs arise.

However, when running VMs in a BonFIRE cloud, we have also to assume that an experiment (i.e. the allocation of VMs to a user according to his requests) is immediately started, and in addition, since a duration for the experiment has to be specified in advance, it is likely that the user will have to ask for more resources and for a longer time than needed because in case the application is not completed at the end of the requested period, the experiment will be stopped (and in this case will have to be started again).

From application level it is difficult to assess the potential reduction of environmental impact that can be gained from the ability to manage VMs, thus there are opportunities for user and the application to better control and manage their allocated resources. However, this depends on the initial configuration of the experiment, as well as from the type of the applications. For instance, in our experimentation first simulations show a potential impact from 10 to 50%.

	Wh per year	max CO2e	min CO2e	max energy reduction	max CO2e reduction
initial configuration	11650800	8225464.8	990318	-	0.88
server consolidation	3883600	2741821.6	330106	0.67	0.96
VM application level mgr	1941800	1370910.8	165053	0.83	0.98

Figure 3: Adaptivity analysis vs initial configuration.

In Fig. 3 we report a first evaluation of the potential reduction, with respect to the given initial situation. In the figure it is clear that in cases such as the one considered in the cloud federation, running in three different countries, the impact of the location is preponderant, and, combined with dynamic resource management, the potential gain could be on the order of two orders of magnitude. However, some additional considerations are necessary and will be discussed in the next section.

4 DISCUSSION ON EVALUATING THE ENVIRONMENTAL IMPACT OF CLOUD APPLICATIONS

From the reported example, it becomes clear that the simple definition of eco-metrics is not sufficient for an assessment.

First of all, a coarse evaluation based on total energy and CO_2e emissions can be misleading in some cases. In fact, it might lead to allocating the load only on a few of the available servers, and only in a single country when the energy mix is very different in the federated cloud.

In addition, it has to be considered that reducing power does not always imply reducing energy

consumption (see, for instance the discussion in (Chen et al., 2011)). In fact, applications might take longer to execute, so the reduction in energy consumption is not necessarily proportional to the reduction of power, and in some situations might even result in an increase of power consumption.

Alternative approaches can also be considered, based on the available metrics, to take into consideration other factors. One aspect is that considering only energy and CO_2e could result in violations of other parameters, for instance Quality of Service. To avoid this, assessment of environmental impact should be based on the evaluation of many factors. As in service-oriented systems, this approach can result either in considering a set of thresholds to be satisfied, or in defining a utility function for a global assessment of the system. In this case, other factors could be considered, such as the importance given by the users to some quality parameters or for a given energy mix (e.g., excluding coal or nuclear sources). Since the evaluation of importance could vary based on the user preferences, or even based on the specific nature of each single application, the user should be enabled to establish his own preferences for making an evaluation.

Other factors, even if not relevant at the moment within the BonFIRE platform as it is currently provided, could be linked in the future to variable costs of the provided service under different conditions such as the use of specific infrastructure at specific time, under specific QoS parameters and under specific energy consumption or CO_2 footprint related constraints.

These considerations would result in different evaluations when considering the user views and cloud provider view, which would give a different emphasis on different parameters. A comparison in such cases might be difficult, as well as an assessment of the final result.

A completely different approach could be based on management considerations, such as avoiding critical events (as proposed, for green IS, in (Reiter et al., 2013)). Critical events in cloud computing, when focusing on energy and environmental impact, could be the need to avoid reaching power limits in a data centre, which usually results in limited service or in additional costs for energy provisioning, or using on-demand resources in one of the sites of the federated cloud when other resources are available instead in other sites.

Finally, giving the users information about the energy consumption and related monitored information could raise awareness of ecological implications of their computing requirements, which in turn could encourage modification in user behaviour. For instance, if a user needs to report CO_2e emissions for his applications, and he sees a potential for reduction while running the application in a given site or in a given time of the day, he might schedule to run his applications, if not time critical, taking also these factors into consideration. In other cases, the user might realise that his use of allocated VMs is not optimal (in terms of energy consumption or CO_2e emissions) in a specific deployment configuration and that different configurations might reduce wastage of available computing resources e.g., by consolidating certain VMs in a specific host, exploiting better multicore architectures, or interleaving I/O intensive applications with computing intensive ones. In this respect, awareness of energy consumption or environmental impact of computation can encourage users to change their behaviour and consider different factors in application deployment and execution decision making model.

5 CONCLUDING REMARKS

In the paper we have presented the ECO_2Clouds approach to monitoring energy consumption and CO_2 emissions as eco-metrics in a federated cloud environment. We have discussed the potential for exploiting the use of eco-metrics in different directions, ranging from the evaluation of environmental impact of cloud computing to encouraging the changes in behaviour of users.

ECO_2Clouds will also develop sophisticated mechanisms for automatic optimization of application deployment configurations based on context-aware service provisioning in the cloud. Optimization will be carried out both at the scheduler level and at the application level during the execution lifetime of applications.

Experimentation in the project will be aimed at testing different types of application case studies, ranging from computing intensive to more interactive and cloud specific long running applications, to analyse how different factors could have an impact on approaches for assessment of environmental impact and create new opportunities for optimization of energy consumption and CO_2e footprint or for a more informed user behaviour that can lead to further developments and innovation in this area.

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On Energy-efficient Checkpointing in High-throughput Cycle-stealing Distributed Systems

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Abstract: Checkpointing is a fault-tolerance mechanism commonly used in High Throughput Computing (HTC) environments to allow the execution of long-running computational tasks on compute resources subject to hardware and software failures and interruptions from resource owners. With increasing scrutiny of the energy consumption of IT infrastructures, it is important to understand the impact of checkpointing on the energy consumption of HTC environments. In this paper we demonstrate through trace-driven simulation on real-world datasets that existing checkpointing strategies are inadequate at maintaining an acceptable level of energy consumption whilst reducing the makespan of tasks. Furthermore, we identify factors important in deciding whether to employ checkpointing within an HTC environment, and propose novel strategies to curtail the energy consumption of checkpointing approaches.

1 INTRODUCTION

The issue of performance and reliability in cluster computing have been studied extensively over many years (Jarvis et al., 2004), resulting in techniques to improve these properties. The issue of cluster *'performability'* is relatively well understood, but until recently few have considered its consequences for energy consumption.

High-throughput cycle stealing distributed systems such as HTCondor (Litzkow et al., 1998) and BOINC (Anderson, 2004) allow organisations to leverage spare capacity on existing infrastructure to undertake valuable computation. These High Throughput Computing (HTC) systems are frequently used to execute long-running computational tasks, so are susceptible to interruption due to hardware and software failures. Furthermore, in our context of an institutional *'multi-use'* cluster comprising student cluster machines, jobs may also be interrupted by the arrival of interactive users to cluster workstations.

Checkpointing is a fault-tolerance mechanism commonly used to increase reliability by periodically storing snapshots of application state. These snapshots may then be used to resume execution in the event of a failure, reducing wasted execution time. Checkpointing has previously been employed on HTC clusters with little consideration of the energy consumption incurred by checkpointing overheads.

In recent years attention has turned to the energy consumption of IT infrastructures within organisations. Aggressive power management policies are often employed to reduce the energy impact of institutional clusters, but in doing so these policies severely restrict the computational resources available for research computing.

We demonstrate through trace-driven simulation using real-world datasets (Section 2) the detrimental effect of existing checkpointing policies on energy consumption (Section 3), motivating the need for an increased understanding of the impact of checkpointing strategies within HTC clusters. Finally we discuss key considerations when adopting checkpointing in HTC clusters and go further to highlight possible future directions for more energy-efficient checkpointing (Section 4).

1.1 Related Work

Previous works in energy-aware checkpointing have primarily focused on real-time systems (Zhang and Chakrabarty, 2003; Unsal et al., 2002; Melhem et al., 2004) subject to strict energy budgets and deadlines.

More recently, research has sought to understand the overheads and energy implications of fault tolerance mechanisms, including checkpointing, in an-

ticipation of exascale High-Performance Computing (HPC). At exascale, increased frequency of faults are anticipated and energy consumption is a key issue (Cappello et al., 2009). To this end, Diouri *et al.* explore the energy consumption impact of uncoordinated and coordinated checkpointing protocols on an MPI HPC workload (El Mehdi Diouri et al., 2012), while Mills *et al.* demonstrate energy savings by applying Dynamic Voltage and Frequency Scaling (DVFS) during checkpointing (Mills et al., 2013).

The application of checkpointing in Fine-Grained Cycle Sharing (FGCS) systems is explored extensively in (Ren et al., 2007; Bouguerra et al., 2011), though without consideration for its implications for energy consumption. In (Aupy et al., 2013), energy-aware checkpointing strategies are investigated in the context of arbitrarily divisible tasks.

2 EXPERIMENTATION

In this paper, we evaluate the efficacy of existing checkpointing schemes using trace-driven simulation on a real dataset collected during 2010 at Newcastle University (McGough et al., 2011), comprising details of all job submissions to Newcastle University's HTCondor (Litzkow et al., 1998) cluster and interactive user activity for the twelve month period.

In 2010, the Newcastle University HTCondor cluster comprised 1,359 machines from 35 computer clusters. The opening hours of these clusters varied, with some respecting office hours, and others available for use 24 hours a day. Clusters may belong to a particular department within the University and serve a particular subset of users, or may be part of a common area such as the University Library or Students' Union building.

Figure 1 shows all HTCondor job submissions for 2010. To aid clarity, the figure is clipped on 3rd June 2010 which featured ˜93,000 job submissions. Figure 2 shows the seasonal nature of interactive user activity within these clusters, demonstrating clear differences between weekends and weekdays, as well as term-time and holiday usage.

2.1 Checkpointing and Failure Model

Choi *et al.* (Choi et al., 2004) present a classification of two types of failures encountered on desktop grid environments; *volatility failures* including machine crashes and unavailability due to network issues, and *interference failures* arising from the volunteer nature of the resources. It is these *interference failures* which we consider throughout this work. Furthermore, we consider resource volatility in the form of scheduled nightly reboots for maintenance.

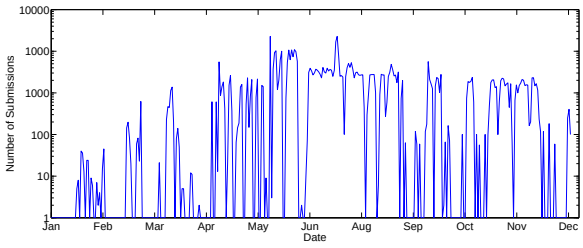


Figure 1: HTCondor job submissions.

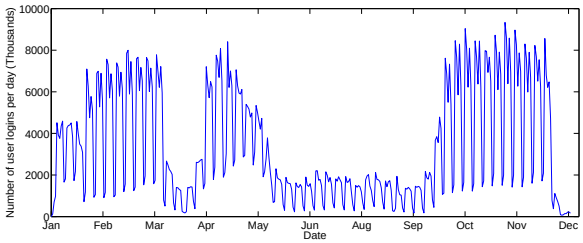


Figure 2: Interactive user arrivals.

Figure 3 shows the state transition diagram for the execution of a single job in our system in the presence of these failures. Our checkpoint model differs from those presented in the literature because we assume interruptions may occur during checkpointing.

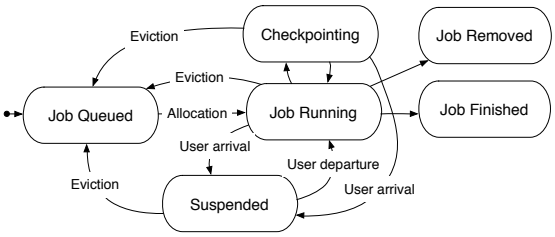


Figure 3: Job state transition diagram.

2.2 Policies

In these preliminary experiments, we evaluate the following three checkpointing strategies:

NONE. This policy represents the policy enacted during 2010 in the Newcastle University HTCondor pool, where no jobs were checkpointed.

C(*n*): Each job is checkpointed every *n* minutes. Hourly checkpointing (**C**(*60*)) is frequently considered in the literature and the HTCondor default strategy equates to **C**(*180*) (UW-Madison, 2013).

OPT. An optimal checkpointing strategy for best case comparison, whereby jobs are checkpointed immediately prior to eviction.

3 RESULTS

Figure 4 shows the mean job overhead under each policy, while Figure 5 shows the impact of these policies on energy consumption. The results shown are mean values taken from twenty simulation runs, with error bars signifying $\pm$1SD. While checkpoint is effective in curtailing wasted execution for long-running tasks, our experimentation finds significant overheads incurred by the checkpointing of short-running tasks unlikely to face interruption. These overheads prolong execution and have a detrimental impact on overall energy consumption.

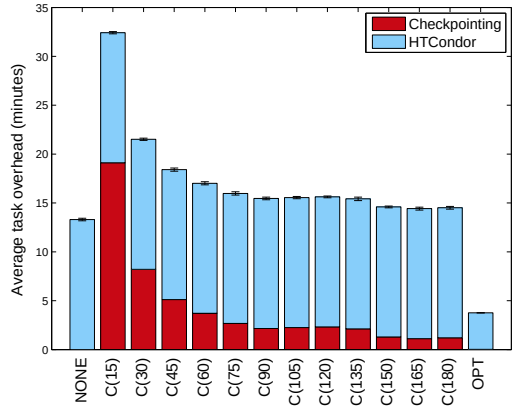


Figure 4: Average Task Overheads.

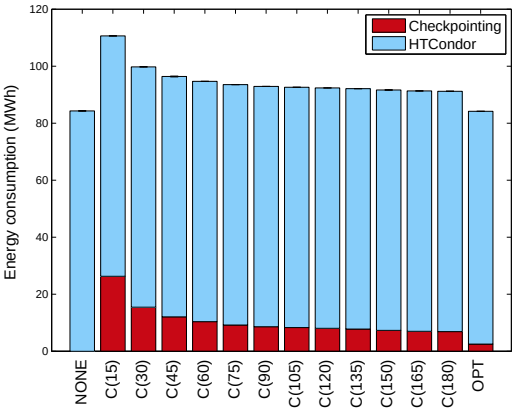


Figure 5: Energy Consumption.

4 DISCUSSION

In this section, we outline the considerations the administrator of an HTC cluster should make when deciding whether to employ a checkpointing mechanism within their environment. Furthermore, we highlight a number of areas of research interest, both with respect to energy-efficient checkpointing generally, and also issues specific to the application of these approaches in the context of multi-use clusters.

Operating Policies. FGCS systems are typically configured to operate conservatively, with the interactive user of a machine given priority over the HTC workload running on the machine. Historically there was significant potential of interference from an HTC job, degrading performance and resposiveness for interactive users of a system. However, now in multicore systems, and with the additional separation afforded by virtualisation technologies, the impact of HTC workloads on interactive users has been shown to be negligible (Li et al., 2009). Relaxing operational constrains preventing HTC jobs from running on resources with interactive users not only increases the capacity and throughput of the system, but also offers significant reduction in energy consumption.

Workload. The efficacy of checkpointing is largely dependent on cluster workload. Checkpointing is most useful when the execution time of a large proportion of the workload exceeds typical resource mean time to failure (MTTF) or user inter-arrival durations, increasing the likelihood of interruption. Furthermore, some jobs do not support checkpointing, while others are unsuitable for checkpointing e.g. those with particularly large application states.

User Base. The Newcastle University HTC cluster supports a diverse user base, from experienced system administrators and Computer Scientists interacting directly with the system, to scientists leveraging its capabilities through user interfaces or submission mechanisms provided to them. Consequently there is a need for checkpointing mechanisms to be transparent and not require in-depth understanding of HTC or programming ability for users to benefit.

Resource Composition. Modern HTC clusters commonly comprise both volunteer and dedicated resources, and increasingly leverage Cloud resources to handle peak loads and offer runtime environments not supported locally. The composition of a cluster is an important factor in determining whether checkpoint mechanisms should be employed. In clusters solely relying on volunteer resources, checkpointing offers an attractive means to deliver favourable makespan in the presence of interruptions. As the proportion of dedicated resources increase, similar benefits may be sought by steering longer-running jobs to these more reliable resources. The implications of checkpointing on workloads running on Cloud resources has not previously been investigated in the literature, but data transfer/storage and instance costs will exacerbate the impact of any checkpoint overheads.

4.1 Checkpointing Support

In determining the benefit of employing a checkpointing mechanism within a cluster, it is important to understand the proportion of the workload and compute resources who support checkpointing. A number of barriers currently exist including operating system dependence of checkpoint frameworks and the requirement to re-compile or re-link executables.

At present, the HTCondor transparent process checkpoint/migration is not supported under Windows. The issue of operating system dependence is often exacerbated in institutional multi-use clusters, with workstations provisioned for the needs of the primary (interactive) users of the system. Students generally demand Windows-based machines so the proportion of resources capable of checkpointing is limited. At Newcastle University, Linux-based machines constitute only ˜*5%* of resources available to HTCondor.

Overcoming this operating system dependence presently relies on application- or user-level checkpointing. These offer greater checkpoint portability and allow checkpoint operations to be conducted at times when application state is smallest. However, these mechanisms assume expert knowledge and often requires access to original source code. Here we propose two approaches to improve checkpointing support while maintaining user-transparency.

Virtualisation. HTC jobs could be executed within a virtual machine on a worker node, providing support for VM- or process-level checkpointing. However, this approach has been shown to prolong execution time for HTC jobs by between *11.7%* and *22.3%* (Li et al., 2009), which combined with increased resource utilisation will increase energy consumption. Furthermore, in VM-level checkpointing, larger snapshots will lead to increased overheads.

Dual-boot Clusters. Booting into a Linux environment would enable support for Kernel-level checkpointing. The use of dual-boot clusters has been considered in terms of HPC clusters (Liang et al., 2012), but its application in multi-use clusters presents additional considerations required to maintain interactive user quality of experience (QoE). The time required to boot between operating systems is likely to be prohibitively long for use during periods with short user inter-arrival durations, though it may prove effective during quiet periods or when clusters are closed for public use. This approach presents the additional benefit of increasing the flexibility of the HTC cluster, offering increased support for Linux jobs which may otherwise have required dedicated or cloud resources.

4.2 Reducing ‘Wasted’ Checkpoints

Through our experimentation in Section 2, we have shown conventional checkpointing policies to be inadequate in reducing the makespan of tasks while maintaining acceptable levels of energy consumption. The predominant factor in the prolonged execution of some tasks and increased energy consumption incurred by these approaches is ‘wasted’ checkpoint overheads, the overhead of checkpoints which are not subsequently requested for recovery. We hope to mitigate these effects by intelligently identifying particular jobs and opportune moments at which checkpoint operations are likely to be beneficial.

Short-running jobs are less likely to be impacted by failures, with checkpointing overheads more likely to increase makespan for these jobs. While execution time is not known *a priori* and user estimates have been shown to be inaccurate (Bailey Lee et al., 2005), we may estimate the execution time of jobs belonging to a batch based on the execution time of other (ongoing or completed) jobs. This leads to the potential for adaptive checkpointing strategies considering expected runtime of jobs.

If we are able to measure the probability of interference from interactive users, we may design checkpointing and resource allocation strategies to mitigate such failures. While we have previously shown the interactive user workload to be accurately forecastable (Bradley et al., 2013), we hope to achieve comparable results through intuitive policies leveraging system knowledge. For example, adaptive checkpoint intervals may be applied depending whether the cluster is open or closed for use by interactive users. Also in the case of departmental clusters used for teaching and practical lab sessions, the central University timetabling system could be used to inform checkpointing and resource allocation decisions, avoiding allocating jobs to a cluster with scheduled sessions approaching, and checkpointing jobs before these scheduled sessions commence.

4.3 Energy-aware Checkpoint Storage

Typical checkpoint schemes in the literature assume nodes acting as centralised checkpoint repositories for all tasks in the system. This relies on the availability of dedicated infrastructure for the purpose, and represents a central point of failure and performance bottleneck. Furthermore, these centralised checkpoint repositories constitute a significant baseline energy load, impacting the energy proportionality (Barroso and Holzle, 2007) of the system as a whole.

The energy cost of centralised checkpoint repos-

itories may be reduced through the use of energy-aware server provisioning to power off repository nodes during periods of low utilisation to save energy. This dynamic scalability introduces a policy decision surrounding the trade-off between worker- and repository-side energy consumption and checkpoint availability. By reducing the frequency of checkpoints taken by the system, it may be possible to allow a checkpointing repository to transition into a low-power state, but in the event of failures, the repeated computation may be more costly in terms of energy than if the checkpoint repository has remained powered up. Furthermore, powering down checkpointing nodes would make the system more susceptible to failures of the remaining checkpoint nodes.

Alternatively, worker nodes performing computation could operate as checkpoint repositories, storing checkpoints for other jobs. While High-Performance Computing (HPC) workloads such as MPI-based parallel applications rely on low-latency interconnects between nodes, HTC jobs typically have minimal network requirements so we expect the impact on the resident job to be negligible. The energy consumption of a given node is dominated by the CPU consumption on the resident job, with only a small proportion of its dynamic power range attributed to system memory and network subsystems, making this manner of checkpoint storage cheap in terms of energy consumption. However, unlike centralised checkpoint repositories which are assumed to be available except for machine or software failure, these resources would be subject to interruptions by interactive users, raising a number of key policy decisions:

Node Selection. In addition to the energy consumption of a node, transfer time is an important factor in checkpointing performance. Network costs are lower to transfer checkpoints to machines within the same cluster, but strong inter-cluster correlation of machine availability increases the likelihood that these checkpoints will subsequently be evicted.

Checkpoint Replication. Whether dealing with volatility failures on dedicated resources, or interruptions from interactive users, checkpoint replication is required to ensure availability of checkpoints. There exists a trade-off between the cost of replication and checkpoint availability. Storing too many replicas incurs an overhead and energy cost, while insufficient replication leads to repeated computation.

Retention. As checkpoints age, the benefits of their use for recovery diminishes, hence, there is a need for a mechanism to curtail the retention of outdated checkpoints. In an uncoordinated approach, checkpoint retention is managed through the use of a retention interval, after which checkpoints are discarded. In a coordinated approach, a checkpoint repository is informed when a job completes or leaves the system, or subsequent checkpoints are produced, signalling that its checkpoints may safely be removed. This requires additional communication between the system and checkpoint repositories, though offers potential benefits through multi-version checkpointing.

4.4 Energy-aware Proactive Migration

In addition to enabling recovery from failures, checkpointing mechanisms may also be used to support proactive migration of computational tasks to reduce makespan and energy consumption. Examples of such migrations include:

1. Migrate a task to a more computationally powerful resource to reduce execution time. These more powerful machines are typically newer and more energy efficient, leading to further energy savings.
2. Migrate a task to a more energy-efficient resource to reduce energy consumption.
3. Migrate a task to a quieter resource to reduce the likelihood of job eviction by interactive users.
4. Migrate a task to avoid scheduled interruptions, e.g. all campus computers at Newcastle University reboot daily between 3am and 5am to perform routine maintenance and apply security updates.

In each instance, the cost of the migration operation must be balanced against the potential benefits to determine whether a migration is viable. These migration policies are not mutually exclusive, and we anticipate combining these will yield the greatest benefit.

4.5 Impact on Policy Decisions

The introduction of a checkpointing mechanism introduces an interesting interplay between a number of existing policy decisions within an HTC cluster.

Resource Allocation. In (McGough et al., 2013) we introduce resource allocation strategies to minimise the likelihood of job eviction and reduce energy consumption. The introduction of checkpointing provides opportunities to develop novel checkpoint-aware resource allocation strategies. For example, in HTC clusters where only a subset of resources or jobs support checkpointing, wasted execution can be reduced by allocating longer-running jobs to resources which support checkpointing and non-checkpointable jobs to quieter resources. Resource allocation should also consider data locality when resuming larger jobs, selecting resources with lowest checkpoint transfer cost. Furthermore, in situations where a given job

may only run on a particular subset of resources, it would be beneficial to store checkpoints on or close to resources capable of resuming its execution.

Replication. Replication of jobs in an HTC system is generally dismissed due to increased overheads and reduced system throughput. While this holds true for heavily utilised HTC clusters, there is a case for energy-conscious replication of jobs. The Newcastle University HTC cluster features significant spare capacity so the replication of certain jobs need not impact the makespan of other jobs. If replicas were to run alongside interactive users, the energy cost associated with the HTC workload would also be minimal.

Vacation. Furthering the desire to minimise the impact of HTC workloads on interactive users of computers, HTC clusters are configured to ensure an interrupted job vacates a resource quickly. Many clusters including Newcastle are configured to vacate HTC tasks immediately without checkpointing, leading to wasted execution. A more beneficial approach would be to allow checkpoint at the time of vacation, but limit the impact on users with a timeout interval after which the checkpoint operation is abandoned.

5 CONCLUSION

In this paper we have shown existing checkpointing mechanisms to be inadequate in reducing makespan while maintaining acceptable levels of energy consumption in multi-use clusters with interactive user interruptions. Our preliminary experimentation shows the naive application of checkpointing approaches to have the potential to negatively impact energy consumption, but small changes to make these strategies energy- and load-aware may lead to significant benefits. We highlight key considerations when adopting checkpointing in an HTC cluster and motivate a number of areas of future research interest in energy-efficient checkpointing. A detailed evaluation of new energy-aware checkpointing strategies will form the basis of our ongoing research.

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SMART CITIES

FULL PAPER

Developing Dynamic Heterogeneous Environments in Smart Building Using iPOPO

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Keywords: Ambient Intelligence, iPOPO, Energy, Smart-home based Architecture Component.

Abstract: This paper contributes to the design of a smart monitoring system. The objective of this paper is to show that by using iPOPO framework, as an embedded application for sensors/actuators, it is possible to improve the configuration/reconfiguration of monitoring system. The proposed experimentation platform, called PREDIS/MHI (Monitoring Hbitat Intelligent), based on iPOPO framework, is characterised by its openness, its scalability and its capability to manage diversity. In this paper, we show how application based on iPOPO framework, well adapted to represent problems spatially distributed and opened, can dynamically be adapted to various contexts of environments.

1 INTRODUCTION

A monitoring system basically consists of sensors and actuators linked via a communication network allowing interactions for control purposes. Thanks to this network, a load control mechanism can be implemented: this is called distributed control. A monitoring system is made of sensors, which measure physical quantity, and actuators, which control some devices. However, faced to the increasing number of sensors and actuators in buildings, it is necessary to develop monitoring systems able to plan ahead changing configuration of buildings. The development of a dynamic environment composed of heterogeneous devices and technologies is very complex. Smart dynamic environments can be found in many domains such as: domestic, social, biology, medical, etc.

(Lesser et al., 1999) proposed a GatorTech Smart House system. Sensors and actuators are fitted on a number of devices: mailbox, entrance door, floor etc which are connected to an operational platform designed to optimise the comfort of the inhabitant. It also uses a high precision ultrasonic tracking system to locate occupants and evaluate their mobility habits to better control the environment (Helal et al., 2005).

(Mozer, 1998) proposed an adaptive control of home environment. It monitors the environment and observes the actions taken by the inhabitants (using lights, adjusting thermostat). This data is further used to infer patterns in the house, using reinforcement learning, a stochastic form of dynamic programming.

In the "House of the future" project (Tapia et al., 2004) aimed to design strategies for more flexible environments that meets inhabitants physical and cognitive needs than current environments. The system consists of three components, set of state-change sensors used to collect data about the use of objects, a context aware experience sampling tool (ESM) used by the inhabitant to label his activities, and pattern recognition and classification algorithms for recognising activities. Naive Bayesian classifier is used to train the model and predict future activities of inhabitants

However, the previous works based their control system on a centralised approach; they do not opt for solutions fostering modularity.

Problem Statement

Owing to the number and diversity of sensors/actuators in the home, leads us to opt for solutions fostering modularity. The need for structural

self-adaptation, or more technically the need for plug-and-play appliance, leads to a Service-Oriented Architecture (SOA) platform. Indeed, a home monitoring system must be open-ended and extendible: it must be possible to add or remove appliances (or new types of sensors/actuators) at any time without calling into question the overall operation of the system.

This paper focuses on the development of smart domestic environments for connecting evolving sensors and actuators. The framework iPOPO has been used in order to develop a smart dynamic environment for PREDIS/MHI. It is an experimentation platform consisting of many kinds of sensors/actuators of different technologies such as X10, Oregon Scientific, Zigbee, HTTP GET and USB (FIG. 1).

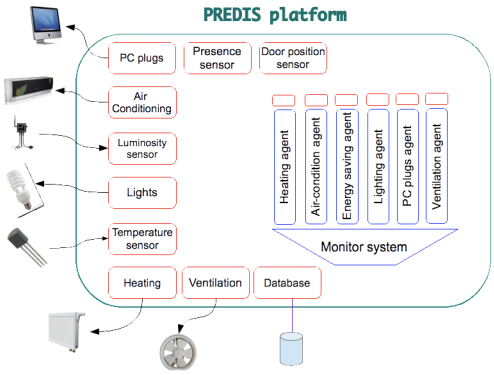


Figure 1: Components of PREDIS platform.

In what follows, in a first section, the paper describes briefly the PREDIS/MHI platform. In a second section, an iPOPO framework is presented. Section 3 describes the architecture of the iPOPO-based implementation of PREDIS platform. Finally, a conclusion of the contribution of the iPOPO framework based on SOA techniques to the monitor system is presented.

2 PREDIS/MHI

PREDIS is a smart building experimentation, which aims to ensure better energy management and human comfort in buildings: the building's maximal energy consumption did not exceed 50kWhPE $(PrimaryEnergy)/year.m^2$ (Dang et al., 2012).

It combines physical models and experimental measurements in order to have more adapted models for virtual simulation and optimal control (Dang et al., 2013).

This platform are developed around:

- Multi-sensor monitoring.
- User activities and their energy impact analysis.
- Multi-physical modelling, measurement handling and sensitivity analysing.

The first floor of this building is composed of two rooms: teaching room and researcher open space. The teaching room is used for training courses of Grenoble University and equipped with laptops, which are connected to the electrical grid and to photovoltaic generators. The researcher open space, where the control, supervision and measurement are installed, is daily occupied by about six researchers.

The first floor of PREDIS is equipped of many systems:

- Heating, Ventilation and Air Conditioning system.
- Lighting control.
- Experimental instrumentation: temperature sensors, airflow sensors, CO_2 sensors, energy meters, and switching devices.

In this platform, a system called HAL (Home Abstraction System) has been added as a general interface to the control systems and sensors.actuators. HAL integrates drivers of different communication protocols relating to physical devices. It shows data through a RESTful Web interface, accessible via a web browser or a client application. Its objective is to provide a uniform access to devices and information. The HAL system has been developed in Python because most of sensors drivers have been provided in Python. Figure 2 illustrates the architecture of components of the presented system (HAL).

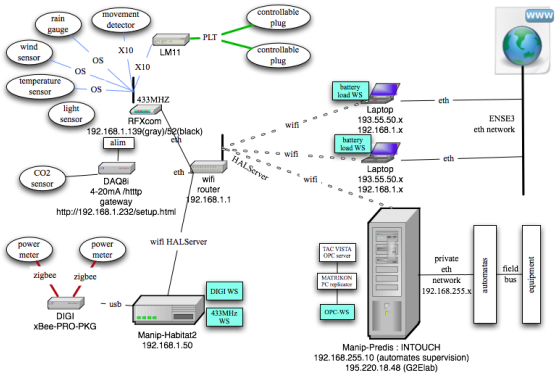


Figure 2: Architecture of HAL system components.

In figure 2, many types of sensors are used: temperatures, humidity, CO_2, airflows, electric energy, electric power, light, presence, door position. Theses sensors rely on many technologies: X10, Oregon Scientific, Zigbee, HTTP GET and USB. There is a legacy energy management system: an Intouch

SCADA system, which can be connected via the OPC protocol.

Once the HAL system has been deployed in the PREDIS system, all functions and facilities of this system can be used. However, if a driver linked to sensors/actuators fails, the entire integrated system does not well work: it leads to the failure part or the whole of the system. Indeed, when an additional sensor or actuator is put in operation, it call into question the overall operation of the system: restarting the system must be done in order to take into account the new appliance. If a driver linked to sensors/actuators is put out of operation, either accidentally or through administration action, the system and its peripheral components are severely affected.

In the HAL system, the life cycle of each sensor, actuator or driver is managed by the developer. For example, for each time, when a new sensor is added to the system, the developer has to do new configuration for the whole system, which takes a time for restarting the system. The HAL system depends on the life cycle of sensors and the configurations defined by the developer. The HAL system has to manage the access to the functionalities provided by each each of its elements. But, it has also to manage dynamism of the models representing the environment, which should be outside its scope. These two aspects of the system being particularly different, the implementation of HAl system has become complex, leading to a number of malfunctions.

Progress in the fields of Service-Oriented Architectures (SOA), Component-Based Software Engineering (CBSE) and Service-Oriented Component Models (SOCM), which are particularly adapted to distributed and open problems, is likely to lead to a "Home Monitoring System" made up of bundles providing the different sensors and actuators. Those bundles could, with embedded algorithms of intelligence, make joint decisions with respect to the operating requirements of the appliances to which they are connected.

A work close to this domain is that of Eclipse Smart Home project (Ecl, 2013), a framework for smart home and ambient assisted living which focuses on heterogeneous environments. Its objective is to provide a uniform access to devices and information and to facilitate different kinds of interactions with them. However, it is implemented in Java, upon the Equinox framework, i.e. an SOA framework implementing the OSGi specifications.

There are many frameworks for deploying and developing component-based python applications. Whilst some of them provide an interface for mature and well-established component models (such as CCM, EJB, Koala and Fractal), others are pure Python component models (e.g. Envisage[1], Trac[2], yapsy[3], SprinklesPy[4], etc). Most of them rely on a global registry, which acts as a broker, allowing components to register themselves and dynamically resolve their dependencies. Even so, among these component models, any of them take into account components' dynamic availability: they are suited to build an application, but not to handle dynamic changes in the composition, neither to remove components.

Another example is the Zope Component Architecture (ZCA) (ZCA, 2012), a widely used component framework, which defines the concept of interfaces in Python. Components are bound according to their interfaces and to their names. The substitutability of components is based on the components name, which means that when a named component disappears, a new one with the same name and interface must be instantiated to restart the dependent components.

Those frameworks weren't suited for the next step of PREDIS/MHI. This software requires a specification-based substitutability, and it must handle very dynamic environment. This is why the iPOPO(Calmant et al., 2012) framework, an SOCM framework, was selected. This platform has been chosen for several reasons, including:

- The drivers of sensors were already developed and provided in Python.
- iPOPO is inspired on the OSGi specifications, ensuring a robust SOA API.
- It supports Remote Services natively, allowing to turn the application in a distributed architecture easily.
- iPOPO combines many advantages:
  - Simplicity: iPOPO provides a very simple development mode. It provides an excellent foundation for building dynamically extensible Python-based applications.
  - Power: Supporting the principles of OSGi services in Python, iPOPO provides many other features that aim to simplify developing sophisticated applications. For example, iPOPO supports configuring components, notifies of component events, provides a publish-subscribe service, etc. It also provides an embedded HTTP server, specified as an HTTP service,

[1] https://svn.enthought.com/enthought/wiki/EnvisageTh ree/core.html

[2] http://trac.edgewall.org/wiki/TracDev/ComponentArc hitecture

[3] http://yapsy.sourceforge.net

[4] http://termie.pbworks.com/SprinklesPy

that will heavily simplify the implementation of PREDIS/MHI.

- Performance: iPOPO is small and is designed to stay small. The core size of iPOPO is approximately 10k. It has been optimized to instantiate a large number of components in a short time.

In the next section, the principles of iPOPO framework are presented.

3 THE iPOPO FRAMEWORK

3.1 Main Concepts

iPOPO (Calmant et al., 2012) is a Service-Oriented Component Model (Szyperski, 2002) (SOCM). The framework is divided into two parts: the iPOPO Core, which handles the components, and a lower layer, Pelix, which handles the services and the bundles. Pelix aims to implement part of the API specified by the OSGi standard (Alliance, 2011), whereas iPOPO aims to provide features similar to the ones of iPOJO (Escoffier and Hall, 2007), a Java SOCM based on OSGi.

3.1.1 Pelix

A bundle is a Python module, which does not execute code during its loading process. It can define a bundle activator that will be called during the bundle life cycle steps. Pelix provides methods to install, start, stop, update and uninstall a bundle at runtime, allowing a very dynamic approach in Python.

A service is an object instance registered in a centralized registry and combined with the list of the specifications it provides and a set of properties that describe its state and features. Each service has a constant integer identifier, unique inside a Pelix framework instance, and it can have a rank that gives it a priority level in the service registry. A consumer will request the framework the list of services that match a specification and a property filter. This list will be sorted according to the ranking and to the identifier of the matching services.

3.1.2 iPOPO

A component is an instance of a factory class, coupled with an instance manager which will control its life cycle, and a set of handlers which will inject its dependencies and register the services it provides. Those handlers are linked to the component and are managed by the instance manager. The factory is class manipulated by a set of decorators, which contains all the information needed to start a component instance and bind it to its execution environment. A component instance is associated to a unique name, constant during its life time. It can specify properties, which describe its state, its capabilities and its configuration, and which can be updated by the component itself. After its instantiation, a component can be either valid, i.e. all its required dependencies are bound, or invalid. The instance itself cannot modify its own state: its life cycle is controlled by its manager.

iPOPO is based on the concept of injection of dependency, i.e. the dependency handler injects directly into the component instance the services matching the requirements described in the component factory. A requirement is a set of properties describing the service to inject, indicating the specification of the injected service, a filter for its properties. It is also used to configure the behaviour of the dependency handler, i.e. if the service must be injected for the component to be valid, if the handler must inject a list of services instead of the first matching one, etc. The dependency handler is notified of service events by the service registry of the Pelix framework, and injects or removes services accordingly.

To reflect component changes, the service providing handler propagates every change of component property fields to the services provided by the component. Component properties are declared in the factory as a link between a field in the component instance and a property name. As the provided services are updated, the dependency handlers will be notified of those changes by the framework and will update the state of their associated component.

As component are bound by services, using the dependency handlers, they can be easily replaced by other components providing similar specifications and properties. When a service provider disappears, the dependency handler will try to replace it by a matching one and notify the component instance of this modification. If there is no matching service available, the handler changes to an invalid state, and the component will be invalidated by the instance manager.

A component factory, i.e. its implementation, can be updated at runtime by updating the bundle providing it. During this operation, the component instances are deleted and the consumers of their services runs a new binding loop. Those consumers will be either invalidated or bound to other implementations of the required specifications. If the bundle update succeeds, the new version of the component instances will be instantiated, and previously invalidated components will be bound to them; else, the previous version of

the bundle is kept and previous components are instantiated a new time.

3.2 Life Cycles

3.2.1 Bundle

The life cycle of a bundle depends on the one of its host framework. As described in Figure 3, the possible states of a bundle are:

- Installed: the Python module corresponding to the bundle has been found and parsed. If no error occurred, the bundle goes immediately in the next state.
- Resolved: the bundle cannot provide any service in this state, but others can access the members of its module. If the bundle was active, this states means it has been stopped: its activator is called and shall unregister its services.
- Active: the bundle has been started, i.e. the activator of the bundle has been called and may have registered services.
- Uninstalled: the bundle has been unloaded from the framework. A bundle is always stopped before being uninstalled, i.e. this state always follows the Resolved state. The bundle cannot be restarted after being uninstalled: it must be reinstalled.

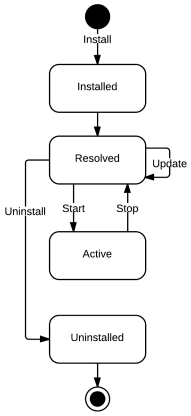


Figure 3: Pelix Bundle State Diagram.

When changing states from Resolved to Active (or from Active to Resolved), the bundle passes in a transition state: STARTING (or STOPPING). In this states, the bundle has the same rights than in the Active state, but the framework will be more permissive in case of error.

3.2.2 Component

In Figure 4, an iPOPO component can be in one of the following three states:

- Instantiated: the component object is coupled to an instance manager and all its handlers have been initialized. The component stays in this state while at least one of its handler is in an invalid state.
- Valid: all its handlers are in a valid state, e.g. all required dependencies have been injected.
- Killed: the component is being deleted and all its handlers are stopped.

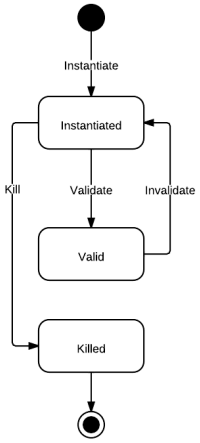


Figure 4: iPOPO Component State Diagram.

A component can be notified of events concerning its life-cycle, by defining callback methods:

- Validate: when the component comes into the Valid state.
- Invalidate: when it comes back to the Instantiated state. It is called only if the component was in the Valid state before.
- Bind: when the component has been bound to a service it depends on.
- Update: when a service bound to the component has updated its properties
- Unbind: when a service that was bound to the component is unregistered.

The life-cycle of a component is dependent of the one of the bundle that provides its factory, and it is handled by the instance manager associated to this component.

3.2.3 Events

The dynamism of the framework implies the triggering of many events.

The framework notifies bundle listeners each time a bundle is installed, removed or changes its state. For example, the iPOPO core service listens to those events in orders to load the factories provided by a bundle as soon as it is started, and to kill all of their component instances when it is stopped.

When registering for service events, listeners are notified when a service is registered, unregistered or if its properties have been updated. It is also possible to add a filter, in order to be notified of events only about services that match it. That is how the iPOPO handler managing the dependency injection can react upon the evolution of the other components. Services events also allows to implement the whiteboard pattern: instead of having consumers that will register to notifications from a provider, the latter can wait for the apparition of listeners according to their service. That way, the provider always an up-to-date list of listeners, possibly managed by iPOPO, while the consumers do not even have to know about the provider: they can just be notified of events by providing the right service.

It is also possible to listen to iPOPO events, i.e. when a factory has been registered or removed, or when the state of a component evolves.

Finally, framework listeners are notified right before the framework beings its stopping process. This is the situation of the iPOPO core service, which refuses to instantiate while the framework is shutting down.

4 iPOPO-BASED INTERFACE FOR PREDIS/MHI

4.1 iPOPO-based Implementation

The objective of this work is to design a Home Monitoring System on a dynamic, modular and configurable basis. Figure 5 shows the new design of HAL system, based on the notion of services. The drivers already developed in Python, in the centralised version, are separated and encapsulated into bundles and transformed into components. This operation is done in two steps: (a) moving all the module initialisation code into the bundle activator and (b) decorate the classes to let iPOPO consider them as components, providing a service according to their features. The sensors and actuators are also represented in components providing probing or control services and consuming driver services.

The new version of HAL system based on iPOPO framework is installed in the PREDIS platform.

In this new implementation of the HAL system, most of the raised problems in the previous version have been resolved: This version charges only access to the functionality of its elements environment, and it is based on iPOPO to manage its dynamic model. This model greatly simplifies the code base, by limiting the functionality of the system, but also by basing on a management tool specialized for a large number of components. In addition, the dynamic capabilities of iPOPO used to manage environmental changes and configurations defined by the developer without restarting the entire system.

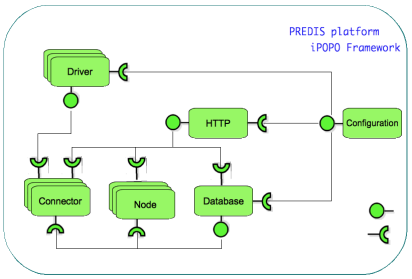


Figure 5: HAL system service oriented architecture.

As mentioned, PREDIS/MHI platform is an experimental platform. Students could be testing the sensors: remove, add or change the configuration of system. With the centralized approach, whenever there is a change in the system configuration, the system must be stopped to do the new configuration change and start it again. This causes a hole in a 5-minutes data received from sensors. This data are generally used in many projects: average structure temperature estimator, occupation estimator, usage and system diagnostic analysis, etc. This data hole has a direct influence on the results of these projects; previously, an estimator of data was used, but it does not always work. Actually, as the new version of HAL is installed, the system configuration is almost instantaneous: there is no more data hole and the results are more interesting.

Recently, Some devices for temperature and humidity based on EnOcean protocol have been installed in the PREDIS/MHI platform.

The integration of this driver in the HAL system was easily done and has no effects on the overall system running. On the other hand, the new version allows the debugging of codes in real time: some modification can be done and uploaded to the HAL system without penalising the overall system running.

It is important to note that while the new version of the HAL system is more modular and has must more features, including dynamic platform updates, it kept the same performances than the old one, in terms of response time as well as memory consumption.

4.2 Discussion

It is difficult to adapt the centralised approach to real home automation contexts as it is not suitable for frequent and variant configurations / reconfigura-

tions. This means that it is not possible to have an open-ended system unlike the service-oriented system where appliances can be added or removed without having to reconfigure the system and without penalising the overall system running that has to be potentially capable of taking on board all kinds of requirements. The service-oriented system based on iPOPO/OSGi techniques allows for extendibility: new types of appliances can be added to the system without it being necessary to entirely reconfigure it. With the centralised system, the platform algorithms must be changed to take into account new appliances, whereas the service-oriented implementation adapts automatically to the type of home automation system, i.e. the physical distribution of different types of sensors/actuators.

5 CONCLUSION AND PERSPECTIVES

Service-Oriented Component Models are an excellent way to ensure that developed software comes with built-in best practices such as reusability, high cohesion, loose coupling, high flexibility and dynamism. The proposed system based on iPOPO does offer advantages over the centralised approach: its openness, its scalability and its capability to manage diversity.

As the new version of PREDIS/MHI global interface was developed both by PREDIS and iPOPO developers, the contributions were not for one side only. This project implied the evolution iPOPO, by bringing new use cases in terms of architecture as well as of metrics. For example, iPOPO had to deal with tens of thousands of components and services during the tests of PREDIS. This implied to rewrite parts of the service registry and of the dependency handler to drastically increase their performances in terms of execution time.

The next step in the development of PREDIS will be to use the remote services provided by Pelix/iPOPO. They will allow to dispatch parts of PREDIS/MHI near the sensors they must monitor, e.g. one in each room, by providing an easy way for them to communicate with the HAL central server. The decoupling implied by remote services will also allow to use sensors develop in different languages. A Java version of Pelix Remote Services is under development, in order to let Pelix/iPOPO components interact with OSGi/iPOJO ones.

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SHORT PAPERS

Optimizing Micro Renewable Generation for Smart Cities by Combining Solar and Geothermal Energy Potentials
A Case Study of the Hannover Region

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Keywords: Micro Solar Energy Potential, Micro Geothermal Energy Potential, Smart Cities, Renewable Energies.

Abstract: In recent years there has been an increasing interest on small renewable energy production systems to supply energy consumption of buildings. In Europe, cities face the challenge of combining energy efficiency and sustainable urban development. This challenge is likely to have an impact on grid infrastructures by implementing intelligent networks and storage facilities in order to secure energy supply. This paper presents an approach for integrating solar and geothermal energy generation on the basis of a spatially explicit assessment of potentials for both energy sources. The results should be applicable for spatial planning. The case study area is the Hannover region. The results demonstrate that with data available in blanked coverage in Lower Saxony the assessment of both renewables energy potentials could be performed. The generated place based information meets the specific demands of regional as well as municipal land use planning. It can be used for allocation and prioritisation of housing development with micro-renewables and for proposing areas with the combination of both.

1 INTRODUCTION

Europe is facing the challenge to reach the so called 20/20/20 objective. This objective includes reducing greenhouse gas emissions by at least 20% compared to 1990, increasing the share of renewable energy sources in final energy consumption to 20%; and improving 20% energy efficiency (European Commission, 2010). To this end a redefinition of strategies may be necessary as several factors like increasing of energy demand, fossil fuel energy scarcity and high environmental impacts are hampering target compliance. An important part of such strategies could be to more efficiently activate the potential of existing and new buildings for producing their own energy. To that end we need innovative strategies and approaches for integrating energy concepts in regional and municipal land use planning. In this context smart cities play a crucial role. Countries in Europe are at different stages of technological, political and administrative development. However, in all cases the development of smart cities depends significantly on smart grids, intelligent grids to leverage energy consumption between the different producers and consumers. The successful combination of smart technologies can help by improving energy efficiency and savings in planning residential development and by adopting measures for existing buildings. Smart technologies need infrastructural changes of energy distribution grids in an optimized way and are seen as a major opportunity to merge energy and ICT industries and technologies (Net!Works European Technology Platform, 2011). Because of the intermittency associated with the most renewable energy production, it is necessary to combine renewable energy technologies and to add some storage mechanism in order to ensure the energy supply. However, energy-saving measures in buildings are either conventional (thermal insulation, energy-efficient air conditioners and appliances) or based on automatic intelligent systems (Wicaksono et al., 2012). The deficits in practice correspond with knowledge deficits about appropriate methods of calculating energy potentials for supporting spatial planning. In this context the *micro renewable heat potential, is especially important because it covers the major part in urban energy consumption. The common sources of micro renewable heat energy production are solar thermal geothermal energy.*

Against this background, the objective of this paper is to present an innovative planning approach which according to energy potentials identifies the best locations for combining solar and geothermal energy. The approach is based on the research conducted in the context of the Project Smart Nord of Lower Saxony, where all renewable energy sources (solar, wind, biomass, hydro and geothermal energy) are taken into account. Here we focus on solar and geothermal energy in order to lead the way for activating the synergies of combining both technologies. In this case, synergies may occur for the following reasons (Tepe, 2011):

- Reduction of borehole depth or number of boreholes in new systems
- Improvement of deficits existing systems to achieve better performance.

The main research questions are:

- How to estimate micro renewable energy potentials? Which methods are needed?
- How to combine solar and geothermal energy systems?

For answering these questions we present in section 2 methods for estimating the geographical distribution of the solar energy potential. In section 3 an application on geothermal energy developed by the LBEG about is presented and integrated with solar energy combinations. Finally we discuss data availability and transferability to other regions as well as possible planning application (section 4) and conclude with recommendations for regional and municipal planning (section 5).

2 METHODS

2.1 General Methodological Approach

To calculate the solar energy potential we have estimated the global irradiation annual average for a horizontal surface, which can be converted according optimized angle for solar panels and solar thermal collectors.

To calculate the geothermal energy potential we have focused on typical shallow geothermal systems for northern Europe. The energy abstraction is achieved by vertical closed loop heat exchangers with a vertical depth of around 100 m. The subsurface model is a three layer model covering the depth of ground surface to 100 m below surface. The horizontal resolution is given by a 50 m by 50 m cell size raster grid.

2.2 Data

In Table 1 datasets used for the calculation of solar and geothermal energy potential maps for the Hannover region, Lower Saxony, northern Germany are shown:

Table 1.

Layer name	Scale/unit	Source
DEM (Digital Elevation Model)	DGM50, 50 m raster grid	Landesamt Bergbau Energie und Geologie Niedersachsen (LBEG) http://nibis.lbeg.de/cardomap3/
Water level in unconsolidated rocks in Lower Saxony	1:200000 only applicable for unconsidated rocks	LBEG (HUEK 200 “Grundwasser-oberfläche”) http://nibis.lbeg.de/cardomap3/
Basal plane of quaternary unconsolidated rocks in Hannover, Lower Saxony	1:500000 edited by detailed point and vector line data	LBEG (GSKH 1:25000) Rohde, P. & Becker-Platen, J. D. Geologische Stadtkarte Hannover 1:25000 NLFB 1998
Geological map 1:500000 Lower Saxony	1:200000	LBEG (GUEK 500) http://nibis.lbeg.de/cardomap3/
Geo-tectonic Atlas 3D	Only uppermost layer from the 3D model was used	Bombien et al. (2012), based on Baldschuhn et al. (2001)
PK OG 2008 “Geothermal Data Catalogue”	Thermal conductivity table of typical rock types in Germany	http://www.infogeo.de/dokumente/download_pool/PKOG_Abschlussbericht_1.3_08-04-25.pdf

2.3 Methodology for the Estimation of the Micro Solar Energy Potential

The solar energy potential is calculated using the r.sun solar radiation model implemented in GRASS GIS (6.4.2) and the PVGIS CM-SAF estimation utility, derived from the Photovoltaic Geographical Information System Interactive Maps (Joint Research Center of the European Commission, 2010). The r.sun model calculates the global solar radiation (beam, diffuse and reflected), for both clear sky and overcast atmospheric conditions from the digital elevation model (DEM) (Šuri et al., 2007). An important factor in producing reliable maps of solar irradiation was the estimation of sky cloud

coverage, as the total amount of cloud cover significantly affects ground irradiation. For this reason, the data was validated using PVGIS. The output of this model is a raster map of the global irradiation annual average for a horizontal surface.

The PVGIS calculation of PV potential for a specific site is based on spatial data automatically taken from the PVGIS database. Generally, the overall error for the whole year is quite small (approximately 5%) (ibid.). The database is based on climatic data from 566 meteorological stations covering the 1981–1990 periods and includes monthly averages of daily sums of global and diffuse irradiation and Linke atmospheric turbidity. Elevations and terrain features are represented by a 1-km digital elevation model. More details about the European solar database implemented in the PVGIS estimation utility can be found on its website (ibid.).

2.4 Methodology for the Estimation of the Micro Geothermal Energy Potential

All calculations were done in ArcGIS (ESRI) version 10.0 and Microsoft Access 2007. Input data as described in 3.2 are vector data (polygons) or raster data (DEM). The raster layer was converted to a point vector dataset. The data belonging to each point consist of x,y-coordinates and the elevation. Additional data from the polygon layers were attached to the point layer. For the calculation of the geothermal energy potential a three layer model was used. The first layer consists of the distance from the ground surface to the water table in the quaternary porous rocks (dry unconsolidated rock). The second layer consists of the thickness of the water saturated porous quaternary rocks (saturated unconsolidated rock). The third layer consists of the thickness and type of the "hard rock" up to 100 m below ground which were defined as the pre-quaternary rocks (hard rock base).

Using the thickness and the thermal conductivity for unsaturated and saturated unconsolidated rocks as well as for each hard rock type an average thermal conductivity up to 100 m could be computed for each 50 m raster point. For the estimation of the specific heat extraction values the transformation from thermal conductivity to specific heat extraction was performed following Pannike et al. (2006). Here, the simplified geological stratification from surface to 100 m depth is derived from the data described above, and the specific heat extraction is obtained from the following equation:

$$P_{EWS} = -0{,}85\,\lambda^2 + 13{,}62\,\lambda + 18{,}8$$

where P_{EWS} = specific heat extraction capacity, and λ = average heat conductivity of the rock.

The raster points were converted to a raster layer with a cell size of 50 m. A continuous raster layer set is the result, expressing the specific heat extraction in each cell with 100 m heat exchangers.

For the solid rocks, there were some data limitations due to the decreasing geological information with the increasing depth. Therefore, the rock type sometimes could only be estimated. The data for unconsolidated rocks were taken from geological maps on a scale of 1:25:000. The information regarding the groundwater flow component was not considered according to the VDI 4640 German directive.

2.5 Integration of the Energy Potentials

A first integration can be performed by an overlay of the two energy potentials, because we assumed that all the micro-energy potential maps are of the same weight. The maps obtained show the best locations for the integration of solar and geothermal energy with vertical loops (40 m and 100 m).

3 RESULTS

3.1 Micro Solar Energy Potential Map

The latitude was computed directly from the DEM raster, while the albedo and the Linke turbidity were believed constant over the entire region, as a first approximation. The clear sky indexes were not available. After validation of the date, the output raster map representing the annual average of global irradiation daily sums estimated on optimally inclined plane (Figure 1).

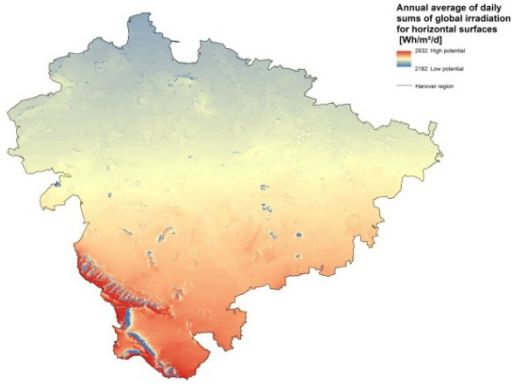


Figure 1: Annual average of daily sums of global irradiation on optimally inclined plane [Wh/m^2/d].

The output units are [Wh/m^2/day].

3.2 Micro Geothermal Energy Potential Maps

As an example, we present here the geothermal energy potential for vertical loops (100 m) (see Figure 2). We calculated for further residential appliance the energy potential for vertical loops (40 m).

3.2.1 Geothermal Vertical Loops (100 M)

The evaluated specific heat extraction capacities, which were calculated from thickness and thermal conductivity of geological strata, has been used to evaluate the geothermal energy potential for the Hannover region. The resulting map was classified into three categories. Class 1 represents very high geothermal energy potential with average specific heat abstraction values of > 45 W/mK, class 2 represents high geothermal energy potential with average specific heat abstraction values of 40-45 W/mK, and class 3 represents standard geothermal energy potential with average specific heat abstraction values of <40 W/mK. Areas not suitable for geothermal energy use because of drilling restriction reasons, e.g. drinking water protection zones, lakes etc., were classified separately as prohibited areas.

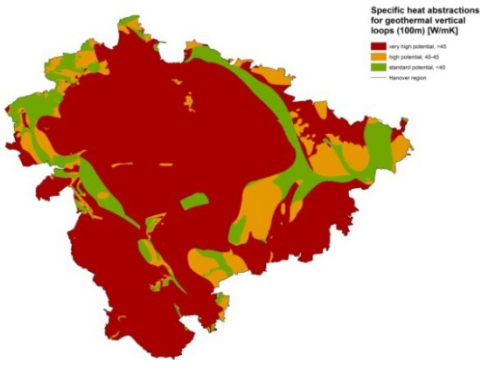


Figure 2: Specific heat abstractios for geothermal vertical loops (100 m) [W/mK]

The GIS overlay results x categories of areas are shown in Figure 3.

The map of the geo-solar combinations demonstrate that the Hannover region is characterized almost by good-high potential for the whole case study area. Nevertheless, areas where the potential is relatively low (areas in green), because of the terrain aspect and slope and rocks characteristics should be integrated with others renewables.

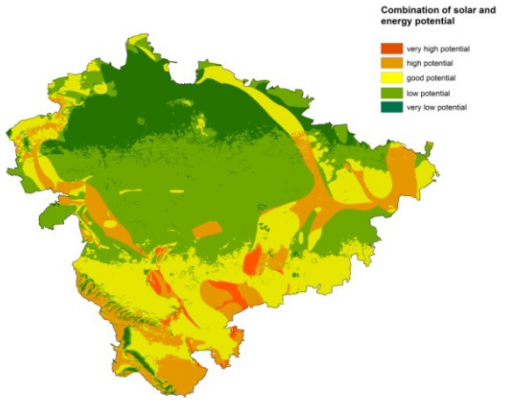


Figure 3: Energy potentials by combining solar and geothermal energy (vertical loops 100 m).

4 APPLICATIONS

The specific heat extraction/geothermal energy potential maps are used for online applications ("Geothermie geht das bei mir?", LBEG 2012) which allow to calculate the required dimension of the closed loop system as subsurface part of a geothermal space heating. With limited input data of a conventional home (area to be heated, energy consumption per area and location of the house) the dimension and costs of the subsurface part can be estimated. This is a powerful tool for architects, planning engineers, and house owners to estimate costs of different heating supply systems.

Furthermore the maps can be used in local and regional planning in various ways: In combination with other spatial information in particular about environmental vulnerability the maps can be used for the allocation of urban development into areas with high potential for a combined micro renewable used. On the regional level this can be prepared by rating and prioritizing areas with reference to the regional or state wide average and by pointing out their potential contribution to regional energy targets. Regional energy targets as to the share of different energy sources will rely on such information. The implementation of such regional planning information may be realized by designations in the mandatory regional plan. On local level, the information can be used in order to allocate housing development as well as to include regulations about adding respective RE facilities in every legally binding development plan. For the technical upgrading of exiting housing areas incentive programs can be set up, which differentiate

payments according to the expected results.

5 DISCUSSION

Both methods produce results that are differentiated enough to serve as information basis for regional and local planning as well as for individual house owners. In our estimation the solar energy potential estimation depends on the application of the *r.sun* model and on the *pvgis* data, therefore it can be applied in every region. However, the accuracy depends on input data (DEM) and on *pvgis* data availability.

For the geothermal energy potential maps we can consider the typical amount of vertical heat exchanger per area, which depends on the urban settlement structure. The necessary input data for this advanced model are land use maps and average density of heat exchangers per land use type. With this approach a comparison based on raster layers with an energy value per cell would be possible. For the geothermal energy potential the output energy for space heating is higher than the energy abstracted from the ground due to the input of a heat pump. The seasonal performance factor (spf) of the heat pump is the dimension of surplus from output energy dependent of the input energy. The energy which is available for space heating should be based on a typical spf factor.

Research projects like Geo-Solar (Pärisch et al., 2012) and first pilot products from the geothermal market are focusing of the combination of solarthermal and geothermal systems. The advantage of solarthermal systems is the high effectiveness of collecting energy, the advantage of the geothermal system is the independent availability of energy 24 hours 365 days a year. Combining both systems provides a constantly available effective heating system driven by renewable energy. However, the potentials of combining both energy sources need further research. In the future, for a better integration of both energy sources and the comparison to other energy forms, all potential maps should be all transformed to the same ordinal scaling and best presented on cardinal scales which quantify kilowatt-hour.

6 CONCLUSION

In many regions geodata already allows the spatially concrete estimation of solar and geothermal energies potentials. Our methodologies allow not only for representing the separate potentials but also give a first insight into the added value of combining both sources. The results should be used in regional and local land use planning as a contribution for allocating housing development specifically designed for micro generation of RES. It also can be used for a targeted and results oriented approach to allocating incentives to house owners for upgrading existing houses by RE installation. Last not least the maps could be made accessible to the public and used by architects and house owners for calculating the efficiency of planned solar or geothermal installations.

ACKNOWLEDGEMENTS

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Parking Lot Management for Charging Stations

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Keywords: Electric Vehicle, Charging Station, Parking Management, Open Charge Point Protocol.

Abstract: During the last years electric vehicles started to gain significant attention from customers and car manufacturers. As the number of electric vehicles on the road increases, new requirements emerge to update existing charging station infrastructures. In this paper we address the issue of management of parking lots where charging stations are deployed since existing parking management systems do not consider charging stations and charging station management systems are not able to manage parking spaces. We propose a solution in which a charging station uses sensors to detect whether the assigned charging spaces are occupied; monitors customer's interaction with itself and forces to take actions within the given period of time. If there is a violation of terms of use, our solution enables to inform the management system in order to take the necessary steps. Furthermore, it provides visual guidance to customers in search for parking space and during the interaction.

1 INTRODUCTION

In recent years, there has been a growing interest in electric vehicles due to concerns about climate change, greenhouse gas emissions and fossil fuel prices. With technological innovations in battery and power management many car manufacturers embrace producing electric vehicles. Despite the fact that more charging stations are deployed every year in parking lots, their numbers are still limited. As a result the more efficient use of parking spaces where public charging stations are deployed becomes invaluable: These parking spaces should only be occupied by authorized electric vehicles. Yet existing parking management systems and solutions only address the availability of free parking spaces.

In this paper we propose a solution that can be employed in existing charging stations. The concept involves the use of sensors in order to determine whether a vehicle is parking or not, monitoring customer interaction with the charging station while introducing time-based restrictions and warning him/her accordingly. If the warning is ignored and therefore the use of the charging station violated, we provide a mechanism to inform a central system about the situation. Moreover, this management system is coupled with a guidance system that proposes the use of luminaries with three basic colors. In the following we differentiate between the terms *parking lot* and *parking space*. A parking space is a location for parking of one vehicle. A parking lot is a dedicated area for parking of multiple vehicles and thereby consisting of many parking spaces.

The remainder of this paper is structured as follows. Section 2 describes related work and Section 3 provides the fundamentals of the proposed solution on an abstract level. Section 4 describes the required changes considering an existing protocol. Section 5 gives an overview of the implementation and Section 6 concludes.

2 RELATED WORK

A number of the works about charging stations focus on location planning and charge scheduling. These are particularly important for distributing load and therefore increasing efficiency. (Hanabusa and Horiguchi, 2011) and (Hess et al., 2012) propose optimizations for charging station placement while taking distance to travel and waiting times into account. (Mehar and Senouci, 2013) deals with the same problem but considers additional factors to minimize deployment costs.

The work in (Timpner and Wolf, 2012) evaluates various scheduling algorithms for efficient utilization of charging stations in project V-Charge. Parking spaces with and without charging stations are man-

aged by a future system where vehicles autonomously navigate as needed regarding the battery's state of charge. (Ruzmetov et al., 2013) proposes a platform where an electric vehicle is automatically assigned to a charging station based on parameters like the power level of the battery, distance to travel, and status of the road traffic. Moreover, the driver is guided to this charging station with a mobile application.

Open Charge Point Protocol (OCPP) 1.5 (OCPP Steering Group, 2012) is a standard open protocol for communication between charging stations and a central system that manages them. It defines message types for authorization of customers, starting/stopping charging of electric vehicles, configuration and reservation of charging stations. However, it lacks a mechanism for the management of parking spaces assigned to the charging station. On the other hand, (U.S. DOT, 2011) and (Litman, 2013) summarize current solutions in parking management but do not consider parking lots with charging stations.

3 APPROACH

This section describes our approach on an abstract level. The charging station is equipped with an occupancy sensor for each single parking space and each parking space is assigned to a socket of the charging station. Charging stations are connected to a central system. We modeled the contexts of a charging station as a set of states – *free*, *occupied*, *authorized*, *charging*, *warning*, *violated* – depending on three sources:

1. **Sensor Information:** Occupancy sensors can detect whether a parking space is *free* (no vehicle parking) or *occupied* (vehicle parking). Subsequently, the central system can be informed about the change.
2. **Customer Interaction with the Charging Station:** After a parking space is *occupied*, the customer must be *authorized* (allowed to charge) and start *charging* his/her electric vehicle (for example by plugging in the cable).

   We also added the state *warning* which implies that the vehicle has to leave the parking space:

   I. The charging station changes from *occupied* to the *warning* state, if the authorization fails.

   II. The charging station changes from *charging* to the *warning* state, if the charging process is stopped (for example by unplugging the cable).
3. **Timeouts:** In order to prevent misuses or abuses of the parking space we introduced time constraints for three states, *occupied*, *authorized* and *warning*. While a vehicle is parking, the customer must take actions within a fixed period of time so that the parking space is not blocked for a long time and the charging station can offer its service to others.

   I. In the *occupied* state, the customer must authorize himself/herself within a fixed period of time, otherwise the charging station changes to the *warning* state.

   II. In the *authorized* state, the customer must start charging within a fixed period of time, otherwise the charging station changes to the *warning* state.

   III. In the *warning* state, the vehicle has to leave the parking space within a fixed period of time, otherwise the charging station changes to the *violated* state. Changing to the *violated* state is the only transition where a network communication is essential since central system must be informed about the situation and additional steps should be taken (such as reporting to law enforcement officials).

   Timeouts are handled by each charging station internally, so the task will not be burden on the central system.

Figure 1 illustrates the functionality of the charging station with the states. It is important to note that state changes are managed by the charging station. This enables to continue using the functionality if the network connection fails and the charging station is not connected to the central system. Beside the obvious hardware-enhancement of including occupancy sensors, the solution proposes changes on the software of both the charging station and the central system. First, the charging station must be able to process information gathered by sensors and change states accordingly. Second, the charging station's internal processes must trigger state changes when authorization succeeds or fails, and when charging process starts and stops. Third, the functionality suggests a communication between the charging station and the central system.

Authorization. We made no distinction between different authorization mechanisms since the chosen mechanism does not affect the way state changes function. They all serve the purpose of allowing the customer to charge or not, hence trigger a transition

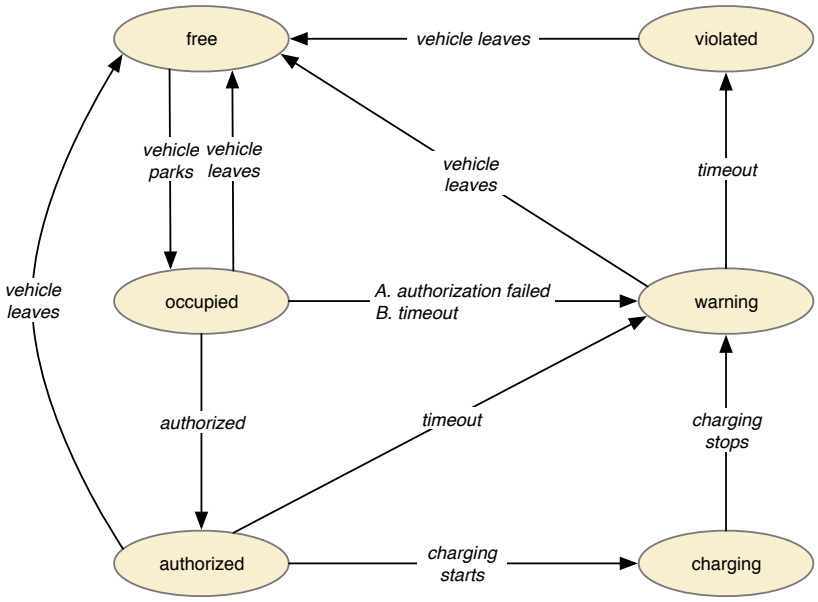


Figure 1: The state diagram of the charging station.

from *occupied* to *authorized* or to *warning*. Different operators may use different mechanisms such as phone calls, sending text messages, near field communication (NFC) with smartphones or radio-frequency identification (RFID) tags attached to membership cards, charging cables or even vehicles. In all mechanisms the customer is typically given an ID and during an authorization process it is checked whether the ID is registered in the database.

Reservation. We also made no exception for the reservation of a charging station for a specific customer. The reasoning is as follows: If a charging station socket is reserved for a specific ID, then only this ID will be authorized to charge and authorization of other IDs will fail even though they might be registered. On the other hand, if there is no reservation at that time, all registered IDs can authorize. The logical distinction between these two cases does not reflect on the implementation of state changes.

3.1 Color Codes

Each parking space features luminaries that code the states (Table 1). The color codes can be divided into two groups: Colors when no vehicle is parking and colors when a vehicle is parking. The first group of colors are intended to guide a customer in search of a parking space from a distance. The second group of colors serve the purpose of guiding the customer during the service of a charging station.

The *free* state has the extra conditions *ready*, *reserved* and *inoperative*. These can be set both by the charging station and the central system. If a charging station is *ready*, it is functional and available to charge for any one. If a charging station is *inoperative*, it is not functional and therefore not available for charging. If a charging station is *reserved*, there exists a reservation for a specific customer.

Table 1: Color codes.

State	Color
free & ready	green
free & reserved	yellow
free & inoperative	red
occupied	blink green
authorized	blink yellow
charging	yellow
warning	blink red
violated	red

The choice of the color scheme based on three criteria: The number of colors should be kept at minimum in order to not confuse the customer. Second, the colors should be distinct from each other so that the customer can recognize them from a distance. Third, the universal association of colors with meanings should be taken into account. Several studies [(Dunlap et al., 1986), (Ryan, 1991), (Silver et al., 2002)] indicate that red has the highest perceived hazard level. Yellow has a medium and green has the lowest perceived hazard level. We complied with these findings in order to prevent a learning curve or making the customer think about what each color represents. Additionally, the states with timeouts are coded

as blinking colors for an emphasis.

3.2 Example Scenarios

This section embodies two use cases where offline behavior of the charging station is excluded, i.e. the charging station is connected to the central system.

Figure 2 illustrates a scenario where the customer is registered or has a reservation. After the vehicle parks, the charging station automatically changes to the *occupied* state, the timer starts and a message is sent to the central system. The customer requests authorization in time with the mechanism that the charging station supports. In this case, the charging station has an integrated RFID reader and the customer passes his/her card in front of the RFID reader. The system grants authorization, the charging station changes to the *authorized* state and the timer starts. The customer plugs in the charging cable in time, charging process starts and the charging station changes to the *charging* state. After the battery is charged or if the customer wishes to interrupt the process, he/she can unplug the cable and the charging station changes to the *warning* state. A timer starts and the vehicle has to leave the parking space. But the timer elapses and the vehicle is still parking. In this situation, another message is sent to the central system about the violation of terms of use.

Figure 3 illustrates a scenario where the customer is not registered or is not the reserved customer. After the vehicle parks, the charging station automatically changes to the *occupied* state, the timer starts and a message is sent to the central system. The customer requests authorization in time but the system does not grant authorization. The charging station changes to the *warning* state and the timer starts. The vehicle leaves the parking space in time, so there is no violation. A message is sent to the central system to inform about the new status.

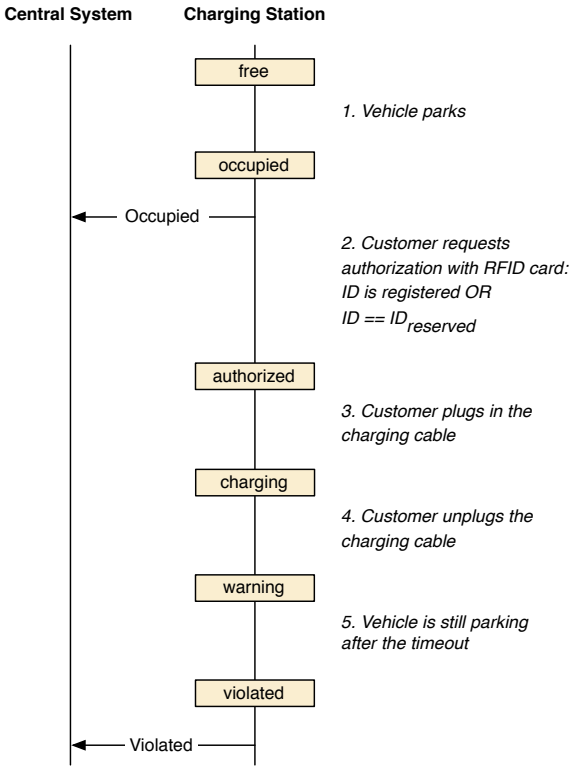


Figure 2: Customer is registered or has a reservation.

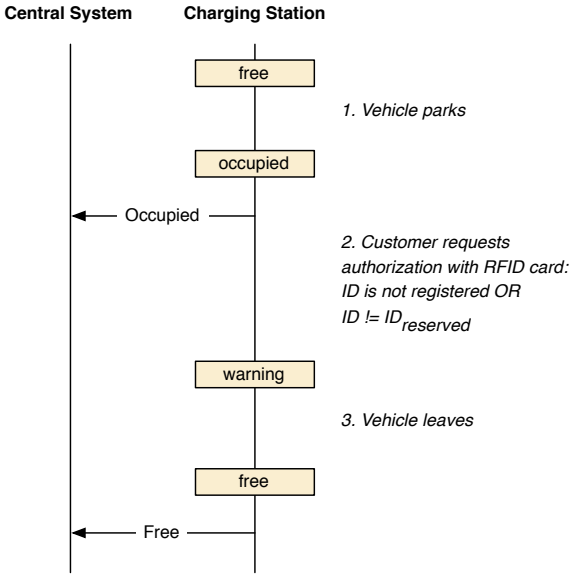


Figure 3: Customer is not registered or is not the reserved customer.

4 THE PROTOCOL

This section describes how our approach can be utilized in an existing communication protocol between charge points and a central system. For this purpose we chose to demonstrate how the OCPP 1.5 can be extended in order to support parking lot management. It is to be implemented with Simple Object Access Protocol (SOAP)[1] over HTTP for minimal overhead and in order to maintain consistency since OCPP uses the same two protocols. As with OCPP, the extension uses Web Services Addressing[2] and contains a

[1]SOAP is a specification for encoding messages that are exchanged in computer networks.

[2]Web Services Addressing is a specification for conveying addressing information of the sender and receiver in SOAP messages.

chargeBoxId element in the SOAP message to identify the charging station.

4.1 Operations Initiated by the Charging Station

In the following we present the necessary changes to the protocol and how existing implementations should be modified in order to support parking management for the operations initiated by the charging station.

4.1.1 Protocol Changes

While automatically changing from one state to the another, the charging station informs the central system about the status of a parking space so that the central system keeps track of changes. Therefore a new operation, *InformParking*, should be initiated by the charging station. We opted only to use the field *connectorId* (the socket identifier) rather than a parking space identifier or sensor identifier since the mapping between these three entities should be unique. The mapping from sensor identifier to parking space identifier to socket identifier should be taken care of by the charging point internally and is of no interest for the central system. Additionally, using *connectorId* preserves integrity since OCPP already contains the definition of this field.

1. InformParking
   - Request:
     - connectorId : int
     - timestamp : dateTime
     - status :
     (a) Free
     (b) Occupied
     (c) Violated
   - Response: *Empty response*

4.1.2 Implementation Changes

Furthermore, the implementation of existing operations in charging station must be extended in a way that they trigger state changes.

- Authorize: If the ID of the customer has been accepted, charging station changes from *occupied* to the *authorized* state, or to *warning* otherwise.
- StartTransaction: If the transaction starts, charging station changes from *authorized* to *charging* state.
- StopTransaction: If the transaction stops, charging station changes from *charging* to *warning* state.

4.2 Operations Initiated by the Central System

In the following we present the necessary changes to the protocol and how existing implementations should be modified in order to support parking management for the operations initiated by the central system.

4.2.1 Protocol Changes

Operations initiated by the central system require minimal modification to support the new functionality. The existing operation *ChangeConfiguration* is extended with following new configuration keys:

1. occupiedTimeout : int
2. authorizedTimeout : int
3. warningTimeout : int

As described in Section 3, these configure the maximum period of time in seconds a charging station can be in *occupied*, *authorized* and *warning* states before it times out. Analogously, the existing operation *GetConfiguration* is extended with the same configuration keys to retrieve the value of the three timeout settings.

4.2.2 Implementation Changes

When the central system invokes the operations *RemoteStartTransaction* and *RemoteStopTransaction* and the charging station accepts to execute them, it should change to *charging* and *warning* states, respectively. Additionally, when the central system invokes the following operations at the charging station, they set the extra conditions for the *free* state. So the implementation of the charging station must be extended to support them.

- ChangeAvailability: If the charging station is able to change to the requested type *Inoperative*, this corresponds to the condition *inoperative*. If the charging station is able to change to the requested type *Operative*, this corresponds to the condition *ready*.
- ReserveNow: If the charging station accepts the reservation, this corresponds to the condition *reserved*.
- CancelReservation: If the charging station is able to cancel the reservation, this corresponds to the condition *ready* and the charging station is available to charge for any one.

5 IMPLEMENTATION

This section describes the hardware and software implementations for our solution.

5.1 Hardware

We evaluated three sensor types to monitor the charging station surroundings: A photoelectric laser sensor, an ultrasound sensor and an inductive loop.

The photoelectric laser and ultrasound sensor share the same operating principal. They feature a sender, which emits a signal that is reflected by an object, and a receiver, which detects the reflected signal. This is then interpreted as an object being nearby. In the case of the photoelectric laser sensor this signal is a beam of light, and in the case of the ultrasound sensor this signal is a sound wave with a high frequency. The photoelectric laser sensor is not cost-efficient to be installed in large scales by operators. Furthermore, this sensor demands direct viewing angle to the object, so the installation is inconvenient since it has to be placed above the charging station. Having the sensor outside would endanger the functionality. Another drawback was that the sensor could detect a nearby object but not the object type. Our evaluation showed that the ultrasound sensor had the same issues. So these two sensors are not suitable for the charging station setup.

The best fitting solution was the inductive loop, but it is also very elaborate to install. An inductive loop utilizes magnetic fields to sense when a large metal object, such as a vehicle, is nearby and causes a change in the frequency of the electrical current. Then, this change is recognized by the detector. The detectors are tested and evaluated, and are able to successfully detect and inform about the occupancy status changes. Thus, we opted to install inductive loop vehicle detectors under the parking spaces assigned to the charging station that is deployed at our university.

5.2 Software

We have integrated the proposed changes into our own OCPP central system implementation *SteVe*[3]. Therefore we were able to extend and modify the implementation as required. SteVe is an open source project that supports OCPP 1.2 and 1.5. It is a Web application designed to run under Apache Tomcat and consists of multiple Java servlets. It uses the Apache CXF[4] framework for creating and receiving SOAP messages. Moreover, CXF supports Web Services Addressing. SteVe was tested successfully in operation.

A prototype software for the charging station has been developed that implements our approach. It is an implementation of the the diagram in Figure 1 as a finite state machine, that supports collecting sensor information and changing LED colors according to the state change. The communication between the charging station that is running an implementation of OCPP and SteVe is currently a subject of work in progress.

6 CONCLUSION

We presented an integrated solution for managing parking lots with charging stations since the existing solutions are exclusive to either parking management or charging station management. Our approach enables the parking spaces to be occupied only by authorized electric vehicles. This is achieved by tightly monitoring and controlling user interaction with the charging station. In addition, charging stations are equipped with luminaries that guide customers in search of a parking space and during the actual use of the charging station.

Future work consists of evaluating and improving our proposed system based on user-centric field tests. The architecture of our system paves way to publish parking availability of the charging stations via the Internet for drivers to check by mobile devices before arriving at their destination. This is due to the fact that the central system keeps track of the parking changes and the user interaction. Furthermore, the currently-only-visual guidance system can be extended by installing speakers in the charging station in order to provide aural assistance during the use of the charging station. This would improve the perception of state changes, timeouts and the run of the timer.

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[3]abbr. for SteckdosenVerwaltung (English: *socket administration*) https://github.com/RWTH-i5-IDSG/steve

[4]http://cxf.apache.org/

[5]Bundesministerium für Wirtschaft und Technologie (BMBF) http://www.bmwi.de/

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Acceptation of a Demand-response Enabling Technology for using Electricity at Home upon a Simulated Marketing Campaign

Role of Sociodemographic Variables and Prior Energy Behaviors, in Tandem with Expectations and Attitudes Formed to the Message Target

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Abstract: The present work addresses the usefulness of IT acceptance frameworks for studying consumers' adoption intentions upon learning of a new technology described as affording demand-response and energy conservation at home. A survey study was conceived which relied on the exposure of respondents to a marketing campaign for this technology. In preceding steps *Theory of Planned Behavior* and *Technology Acceptance Unified Theory* were applied to adequately model and test predictive relations upon intention to adopt that technology and upon expectation of remaining with known methods that compete with the technology, with a Partial Least Squares structural modeling approach. Results suggest that the frameworks are useful for predicting intention to adopt this type of technology. Especially important predictors were *Effort Expectancy, Social Factors* and *Positive Attitudes*. Given validation of the nomological network, the goal is to comprehensively integrate differences in adoption across socio-demographic strata and tied to consumers' energy behaviors with the structural network linking IT predictors to dependents.

1 INTRODUCTION

The present work complements a study on the applicability of Information Technology (IT) acceptance models Theory of Planned Behavior (TPB) (Fishbein and Ajzen, 2005) and Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) to the understanding of residential consumers' response, in terms of intention to adopt a technological proposal for energy efficiency and for demand-response to dynamic tariffs, in the context of a simulated marketing campaign. Empirical support for the applicability and usefulness of these frameworks for predictive purposes was obtained from questionnaire data, i.e., from self-reported perceptions of the message conveyed in the campaign, through building and testing measurement and structural models which model adoption intention, and expectation of continuing to use known methods alternative to the technology, as a function of a set of expectations, attitudes, affect and social factors.

Two alternative models were developed and tested, differing in the operationalization of attitude. The dependent variables were intention to adopt and expectation of remaining with known methods that compete with the technology. Predictors contemplated positive and negative attitudes (bidimensionality), performance and effort expectancies, social factors, and perceived behavior control.

The present study draws on positive evidence on the usefulness of the nomological network with its associated blocks of indicator variables, and inspects the role of consumer variables, e.g. socio-demographic and prior energy behaviors, posited to work in tandem with the cognitive-affective ones. Gender and age have been found to draw associated differences in adoption intention for technology in workplace in the United States. Are they to be found in regard to this particular technology, in a

Portuguese sample? If so, is the structural model proposed also useful to understand or represent processes whereby such adoption differences build across groups of respondents, or are these independent effects (via other social, cognitive and/or behavioral processes)? If they are not independent, do the predictors and structural links in the model convey groups' differences (mediating effect), or is it necessary to differentiate the importance of specific predictors according to groups of respondents (moderation effects)?

Energy behaviors are an important subject matter in sustainability studies (Lopes et al., 2012). In light of the concept of "Intelligent efficiency" (Elliott et al., 2012) energy behaviors become challenged by becoming more involved with technology systems. This is increased with the 'Smart grid', and Demand Response initiatives, (Santacana et al., 2010). These behaviors belong to multiple types (Black et al., 1985); (Stern, 2000) e.g., investment in efficient equipment and whether and how they may impact the willingness to acquire or use automating technology is unknown. Prior energy behaviors of respondents are likely to affect their acceptation intention but they may do so through different processes represented in alternative attitude-behavior or behavior-attitude theories. Moreover given the multiplicity of energy behaviors and their potential similitude to one or the other conative variables (*adoption intention*; *expectation to remain with known methods*), various hypotheses are studied.

Energy behaviors involving technology, similar in that regard to *adoption intention*, may enhance *positive attitude towards adoption*, according to behavior-attitude theory, and thus promote *intention to adopt*. Alternatively, behaviors similar to adoption may strengthen certain heuristic processing such that considerations on the cost or easiness of behavior enactment rather than the considerations on outcomes probabilities become more salient (Kidwell & Jewell, 2008).

2 REVISION OF IT ACCEPTANCE LITERATURE

The Attitude-behavior concepts pertaining to TPB (Fishbein and Ajzen, 2005) have been successfully applied in multiple behavioral domains (Armitage and Christian, 2003), including the energy realm when expanded with personal norm (Abrahamse and Steg, 2009); (Gadenne et al., 2011) pro-environmental behavior (Oreg and Katz-Gerro, 2011), as well as IT acceptation in the workplace (Taylor and Todd, 1995). IT acceptance studies have highlighted the role of users' attitudes and beliefs about the technology as antecedents of acceptance versus rejection, and the importance of understanding the factors that motivate or hinder those attitudes. Acceptance refers to the willingness of a potential user, with some degree of choice, to intentionally employ a technology for the purposes or tasks it was conceived for (Dillon, 2001). A change in measurement paradigm towards expectations/ appraisals referring to spheres of experience (utilitarian, experiential, and enjoyment) underlies Technology Acceptance Model and Decomposed TPB (Davies et al., 1989); (Bagozzi et al., 2002). Framework for measurement of users' perceptions and attitude by operationalization of core constructs after revision of the literature has been proposed by Venkatesh et al., (2003). The UTAUT was based upon seven different models of technology acceptance.

As a novel application of IT acceptance literature, studying the intention or willingness to adopt automation technology for energy efficiency, in the context of transitioning to smart grids, and ensuing dynamic tariff policies for demand-response (Livengood and Larson, 2009), implied conducting a survey, and, subsequently, modeling the adoption response, by broadening the scope of the variables, both the dependent variables and attitudinal ones. Table 1 summarizes the constructs of TPB and UTAUT in IT studies for the prediction of intention under circumstances of little experience with the technology, and illustrates how constructs were operationalized in our study.

2.1 Respondents, Preceding Steps and Results

Respondents were 504 members from a marketing panel from the center region of Portugal. They were eligible to the survey if their educational level was the 12th grade and if they paid their own electricity bill. Sixty two percent (311) were women, age ranged from 25 to 60 years old (mean of 33.5 and standard deviation of 7.2); educational level was balanced across the two levels (54% had higher education). The sample was then randomly divided into two halves, for exploratory factor and confirmatory Partial Least Squares analyses (PLS).

The (future) smart grid context was presented to respondents highlighting its purpose of efficiency, peak reduction, and environmental protection. The technology concept was introduced in terms of tasks

Table 1: Constructs and findings regarding TPB and UTAUT and the adapted operationalization in our survey. Adapted from Venkatesh et al., (2003a).

Theory Concepts	Definition	Operationalization (examples)	Operationalization adaptation for our study (examples)
TPB			
Attitude towards behavior	"an individual's positive or negative feelings (evaluative affect) about performing the target behavior" (Fishbein & Ajzen, 1975)	Global evaluative ratings	(cf. infra) plus Beliefs: *"By adopting the EnergyBox at home, when the Smart Grid exists, I will contribute to the reduction of the greenhouse effect emissions to the environment"; "By adopting this device at home, I will contribute to reduce the grid consumption peaks"; "Using the EnergyBox at home will allow me to increase the habit of saving energy and money"*
Subjective Norm (S.N.)	"The person's perception that most people who are important to him think he should or should not perform the behavior" (Ibid)	"People who influence my behavior think I should use the system"	"*People who are influent to me will think that I ought to adopt this type of device"*
Perceived Behavior Control (P.B.C.)	"The perceived ease or difficulty of performing the behavior (Ajzen, 1991); "Perception of internal or external constraints on behavior" (Taylor & Todd, 1995); Relates to self-efficacy, and facilitating conditions regarding resources, as well as regarding the technology	"Given the resources, the opportunities and knowledge necessary, it will be easy for me to use the system";	*"Using this device will take too much time, considering all I have to do"*
UTAUT			
Performance Expectancy (PE)	"the degree to which an individual believes that using the system will help him or her to attain gains in job performance". It integrates constructs of: perceived usefulness (TAM), extrinsic motivation (MM), job-fit (MPCU), relative advantage (IDT), and outcome expectations (SCT) .	"I would find the system useful in my job" "Using the system enables me to accomplish my tasks more quickly"	"*At home, using a monitor to keep track of the domestic electric consumption will allow me to save energy and money*"; "*At home, if I use the Autonomous Decision aid I will probably be able to displace the consumption to whenever the energy is cheaper"*: "*Even when using the Smart Grid, I trust my own ability to place the consumption times to whenever electricity is cheaper or more available at home, by myself, without the help of the Autonomous Decision aid*"
Effort Expectancy (EE)	"The degree of ease associated with the use of the system" encompassing: perceived ease of use (TAM), complexity (MPCU), and ease of use (IDT)	"I would find the system ease to use" "Learning to operate the system is easy for me"	*"It will be easy to learn how to use the EnergyBox monitor to check consumptions"; "When adapting to the Smart Grid, it will be easy to learn how to use the EnergyBox"*
Social Influence	"the degree to which an ind. perceives that important others believe he or she should use the new system" and relates to constructs of: S.N. (TPB), social factors (MPCU), and image (IDT)	"People who influence my behavior think I should use the system"	*"People from my group of colleagues and friends who use the EnergyBox will have a higher social status than the ones who don't"*
Attitude towards using technology	Positive feelings about performing the behavior; Reflects constructs of: Attitude towards behavior (TPB), Intrinsic Motivation; Affect towards Use; and Affect.	"Using the system is a bad/ good idea" "The system makes work more interesting"	*"Adopting the EnergyBox is a good idea"; "Adopting the E. in a context of Smart Grid is a wise idea"; "I will grow bored of using this type of device"; "It will be hard for me to accept that the Autonomous Decision aid is in charge of the use of electricity at home"; "With the E., managing the expenses at home will be more interesting"*
Behavioral Intention (BehvIntent Expc)	A self-generated instruction to perform an action, "behavioral plan making possible the achieving of a behavioral goal" (Ajzen, 1986)	I intend to use the system in the next () months	*"I intend to be one of the first people to install and use the device"; "I can foresee that I will use this device as soon as it is available" "I think I will use more or less the methods I already use, without any specific devices, in electrical consumption*"

to meet in demand-side initiatives and price policies. The message and the survey followed the principles of the Utilitarian Information and Persuasive Communication. The survey was constituted by sets of questions dealing with socio-demographic information, residence and electricity consumption and behaviors; adoption of the technology under the current and future smart grid, anticipated feelings to monitoring and to using automated decision aids.

Measurement and structural models' tests were performed with PLS path modeling, employing SmartPLS version 2.0.3. (Ringle et al., 2006). Adjusted models aimed at explaining dependent variables of adoption intention (*BehvIntenExpc*), and also resistance to adoption, e.g., expectations of keeping using the methods already known to manage electricity consumption at home (*Pessim_AltMethods*). The models recognized the bidimensionality of the attitudinal concept, making place for positive and negative attitudes towards adoption. Two models were developed and adjusted, and simplified versions with only higher magnitude path coefficients were retained. The first comprises as predictors variables of *Effort Expectancy, Social*

Image and Performance Expectancy, as well as two attitudinal variables with different valences that partially overlap conceptually with *Performance Expectancy*, and are understood as a compound of respectively, *positive, and negative, affect and expectancy*, and, lastly, a variable of *valuations of outcomes of conserving electricity*. The second model (Fig 1) aimed at achieving a higher discrimination between expectancy and attitudinal blocks of items. It operationalized attitude as anticipated emotions to performing behaviors implied in the technology's functionalities, namely, checking on overall and detailed electricity consumptions with a monitor; and relying on an automated decision system to schedule and set in functioning the equipment at home. Otherwise, it was similar to the first model.

Estimation and evaluation of the measurement component of the models afforded psychometrically good measures. The two structural models displayed adequate predictive capacity globally and upon selected endogenous, by criteria of coefficient of determination R^2, R^2 change and cv-redundancy. They converge in the pattern of results regarding prediction of both variables. In the prediction of *Adoption Intention*, three expectations factors about spheres of experience with technology are important: *EE, S.I.; and also P*ositive *affect anticipated to the behaviors*. In predicting *expectations of using already known methods that are alternative to the technology*, the major explanatory factor is *Negative Attitude/Negative Affect;* and *Perceived Behavior Control*.

3 SOCIODEMOGRAPHIC DIFFERENCES

3.1 Research Goals and Hypotheses

The effects of gender and age (Venkatesh et al., 2003a; b); (Venkatesh and Morris, 2000); (Venkatesh et al., 2000) and of prior experience with technology, are addressed within IT acceptance studies. They have been addressed in terms of moderator effects, i.e., group differences in variations in importance of the different factors or predictors that contribute to adoption. Within the framework of TAM (Venkatesh et al., 2003b); (Venkatesh and Morris, 2000), it has been found that men had their intention to adopt more closely associated to Perceived Usefulness (a Performance Expectancy factor); and women to Perceived Ease of Use (Effort Expectancy variable). Under the contingency that experience was low, Subjective Norm was more salient for women (Venkatesh et al., 2003b). In our study experience can only exist with other technology, e.g. with employing other programming devices, experience is assumed to be low by default. Within TPB model, Venkatesh et al., (2000) suggested that *Attitude* was more important to men, and *SN* and *PBC* more for women when experience is low. Regarding age, it was found that younger workers had *Attitude* contribute more to adoption intention, and older workers, *PBC*. *SN* was more important for older women (Venkatesh et al., 2003b).

3.2 Analysis and Results

Moderator analysis for gender and for age relies on multi-group analysis (PLS_MGA), wherein our choice was to employ the parametric approach (Keil et al., 2000, cit in Hair et al., 2014). In the case of age, the variable was discretized into 3 categories: from 25 to 30 years old (212 respondents); higher than 30 but below 41 years of age (215respondents), and over 40 years up to 60 years of age (77 respondents).

Gender (being of female as opposed to male gender) did not have a significant impact in adoption intention (structural path coefficient beta = -0,038; bootstrapping asymptotic t=0,71), nor in expectation to keep with old methods (beta= 0,067; t=1,097).

For moderation analysis, the procedure was to perform separate estimations for each group, followed by a modified version of a 2-independent samples t-test, to compare path coefficients across the 2 groups of data. T test provides the statistical significance of the difference between the two groups' path estimates.

With a simplified model, retaining only one dependent variable (*Adoption Intention*) we find male respondents compared to female respondents give higher importance to *Performance Expectancy of the technology* in forming *Intention to adopt* (betas for the two groups respectively of 0,205 [t=2.38] and 0.116 [t=2.01]) and in *PBC* (betas respectively of 0.314 [t=3.35] and 0.134 [t=1.94]), and female respondents' group had higher salience of Effort Expectancy both in forming anticipated positive affective feelings (betas respectively of 0.47 [t=4.29] and 0.135 [t=1.47])and in Intention to adopt (betas respectively of 0.23 [t=4.14] and 0.14 [t=1.87]). One-tail t tests of the differences were significant at minimum at 0.05 alpha level, exception made of EE to BehIntentAdopt at 0.1 alpha level.

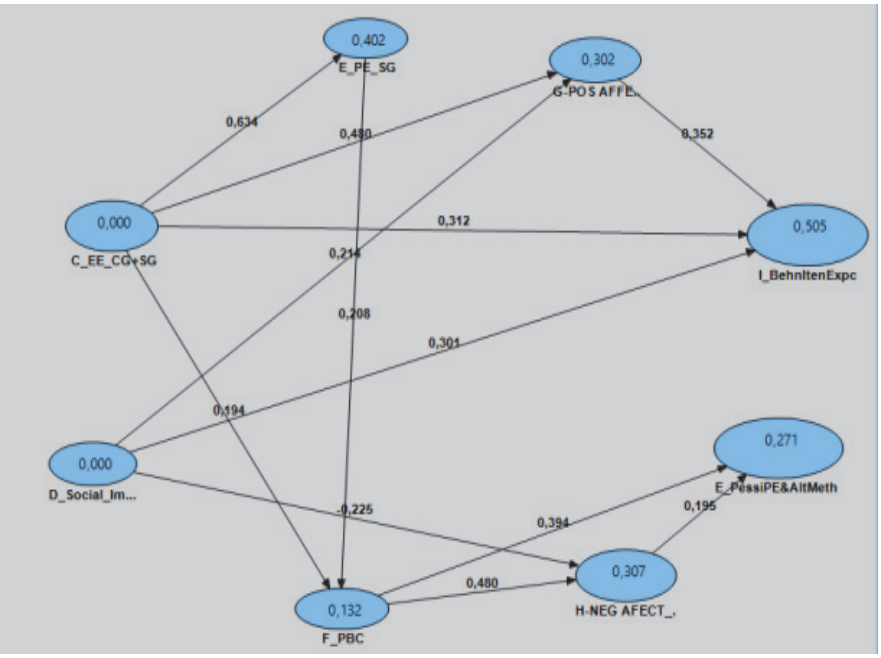


Figure 1: The second structural equation model tested in explanation of the dependent variables Adoption Intention (*BehvIntenExpc*), and Pessimistic expectations and expectation to employ other methods (*PessimPE&AltMeth*).

Age categories were compared in MG approach. Younger than 30 compared to respondents in their 30s: a) Had higher association between PE_SG (performance expectancy items referring to smart grid) and Anticipated Positive Affect to behaviors (beta_category1: 0.25 (sig); beta_ category2: 0,09 (n.s.); p value associated to t test for the difference in path coefficients (2 tail): 0.05; but they had not more important paths from PE_SG to Adoption Intention; b) Maintained less association between PBC and PE-SG (beta_category1: 0.02 (n.s.); beta_category2: 0.27 (sig); p value of t test: 0.005; c) Had less salient path from Pessism_AltMethod to Intention to Adopt: (beta_category1: 0.11 (n.s.); beta_category2: 0.25 (sig); p value of t test: 0.06. Other differences were not quantitatively relevant. In synthesis, significant and relevant differences between younger respondents as compared to ones in their 30s, were that the younger group responded to Intention to adopting in a way that was less consistent with their expressed intention to employ alternative methods, and they gave less importance to valuations of outcomes of conserving in their expressed intention to adopt the technology.

Respondents over 40 years of age compared to the ones in the 30s: a) Had a higher association of *PBC* to *Intention to Adopt* (beta_category3: 0.27 (sig) against beta_category2: -0.12 (n.s.); p value of test for the difference 2-tail: 0.003); b) Lower importance of *Anticipated Positive Affect* upon *Intention to Adopt* (beta_category3: 0.08 (n.s.) against beta_category2: 0.26 (sig); p value of t test (2 tail): 0.03); c) lower importance of *Performance Expectation* (items referring to current grid) to *Anticipated Positive Affect* (beta_category3: -0.01 (n.s.) against beta_category2: 0.23 (sig); p value associated to t test: 0,002).Thus, respondents older than 40, compared to those in their 30s, had higher salience of *PBC* in *Adopting Intentions*, but lower salience of *Anticipated Positive Affect to the behaviors*.

Group differences due to educational level and occupational field were analyzed. Educational level assumed 2 levels: 12th grade (educ_level 1) and higher education (educ_level2). Occupational field was classified according to the degree of importance of ICT technology. Importance of computers and technology for the occupation was coded after Portuguese occupational taxonomies (e.g., taxon of Technology field Portuguese Inventory of Occupational Preferences). This lead to organizing 2 categories: lower use of technological knowledge and skill about computers, software and programming, or higher. There was some overlap between technology load and educational level categories (Pearson's Phi of 0.303).

These variables were first checked regarding their potential role as predictors of the dependent variables, and either non-significant or extremely low, effects were obtained. Relevant differences

among occupational level and field/technology categories were found in path coefficients (thus manifesting moderating roles of these variables) statistically significant at alpha level of 0.05, in a two tail adapted t-test. Respondents with higher education, comparatively with those with 12th grade, gave lower importance to *Performance Expectation* in forming Adopting intentions (beta_educlevel_1: 0.21 (sig); beta_educlevel_2: 0.07 (n.s.); t test (16.66 d.f.) =2.48, p(2 tail)=0.025). Thus for educational level, a significant and relevant effect was that the more highly educated respondents seemed to be less driven in their adopting considerations by *performance expectations*. Respondents whose occupation were classified as less infused with ICT tasks and skills (category 1) displayed higher paths between PE_SG and two other constructs. One of these constructs was *PBC*, so that performance perception depended upon the PCB significantly or the reciprocal, whereas this is not the case with more ICT loaded occupations (Path_Categ1: 0.22 (sig); Path_Categ2: 0.05 (n.s.), t(21.28 d.f.)=3.86, p(2t)=0.001). The other construct more highly linked to PE_SG by Category-1 group was *Anticipated Positive Affect*: They accorded higher importance to *PE_SG* in their ratings of *positive anticipated affect to adoption*. (Path_categ1: 0.18 (sig); Path_Category2: 0.05 (n.s.), t(25.19)= 2.64; p=0.014.

The same former group also had more strong negative association between *Social Image* and *Negative Affect* (so that Social Image factors implied the presence of more anticipated negative affect), a link that was non-significant for the group with more technologically loaded occupations. (Path_Categ1: -0.30 (sig); Path_Categ2: -0.07 (n.s.); t(16.66)=3.44; p(2t)=0.003).

4 ENERGY BEHAVIORS

The concept of Intelligent Efficiency positions technology and people's energy behaviors as integrated parts of efficient solutions, to which accrues demand-response management as policy on tariffs and prices, in the transition toward more intensely digitalized grids. Energy behaviors (Black et al., 1985) are a set of different kinds of behaviors theorized to impact the way energy is consumed at home and the energy consumption outcome e.g., switching off lights in unoccupied rooms; checking the invoice, buying efficient equipment; performing small thermal improvements in the house, but to those we added the use of automation or programming for setting goals (e.g. temperature). For 431 participants for whom a subset of energy behaviors were jointly applicable, self-reported frequency of these behaviors was not highly correlated overall. Instead, a subset of behaviors could be used to compose a consistent formative construct, namely: buy efficient equipment, checking invoice; switch off equipment at button and perform small improvements in thermal insulation of the house. Two other behaviors (regulating ambient temperature according to season; and employing programmer) were studied, treated with a single indicator variable approach. Frequency in the case of highly repetitive behaviors controlled by specific cues may constitute habit.

Hypothesis on relations between energy behaviors and adoption intention can be derived from TPB in Conner and Armitage's (Conner and Armitage, 1998); (Armitage and Christian, 2003) extended version with past behavior as a factor, possibly mediated by self-identity as discussed by Smith, Terry and Manstead (2008). If this kind of influence predominates, different sets of energy behaviors may be direct predictors of each of the dependent variables. Hypotheses relating those behaviors - when accessible to memory - to attitudes originate from frameworks in Attitude literature favoring the behavior–attitude link, namely self-perception theory, under conditions where pre-existing attitudes might not be clear nor supported by knowledge structures (Eagly and Chaiken, 1993); (Olson and Stone, 2005). Thus self-report of specific sets of energy behaviors is expected to covary with Valuation of Outcomes of Conserving, and also with Attitudes, either in favor or counter the adoption of the technology depending upon the behaviors' overlap with technology use. This association may have different causes, such as salient motives for the behaviors, consistency effects of self-perception and self-inference of attitude, and even possible social desirability bias.

Distinct hypotheses on potential moderating role of prior behaviors of a similar kind as the dependent(s), within TPB framework, are formulated by Kidwell and Jewell (Kidwell and Jewell, 2008) by theorizing their role as sources of activation of specific heuristics in the information processing for decision. As prior experience with the behaviors calls attention to information obtained from experience, it is then expected to change the importance of TPB variables upon behavior Intention/ behavior considerations, by decreasing the importance of Attitude (outcome probability), and by increasing the importance of behavioral control

considerations. But, conversely, if the accessibility to memory of sets prior behaviors is the starting point for consumers' inference of own attitudes to the technology adoption, the salience of attitude (e.g., positive attitude) in adoption considerations is not expected to decrease for the respondents with a high frequency of similar behaviors.

Self-ratings of frequency of a sample of energy behaviors were part of the survey. In order for energy behaviors to be analyzed together, they needed to be applicable in the respondents' home with an identical rate (because energy behaviors derive from activation of energy services, they are applicable if the corresponding services are chosen and activated by consumer at home). Groups of respondents who indicated the behaviors as applying were the basis for partitioning the sample of behaviors and the sample of respondents into subsets. For two behaviors - **employing programming devices in setting parameters for ambient temperature for a longer time ahead** and **adjust ambient temperature according to different benchmarks in winter and in summertime –** applicability largely overlapped. A set of other behaviors afforded a consistent formative construct: **buy efficient**, **checking invoice, switch off at button** and **thermal insulation. Employing a programmer** is considered the most similar behavior to *Adoption*, whereas *AltMethods* may be more similar behaviors such as **keeping doors closed of the rooms being heated**, or **switching off equipment using the button**, and **checking the invoice.**

4.1 Analysis and Results

In a first step, a model where each behavior is entered as a predictor of the main dependent variable is estimated and analyzed. In a second step, two sets of moderating effects are checked for: the potential moderation of *Attitude* upon *Intention*, in the present case, *Positive Affect* upon *Adoption Intention*, and also *Negative Affect* upon *Pessismim_AltMethod;* and potential moderation of *PBC* upon *Adoption Intention*, and by extension, the moderation of *EE* upon *Adoption Intention* and *Pessism_Alt Method*.

Employing a programmer had a significant relation to *Effort Expectancy* (0.21; t=2.26); but not to *Positive Affect*, and, differently from other energy behaviors, no association to *valuation of outcomes of conserving electricity*.

Adjusting ambient temperature according to season had a significant association with *Valuations of outcomes of conserving* (0.21; t=2.72), Performance *Expectancy*_CG (0.17; t=2.95).

A formative construct composed of 4 energy behaviors - **buy energetically efficient equipment; checking invoice; switch off equipment at button; thermal insulation of the home**, displays significant paths with *Valuations of conserving* and with *Performance Expectancy_CG* (0.24; t=4.88); with *Effort Expectancy* (0.15; t=3.20) ; with *Social Image* (0.10; t=2.12), with *Negative Affect to behaviors* (0.11; t=2.68);

Results of moderator analysis: **Employing a programmer:** does not significantly (at alpha 0.05) interact with *Pos Affect* upon *Intention to Adopt* (0.10; t= 1.14); nor with *Neg Affect* in predicting *Pesssimis-AltMethod* (-0,08; t= 1,22) although there is a trend in that direction. The second interaction is significant at 0.11, in a one-tail test. T**he latter interaction is negative,** as predicted in the hypothesis that prior behaviors lower the importance of attitudes to adoption considerations. But, regarding its potential role in interaction with PBC, there is no significant interaction, nor with *Effort Expectancy*.

Adjusting ambient temperature according to season does not display significant interaction with *Positive affect* in prediction of *Adoption Intention*; nor with *Negative Affect* in prediction of *Alt Method*. No significant interaction exists with PBC. With EE, however, the interaction reaches a statistically significant coefficient of 0.196 in prediction of Alt Method (t=2.89) which is high. Thus, with higher behaviors of adjusting ambient temperature seasonally there is a trend towards an increase in importance of EE in choosing alternative methods.

5 CONCLUSIONS

Gender, age and occupational groups may differ among each other in several aspects that potentially impact adoption of technological solutions for managing the use of electricity at home, and for conserving in the current conditions, and in the future scenario of the smart grid. Being of female, in contrast to male, gender did not have a significant impact in adoption intention, but it did change the importance of considerations regarding outcomes (performance) and behavior barriers (PBC), lowering them, and the importance of perceptions of ease of learning and of using the technology (EE), increasing it.

The emphasis upon behavior control (behavioral barriers) considerations of older respondents in thinking about technology adoption appears as a theme in several IT acceptance studies and also in

our study. Additionally, our results suggest that this age group (above 40years of age) may also be less concerned with outcome probabilities (performance) and report less importance of hot, emotional, thoughts around the issue of adopting.

Much younger groups (below 30s in comparison with those in their 30s) may be less concerned with consistency between *performance expectancy* i.e., outcome expectations and *behavior control*, and more concerned with coherence between *outcome (performance*) and *affect to behaviors*. Younger respondents may be also less concerned with the consistency between alternative (or competitive) methods of managing the use of electricity.

Regarding education level, the more highly educated respondents seemed to be less driven in their adopting considerations by *performance expectations*, compared to those with high school education. A possible explanation is that more highly instructed respondents may have lower pressure to perform in reducing and controlling energy use in their homes, and this is not the primary motivational source of adoption; but a different explanation is that they may require more precise information to elaborate a perception that they can feel as a bases for decision.

Educational and occupational groups differing in IT knowledge do not differ in regard to the most structural paths with higher coefficients in the overall model: From *Social Image to Anticipated Positive Affect*, and to *Adoption Intention*; from *Effort Expectancy to Positive Affect* and to *Adoption Intentions*; and from *PBC to Negative Affect and to Pessimism_Alternative Methods*. The structural model seems to hold for both groups analyzed. However, less technologically informed respondents had a more consistent or uniform pattern of responses in relating *Performance expectations (outcome probabilities they express), PBC, and positive affect to adoption behaviors,* while more instructed and technology informed respondents have more differentiated patterns.

Energy technology acceptation takes part with energy behaviors, e.g., conservation, monitoring, investments, as well as the use of automation or programming for setting goals (e.g. temperature) or automating decision. An integrated view of energy efficiency, under the conceptual umbrella of Intelligent Efficiency, positions technology and people's energy behaviors as integrated parts of efficient solutions, and furthermore, electrical grid changes towards the digital grid are integral with new market and economic policies on tariffs, including demand-response. Hypotheses on the role of prior energy behaviors of a similar kind as the dependent(s), stem from their postulated role as sources of inferences on own attitudes towards adoption, or alternatively, as sources of activation of specific heuristics in the information processing for decision, by changing the importance of TPB variables Attitude and PBC upon Intention/ behavior considerations. But in the larger context, acceptation of new technology is also designed to help consumers change their energy behaviors.

Energy behaviors appear to constitute a multifaceted construct. Prior energy behaviors are correlated to some predictors of *adoption intention*, or *to alternative methods*. A behavior that presupposes automation technology (**employing a programmer)** enhances *EE*, leading to higher perception of ease of learning to use the new technology, but they were not found to have a role in attitudes, i.e. affect, nor to alter the importance of (positive or negative) attitudes/affect and behavior control, upon considerations of adoption. But another behavior - **Adjusting ambient temperature according to season** incremented *Performance Expectation*, and led to a higher dependence of *Expectation to employ alternative methods* from *Effort expectancy*. Other behaviors studied enhance almost all predictors of adoption, including absence of negative anticipated affect. In this regard, the results in our study are mixed, not leading to closure in the competing hypotheses of processes whereby energy behaviors and adoption considerations meet.

Goals and hypotheses are rooted in well-established attitude, persuasion, and IT acceptance literatures, and jointly contribute to advancing the understanding of issues and processes in the attitude formation for developing technologies for smart grid adaptation, and identifying consumer segments in regard to the adoption of this type of technologies.

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Encompassing Payment for Heterogeneous Travelling
Design Implications for a Virtual Currency based Payment Mechanism for Intermodal Public Transport

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Keywords: Virtual Currency, Mechanism, Incentive, Public Transport, Mobility.

Abstract: As a result of a huge offering of different traffic modes, peoples mobility behavior is more and more characterized by multi- and intermodality. But this growing demand cannot be satisfied adequately yet. People have to use numerous separated software platforms and payment schemes to get access to these modes. Whereas some platforms already offer the access to few transport modes, an unconditional and comprehensive virtual payment scheme for intermodal travelling is not fully developed yet.
This work examines existing virtual payment mechanisms and projects them onto the setting of the mobility sector. First, mechanism design is determined by companies strategies, the competitive environment and the access to the providing software platform. Basis is a scenario of an open software platform that provides offerings of different independent market actors. Critical for developing a comprehensive mechanism is a functional integration of (private) vehicle sharing, the consideration of specific product characteristics and appropriate system restrictions.

1 INTRODUCTION

Innovations and technological development cause a growing number of alternative traffic modes. For example, electrification changes the urban landscape by impacting modes and infrastructure. Furthermore, peoples mobility behavior changed significantly over the past decade. They consider and support alternative transport modes, like car or bike sharing (Rehrl et al., 2007). People use these offerings and combine them to heterogeneous travel chains. This issue is becoming more and more urgent in our society (Yogesh Malhotra, 2000). But multi- and intermodal traveling is still uncomfortable to realize, because of a huge number of different software platforms, which provide access to these services.

Whereas intermodal traveling is a coherent activity for people, the software landscape to realize this is partially divided. There are already some intentions to consolidate the access to transport modes. One the one hand, providers establish in-house platforms, which offer access to their own product portfolio. On the other hand, comprehensive access to transport modes between different competitors is also developing.

Table 1 shows some examples of software platforms and their functionalities across the German mobility sector. Common platforms, also called brokers, integrate different mobility modes, combine and present them concentrated. Across these platforms, the range of functions varies significantly. The frame for all following examinations is an open software platform, which integrates the offerings of independent market actors. In the following descriptions, ”open” means the possibility to provide services on a platform, without discrimination by any superior instance.

Within this context, the payment via virtual currencies offers highly interesting possibilities. Cash payment is increasingly substituted through virtual currencies (Thomas Lammer, 2006). Electronic and mobile payments are emerging. Forecasts show a significant rise in global mobile transactions volume (Statista GmbH, 2013). Virtual currencies originally are designed as loyalty programs to bound customers to in-house services. A modified strategy is the cooperation scheme, also defined as coalition loyalty or cross loyalty, which describes the facilitation of loyalty cards at multiple, possibly competing, retailers (Buchinger et al., 2013b).

This work gives general design implications for an e-payment scheme for traveling via multiple trans-

Table 1: Broker Software Matrix.

Platform	Moovel[1] (Daimler Mobility Services)	DB Navigator[2] / bahn.de[3] (Deutsche Bahn AG)	quixxit.de[4] (Deutsche Bahn AG)
Region	urban region offering	national public transport	offerings in Germany
Functionalities	information, routing, navigation, ticketing	information, routing, navigation, assistance, ticketing	information, routing, navigation, assistance, ticketing
Modes	local public transport, taxi, car sharing, bike sharing	local public transport, taxi, car sharing, bike sharing	local public transport, taxi, car sharing, bike sharing (reduced functionalities concerning flight offerings, rental cars, ferry boats, ...)
User interfaces	web service, mobile application	web service, mobile application	web service, mobile application

port modes within one route. Therefore, the conceptual basis and the general requirements of the mobility sector are described in part two. The third part discusses the applicability of existing virtual currencies on intermodal urban public transport. Thereupon, some recommendations are stated to develop a constitutive framework of a virtual currency mechanism for intermodal travelling.

2 CONCEPTUAL BASIS

To establish a basic understanding, Figure Figure 1 defines the general scope of the context. Furthermore it pictures the relations between stated terms and definitions, used in the following.

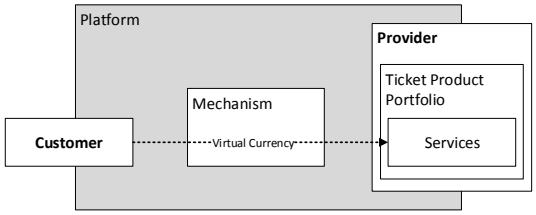


Figure 1: Conceptual Basis.

Transactions between customers and mobility service providers are enabled via an open software platform for multimodal transport services. A Virtual Currency (VC) is a fundamental instrument of payment, on which the constitutive mechanism relies. The virtual currency mechanism regulates the specific way of cash flows and transactions. Within this context certain interdependencies determine the design of each component. To develop a suitable and beneficial virtual currency based mechanism for intermodal travelling, it is essential to consider these interdependencies, especially in the mobility sector.

Because shared based transport modes are a growing part of intermodal travelling, integrating them is desirable, but challenging. Compared to traditional modes, car or bike sharing is distributed in a different way. The offerings vary significantly in terms of capacity, characteristic, location and price. Therefore, it highly depends on individual preferences. A virtual currency based mechanism has to project these individual preferences in an adequate way.

(Buchinger et al., 2013a) showed an inclusion of vehicle sharing into a theoretical concept of a virtual currency. It offers the possibility of a multimodal portability towards other transport modes. Figure 1 shows the systematical virtual currency flows under consideration of vehicle sharing. All activities are centralized in a personal digital wallet. This method is already practiced in various virtual currency based concepts, e.g. ClickandBuy[5]. Virtual currency funds can be received by exchange for cash money or by providing private vehicle capacities. Earned amounts of private car sharing can directly be reused for travellings via other transport modes.

This primer is not solely sufficient to develop a practicable currency scheme. Currency and in addition mechanism design are not only determined by transport mode specifications, but also by provider's product portfolio conditions. Within this work, products are defined as tickets, which authorize customers to use different services on certain prices. Obviously in the mobility sector, product characteristics diverge significantly compared to other industries. The consideration of this fact is a necessary enhancement of existing concepts. For example, some tickets have a time limited subscription towards the usage of special transport modes. This attribute impacts virtual currency flows substantially.

[5]https://www.clickandbuy.com/DE_de/home.html

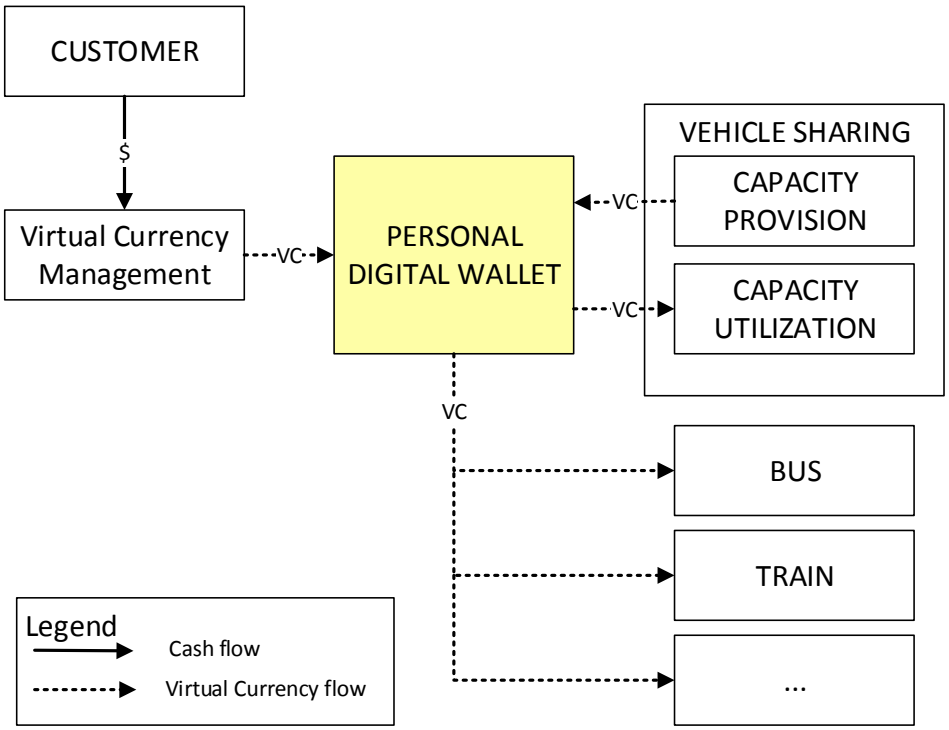


Figure 2: Multimodal Cash Flows.

3 VIRTUAL CURRENCY MECHANISMS IN CONTEXT OF INTERMODAL TRAVELING

There is a large variety of loyalty concepts on virtual basis. (Buchinger et al., 2013b) examined various virtual currency schemes in detail. This constitutive work, investigates especially the applicability of existing concepts, or components of them, to urban public transport.

3.1 Miles and More

The Miles and More program rewards customers with miles per flight with the German airline Lufthansa. Originally designed to raise customer loyalty towards the German airline, the program became extended: miles are now not only rewarded to customers, but also sold to third parties, e.g. banks, retailers and hotels. More concrete, the platform sells the ability to reward miles to third parties. Those miles expire at the end of a respective time period (Buchinger et al., 2013b).

Synergy effects enhance also third party services with additional value for the customer and for the primer platform service. As a drawback, the system favors a centralized service. Under certain circumstances cooperation between competitors is indeed possible, however only by subordination to a general instance and a favored service. Various mechanisms have this feature in common, because of strategical considerations by service providers. But this fact hinders the nonrestrictive integration of private car sharing and therefore it is not applicable to the reference scenario. In contrast to this, the constraint of exposing virtual currency funds is quite practicable in the context of urban public transport. Intensifying the incentives of the mechanism is one possibility and also feasible option.

3.2 Bahn.bonus

The bonus point system by the German mobility provider Deutsche Bahn, bahn.bonus[6], rewards customers for travelling with different transport modes. It refers to a multimodal offering, but is limited to in house modes only. Bonus points can be reinvested for travellings at discounted prices, or exchanged for other products, e.g. suitcases. Furthermore the system offers the possibility to classify customers into

[6]http://www.bahn.de/p/view/bahncard/bahnbonus/bahnbonus.shtml

levels. There is another sort of points, called status points, which solely serve to upgrade a personal level. This enables customers to get access to additional services or other benefits. In other words, a personal bonus point deposit consists of two types of bonus points with diverging functions.

3.3 Facebook Credits

Facebook Credits support loyalty towards other service providers, but moreover create a source of revenue from the platform's customer basis. Third party developers are able to provide services, e.g. gaming applications, which can be used due to the platform. Facebook credits serve the virtual currency mechanism within this specific application. Facebook's currency is automatically converted to the currency, used in the application. This process is not recognized by the application users (Buchinger et al., 2013b).

Although this system is originally not operating in the mobility sector, its characteristics can fit to this area: the mechanism is suitable to consolidate different services hosted by independent providers. The key advantage is the function of keeping loyalty towards individual third party providers sustainable. Thereby the basic function of loyalty programs can be maintained towards separated companies.

3.4 Auctions

The offerings of car sharing are characterized by a large variety and complexity. People have individual and heterogeneous preferences which determine their decisions. A functional virtual currency mechanism has to be designed under consideration of these circumstances. In this context, the fact of conflicting preferences is critical. An auction seems to be adaptive to picture individual preferences and solve conflicts connected to them.

(Krempels, 2009) investigates different options of solving agent preference based conflicts. The stated auctions, where a secret bidding round occurs and the highest bid is the winning one, are called announcements. These announcement auctions can be modeled in different forms: first, only the winner has to pay his bid and all losing entities keep their amounts completely on their own. A second possibility is to distribute shares of the winning amount between all losing entities. An increase of funds across the loosing entities effects an improved preference conflict solving. In matters of this procedure, there a some possible variations stated. Simulation results showed that a predefined, time based decay of money added by auctions, is the most promising solution to solve these conflicts. Diverse constraints ensure the stability of the overall system.

Despite these simulation results, such an e-payment concept could be problematical in terms of broad consumer acceptance. On the one hand, using this auction system might be less intuitive for customers. On the other hand, the system might be too complex to manage. In fact a simplified auction system should be considerated.

4 CONCLUSIONS AND FUTURE WORK

Choosing the right design of a virtual currency based payment mechanism overall depends on companies strategies, the form of providing their services and the competitive environment. The rate of discrimination concerning a platform access determines these factors in large part. Therefore the way of cooperation between companies to provide intermodal traveling is essential. In this case, examinations focus on a scenario, within an open software platform, which provides offerings of different entities without discrimination. There are preliminary considerations about establishing a virtual payment scheme in this specific context (Buchinger et al., 2013b). This work advances these considerations by the following implications:

Product Portfolio Chracteristics

Central implication for designing a virtual currency based mechanism for intermodal traveling is the conceptual consideration of provider's product portfolio characteristics. Ticket products diverge significantly from products distributed in other industries. Many ticket products allow transport mode utilization through time limited subscriptions. An adequate virtual currency mechanism has to feature these conditions in a flexible way. This characteristic also aggravates the integration of vehicle sharing.

Vehicle Sharing Integration

The integration of a highly diverging modes is challenging but offers extensive value potentials. Combining traditional modes with vehicle sharing means to connect two different transaction methods altogether via a virtual currency based mechanism. Figure 3 shows a conceptual mechanism integration. Users' personal digital wallet consists of two components: The first components allows the unlimited participation on transport services in a certain time, based on a subscription agreement. Within this part,

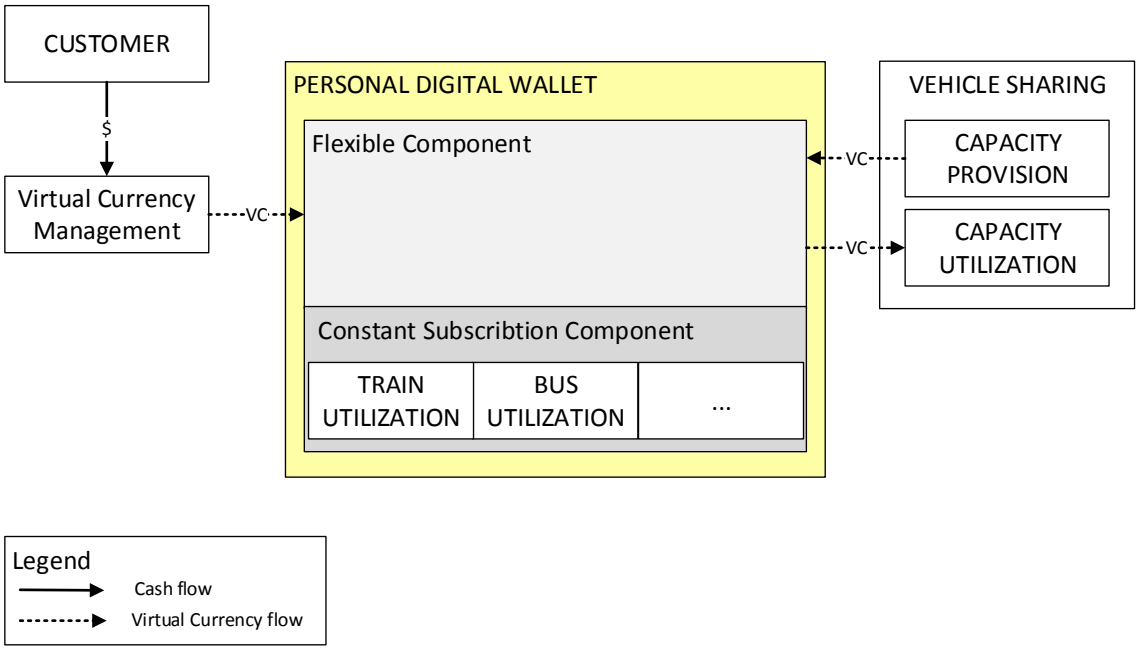


Figure 3: Compined Digital Wallet Scheme.

no virtual cash flows need to occur - depending on the certain ticket conditions. The second component includes a predefined amount of virtual coins. These coins can be earned for providing vehicle capacities and are reusable for car sharing or other services.

This combination allows the flexible integration of (private) vehicle sharing. Furthermore this scheme allows to model preferences via auctions. Compared to traditional transport modes, vehicle sharing depends substantial on specific vehicle attributes and individual customer preferences. An auction seems to be adaptive to reflect individual preferences and solve conflicts connected to them. In fact it could allocate more efficiently with regard to these conditions. Auctions can be constructed in diverse forms. These forms feature different potential of preference conflict solving, but consumer acceptance has to be considered in addition.

System Restrictions

This leads to another implication: an establishment of mechanism restrictions. Virtual currency mechanism restrictions are already approved in other areas. For example expiring currencies are well adaptive to the mobility context. Thus incentives regulate customer behavior and foster the system balance. Another adaptive restriction is a limitation of earned amounts by providing capacities of vehicle sharing. A concrete form is to avoid, that the earned currency amounts exceeds a predefined starting budget. This prevents the systematic disadvantage of other transport modes.

4.1 Future Work

This investigation is intended to form a conceptual basis for a virtual currency mechanism on an open software platform for intermodal traveling. This mechanism is going to be modeled and technologically realized. Refering to this, there are already some reliable technical solutions connected to this area. For example concerning payment APIs or virtual currencies, which have to be considered as well. Subsequently, the procedures are going to be evaluated to examine the basic contributions.

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SPECIAL SESSION ON ICT FOR ENERGY EFFICIENCY IN HUMAN SMART CITIES

FULL PAPERS

Service Oriented Development of Building Energy Management Systems
An Architecture Blueprint

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Keywords: Service-oriented Architecture, Building Automation, Energy Management.

Abstract: Building automation and energy management systems increase the value of buildings by making them more comfortable, productive, and energy efficient. However, the hardware and software technologies underlying actual systems are largely monolithic and incompatible with each other hampering extensibility and favouring consumer lock-in. In order to overcome this problem we propose to create an middleware architecture, that abstract the heterogeneity of automation systems and provide sophisticated functionality to applications for intelligent control and energy management. Our middleware, will expose services that allows to abstract the numerous protocols and technical requirements associated with each manufacturer to applications, allowing developers to apply all their effort designing algorithms and innovative techniques that maximize the energy efficiency, without worrying about the technical details of each existing system. The concept will be applied in a real-world setting with the implementation of a service-oriented architecture prototype for energy management and intelligent control of Instituto Superior Técnico (IST) office rooms.

1 INTRODUCTION

This document addresses the topic of creating an appropriate architecture for intelligent control and energy management of building offices. Given the current economic and social situation, it is of utmost importance to focus on systems and technologies that enable energy efficiency, particularly in large buildings. In Europe, buildings account for 40% of total energy use and 36% of total CO_2 emission (European Parliament and Council, 2010), and these values are expected to grow in the coming years. This aspect result in a major concern for more energy conservation. Large buildings require technologies with sophisticated applications, such as automatic control of lighting and temperature set-points, as well the need for the system to learn with the activity of users inside the building. In addition, these environments must be energy efficient and must simultaneously ensure the comfort and well being of the occupants in order to enable them to become more productive. The main hindrance in developing this vision are the lack of interoperability that automation systems offer. Each manufacturer keeps developing their proprietary specifications and has little motivation to evolve their systems to the emerging trends of communication standards (Litvinov and Vuorimaa, 2011). As well, there is still no solution for the development of applications for intelligent control and energy management in a modular way, based on Service-Oriented Architecture (SOA), where it is possible to reuse and compose services in order to implement new functionality. The current solutions of Building Automation (BA) and Energy Management (EM) are vertically integrated and do not allow communication with devices in a standard way, and poorly support their heterogeneity. Re-designing and re-programming BA and EM systems, in order to change and extend features to support new devices and functionalities are still too expensive and to slow to achieve. Web Services (WS) and SOA has allowed it, more precisely in Information Technology (IT) systems (Lee et al., 2010), due to several business needs, but not embarked on the automation and energy management domain yet. What really happens is that both services and the programmer has to know the details and characteristics of the Building Automation System (BAS), which causes a massive consumer lock in. Increasingly it is necessary that the IT system and BAS are integrated in the architecture that supports the business, since the optimization of the energy and the business processes is something that has to be done in an integrated way.

This work will analyse the various existing functionalities in Building Energy Management System (BEMS) and propose a reference architecture with a set of services collections required in order to create modular intelligent energy management and automation control applications on top of these services.

1.1 Motivation

To illustrate the addressed issue take into account the following scenarios:

Scenario 1 consider a daylight-harvesting system, which aims to use daylight to control the amount of electric illuminance needed to properly light a space, in order to reduce energy consumption. These systems uses a set of sensors and actuators inside the room to measure luminance and adjust the lighting of the lamps, respectively. In this scenario it is necessary to deal with interoperability of diverse devices, their functionality and technical features, since many are from different manufacturers and communication protocols.

Scenario 2 consider a scheduling system, which execute some tasks periodically. This tasks are triggered after an event or set of events have occurred. Events can be a time value or a specific event from the user's activity. In this scenario it is necessary to understand how the scheduling system of each device technology works and map the logic of scheduling with the operation logic of each device.

Existing solutions to address the requirements of scenarios 1 and 2 consist of monolithic applications that do not provide modular services, and also do not allow interoperability with other automation technologies used. In addition, most existing solutions are proprietary and not expose their insights, which don't allow the reusing and extension of its functionality. This situation is illustrated in Figure 1, which compares a monolithic system with a layered architecture (Bastide et al., 2006).

SOA is a paradigm that defines services as key elements of software design. The main goal of SOA approach is to reduce the dependencies of software parts, where each part is typically a remote piece of functionality accessed by clients. By reducing such dependencies, each element can evolve separately and the application becomes more flexible than monolithic applications. The advantages of SOA also apply to automation applications: loose coupling, run time service binding, and location transparency. Indeed, services abstract implementation to provide the desired functionality; they provide faster prototyping based on creation of new services from existing (service composition); they enable handling the diversity of devices and applications, because they are easier to integrate and evolve; they enable integrate BAS functionality with the IT systems underlying the occupant business. Technically, SOA provides abstraction: upon a call to the specific service, the implementation is invoked regardless of whether it is deployed in a device, or in another software module. This latter paradigm motivates the need of a SOA-based reference architecture for Smart Building (SB) systems.

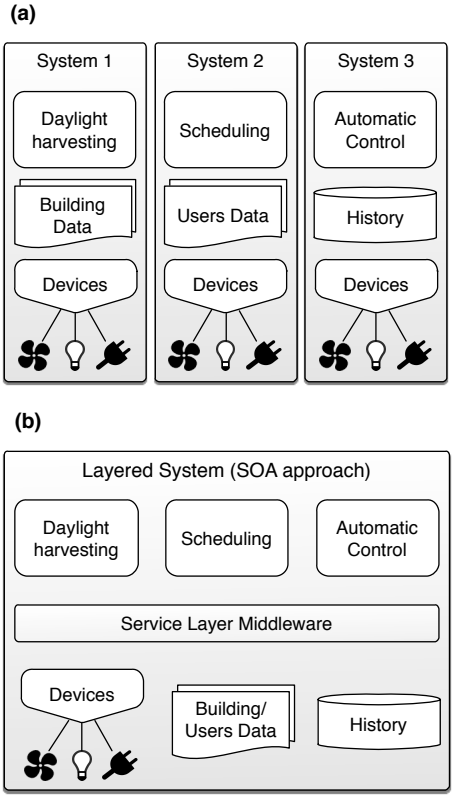


Figure 1: Actual systems vs. SOA approach. (a) Monolithic architecture where high level applications are highly dependent on the original software design. (b) Layered horizontal solution that enables technology abstraction, interoperability, and extensibility.

1.2 Problem Definition

Solutions to this problem are quite complex as is necessary to realize the system's architecture and services that the middleware service layer has to offer. Typically, architectures for these systems include services for energy consumption and a services for commanding devices. Indeed, these service components are needed. It's necessary to integrate all context information (e.g. retrieve the state of electrical devices,

the energy consumption data, and the user presence data), to derive control decisions that meet the user preferences and needs while ensuring the best values of energy consumption in the building.

Solutions, as detailed in *Related Work*, are trying to solve this issue using service-oriented architectures to provide some interoperability between different systems. However, they only expose devices as service calls along with the idiosyncrasies associated with each device. There is no semantics on top of these services, such as logical services to reuse and extend. The characteristics of different devices, the different protocols and different drivers continue to exist, but now at the service level, maintaining the lack of interoperability.

Herein, we propose a way to build BA applications atop of a modular service layer middleware that also abstracts the heterogeneity of BAS. The middleware abstract all systems and low level devices to BA applications, making less complex to develop these software. This novel approach enables taking advantage of systems that already exist, orchestrating and reusing the services they offer to implement new features that take into account the needs of the business. Conceivably in the near future, BAS will enable adding new features without having to redesign the original architecture of the system.

1.3 Contributions

The contributions of this document are as follows:

- An review of the existing solutions concerning service-oriented architectures of BEMS,
- A architecture blueprint for a BEMS, that enable the easy extension and fast development of new BA and EM applications.
- A architecture case study in a real-world setting. Our architecture prototype will be used in IST building, particularly in offices rooms, in order to validate the proposed architecture to this scientific problem.

2 BACKGROUND

In this section, it is given a brief description of some of the key terms and systems addressed, in order to provide a better reader understanding.

2.1 Building Energy Management System

A Building Energy Management System (BEMS) is part of a Building Management System (BMS) and is a computer-controlled system, which when installed in a building, controls it's power systems, including lighting, heating, ventilating and air-conditioning. The basic functions of a BEMS are: monitoring, controlling, and optimizing (Levermore, 2002). The functional aim of BEMS is to manage the environment within a building, so that energy consumption perfectly balances with the way of building utilization and its normal activities. BEMS functionalities addressed in ISO 16484-3 and EN 15232 standards (International Standard, 2007; European Standard, 2006) are: grouping/zoning; event notification; alarm notification; historical data access; scheduling; and scenarios. Also according to ISO 16484-7 standard (International Standard, 2013), a BEMS shall provide the following control features to enable energy performance in buildings: heating and cooling control; ventilation and air conditioning control; lighting control; and blind control.

BEMS are dependent on the other two systems: Building Automation System (BAS) and Energy Management System (EMS) (Bloom and Gohn, 2013).

2.2 Service-oriented Architecture

The idea of a service-oriented architecture (SOA) refers to a paradigm for the construction and integration of software systems where the primary structuring element is the service. In SOA, any subsystem is described by the services it offers (Open Group Standard, 2011). Web Services (WS) are the most common implementation of SOAs. WS consist of modular and independent software applications that can be executed over the web. These applications usually use XML and SOAP over standard network protocols, to implement the communication channels. Organizations that focus their development effort around the creation of services, will realize many benefits, such as, code mobility and reusability, scalability and availability, and better testing.

2.3 OSGi

Open Services Gateway initiative (OSGi) is a component framework specification that aims at bringing modularity to the Java platform. It enables the creation of highly modular and dynamic systems. These

systems are highly modular in the sense that OSGi-based applications are composed by multiple independent modules or components, and the development, testing, deployment, updating, and management on each module have minimal or no impact on the overall system. This means that bundles can be safely added and removed from the framework without restarting the application process (Hall et al., 2010).

3 RELATED WORK

Smart buildings require integration of various building automation systems that are usually made by different manufacturers (International Standard, 2013). Most of the manufacturers tend to focus on a specific domain, while others try to comprise all domains in one application. The need to integrate several network technologies and communication protocols into applications has forced developers and researchers to create service-oriented frameworks or use existing to accomplish that objective.

An bottom-up analysis is presented below, starting from the need of *heterogeneity abstraction and interoperability* of several field devices technologies, where it's required that this systems provides *services exposition and composition* in order to compose all various systems in a *technology independent integration* way. After being achieved the integration of various technologies, it is possible to provide several *energy management and automation functionalities* that will deliver application-level services to the end-user applications.

3.1 Field-bus Heterogeneity Abstraction

Given that there are several automation devices from different manufacturers, they are incompatible and can't communicate with each other. A popular method to achieve integration is defining a common protocol between centralized front-end and individual gateways to proprietary systems.

Building Automation and Control Network (BACnet) (Bushby, 1997) protocol has been widely accepted and used in BAS industry. BACnet is a communication protocol, developed by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and its concept is to replace the communication portion of each device with a common, standard set of communication rules, so that all devices can exchange information using only one language.

LonWorks (Corporation, 1999) is another completely different solution and a great competitor. LonWorks is actually a family of products and at the core of this technology lies a communication protocol called LonTalk.

Despite the fact they seem good solutions as it is, both require Web Services interfaces to accommodate functionalities integration (Szucsich, 2010), as you will see in the next sections.

3.2 Services Exposition

The primary technologies used in SOA domains are Web Services since they have broad industry acceptance. In the BA, there is an increasing need and opportunity to create interfaces between the physical devices and software applications. BAS developers, inspired by Web Services technologies, began researching for a way to extend the SOA paradigm into the device space, that is, implementing a high-level communications infrastructure based on Web Services protocols at the device level (Jammes and Smit, 2005).

Devices Profile for Web Services (DPWS) (Mensch, 2009) is the extension of the Web Services protocol that surfaced. With DPWS, all messaging, whether related to discovery, control or event notification, is based on the use of SOAP. In that context, a target service is a device. Once discovered, a device exposes the services. This protocol is a service enabler for devices, i.e. converts binary communication to XML via SOAP, and the technical features of the devices still exist and it is necessary to deal with them at the higher level.

Service-Oriented Device Architecture (SODA) (Deugd et al., 2006) is an adaptation of SOA which aims to integrate a wide range of devices into an enterprise system. Once again, devices like sensors and actuators are dealt as services. A SODA implementation adds a new layer to the SOA model, wherein device interfaces and protocol adapters are provided, enabling communication between proprietary and standard device interfaces, and other SOA services over the enterprise network. This protocol is also a service enabler, but offers some integration of devices and provides services extension and composition to the software layers above.

3.3 Technology Independent Integration

System high level protocols are used to connect these automation systems with each other and also to integrate them with management software components.

BACnet/WS (Szucsich, 2010) is a standard designed to be a Web-Service based communication

protocol in the industrial and home automation which can be applied to any fieldbus system. BACnet/WS is independent from the underlying BAS and allows heterogeneity abstraction and exposes their data model and attributes through a web service interface. Although this technology allows to expose services, these are fairly primitive and generic, as only provides basic operations of read, write, and collect historic data of nodes.

OPC Unified Architecture (OPC UA) (Leitner and Mahnke, 2006), is an architecture designed by the *OPC Foundation* to connect industrial devices to control and supervision applications (Hadlich, 2006). The focus of OPC is on getting access to large amounts of real-time data while ensuring performance constraints without disrupting the normal operation of the devices.

Open Building Information Exchange group (oBIX) (OASIS Open, 2013) is a specification and aims to integrate enterprise functions in several building control systems. This specification is designed to provide access to the embedded software which sense and control the environment around us. Current version of oBIX defines two protocol bindings designed to leverage existing Web Service infrastructure: an HTTP REST binding and a SOAP binding.

Home SOA (Bottaro and France, 2008), is an open architecture for home service deployment. It is based on a service platform concept, where distribution and protocol heterogeneity are managed by service-oriented drivers. Home SOA allows developers to model networked applications as a local composition of uniform service interfaces, which become bounded at runtime. This architecture is implemented regarding the OSGi standard (Dobrev et al., 2002), where its specification defines how to deal with device's access: how to share and isolate resources between modules. It proposes a modular architecture that can be opportunistically adapted on various topologies, protocol sets and platform technologies, as it integrates various home protocol drivers in an architecture where functions are registered in a uniform programming language API. This model was applied in multimedia, home automation and device management domains.

DomoNet (Miori et al., 2006) is a service-oriented solution framework designed for home environments. This prototype implements an architecture which makes the connection between lightning devices of two different middlewares: UPnP and KNX. This solution is based on a SOA and uses web services to reach the interoperability between different home computer middlewares. The aim of this solution is to prove how an approach that relies on XML, Web Services and Internet protocols, can provide a uniform architecture to home automation.

LinkSmart middleware, formerly named Hydra middleware (Eisenhauer et al., 2011), is part of a European project for the development of service-oriented software to expose heterogeneous device functions in a universal way and target domains such as home automation, among others. The main idea is to generate the software components and web services in order to integrate within the supported device instances, based on the semantic model meta-data. Decoupling the application development from the device programming brings advantages with regard to modularity, reusability and extensibility.

Service-Oriented Cross-layer Infrastructure for Distributed Smart Embedded devices (SOCRADES) (Cannata et al., 2008) is a Framework for developing intelligent systems in manufacturing and relies on European research project addressing SOA-based manufacturing paradigm. It's primary objective is to develop a design, execution and management platform for next-generation industrial automation systems, exploiting the SOA paradigm both at the device and at the application level. SOCRADES Framework uses a improved DPWS specification in order to perform a Web Service-based network architecture. This defines a set of built-in services that allow service orchestration, service management, semantic web services, and service gateway. At application level, SOCRADES allow a unified enterprise integration via a cross-layered web service infrastructure (Karnouskos et al., 2007).

3.4 Energy Management and Automation Functionalities

Some solutions focuses on energy management and building automation functionalities to provide best comfort while ensuring efficient energy consumption. This aspect is the most important functional requirement in a BEMS.

PoliSave (Chiaraviglio et al., 2010) is a software designed to reduce power consumption in computer networks. It manages the scheduling of power on and off of building computers in order to save energy. The process is carried out via a graphical web-application interface. A similar solution is what we aim to develop in this project regarding the computers, displays and datashows present in the building.

MEDUSA (Davidyuk et al., 2009) is a middleware based on Activity-oriented computing (AOC) paradigm. This paradigm promotes run-time applications by composing ubiquitous systems based on abstract specifications of user activities. It is an interest-

ing approach if we think about the SB context when we define different possible scenarios to be achieved in terms of a lecturer wishes to give a class, an exam or do a presentation.

aWESoME is a Web Service Middleware for Ambient Intelligence environments (Stavropoulos et al., 2013). aWESoME aims to implement a large-scale building system, regarding energy consumption savings. The middleware is the middle layer that establishes the connection between the hardware layer and the various applications layer. The main goal of this solution is to fulfil functional and non-functional requirements of the system and to ensure universal, homogeneous access to the system's services.

Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) (Osello et al., 2013) is an European project that aims exploiting ICT monitoring and control services to reduce energy usage and CO_2 footprint in existing buildings. This approach focuses on easily integration of existing BMS with new sensors and actuator networks. The main goals of this project are: a integrated Building Automation and Control System (BACS); a middleware for energy-efficient buildings domain; and a multi-dimensional building information modelling-based visualization. SEEMPubS layered architecture are composed by three layers: LinkSmart Proxy Layer, SEEMPubS Middleware Layer, and SEEMPubS Application Layer. This solution lacks in providing application-level services to BEMS.

3.5 Discussion

Previous section was addressed several technologies that focus on trying to solve different domain issues, such as automation field-bus heterogeneity abstraction, BA services exposition, BAS technology independent integration, and energy management and automation functionalities providing.

3.5.1 Non-Functional Requirements

Most solutions are supported by SOA, thus providing greater extensibility and interoperability with other technologies in an easier way. Systems that stand out for a higher extensibility and interoperability are: OPC UA, HomeSOA, LinkSmart, SOCRADES, aWESoMe and SEEMPubS. These solutions solve some issues of the problem, because they can help development of BEMS supporting BA technology integration and abstraction. As they are based on SOA it is possible to implement EM and BA functional application-level services over this systems, using a modular service composition, being that the focus of our architecture. The aWESoME and SEEMPubS middleware are the most similar approaches regarding the architecture objectives, as it integrates different layers: hardware, services, integration between services and devices layer in order to achieve their interoperability, and application layer to provide the users of the system a form to manage the devices and the energy consumption of the building rooms within a user-friendly interface.

3.5.2 Functional Requirements

Despite all solutions support BA and EM functionality, majority have a lack support of BEMS functionality, which causes a need to implement a new system with all the standard features. Application-level services providing is an important feature, that enables extension and development of BAS applications easily. No solution fulfils all the characteristics surveyed. However, they all complement each other, increasingly motivating the creation of a new reference architecture. One aspect that lacks enough, are the system ability to provide BA and EM application-level services in order to help the developers to build easily and quickly BEMS sophisticated applications.

4 ARCHITECTURE BLUEPRINT

The main goal is to develop a new middleware architecture in order do overcome the identified issues, such as interoperability and extensibility of BEMS. It is presented a middleware architecture vision and its software layers, and a collection of different services that the middleware must provide and also is presented and described what is the purpose of each service collection.

To achieve the middleware goals, existing building automation and energy management software standards must be refactored into a modular architecture. OSGi framework can be used to implement such architecture, since it has mechanisms that promote modularity and also can afford all requirements of BEMS. The first step to modularize the application, is to identify its essential structure. This will help to understand the dependencies and identify interactions. From there its possible to define the building blocks that constitute the middleware. Finally, with a fully modular and functional middleware it's possible to implement a sophisticated BEMS fully based on SOA, being also highly functional and extensible system.

4.1 Architecture Overview

This section proposes an architecture for the service layer middleware, aiming at flexibility and scalability, enabling easy development of new applications in a modular way.

As opposed to other solutions, this architecture is based on the BA and EM standards (International Standard, 2007; European Standard, 2006), regarding also to the latter paradigms of software architectures. This platform will centralize all the building's control functions, in order to reduce the installation, commissioning, maintenance and hardware costs. The proposed layered architecture is composed by several extensible blocks with well-defined interfaces that abstract it's implementations. The implementation of each block can be a software module or even can be in other proprietary software solution module.

This novel architecture will be very useful, to the extent that at the end we will take advantage of several benefits:

- *Abstraction* - modular service components will allow multiple levels of abstraction;
- *Fast prototyping* - creation and utilization of existing services;
- *Heterogeneity handling* - services will enable integration of devices diversity;
- *IT integration* - will be possible to create services that integrate automation systems with the IT systems present in the building;
- *Lower operational and maintenance costs* - there is no more maintenance dependence with suppliers and manufacturers of equipment and systems.

As depicted in Figure 2, this architecture is able to manage and interoperate with several fieldbus technologies and their devices, thus solving the problem of heterogeneity. The system also implements energy management and intelligent control functionalities on service layer middleware instead on expensive hardware controllers. High-level services, will provide all the necessary functionality to the fast development of BEMS applications. The various services presented are divided into four layers, corresponding to different types of features. Each layer is a different level of abstraction, where the lower layer offers services to upper layer, which simultaneously uses the services of layer below. Service Bus, will enable interoperability between service layers, promoting communication between service providers and service consumers.

4.2 Service Collections

In Figure 3 are shown the set of services that will provide sophisticated functionality to Applications layer. The services were divided into multiple logical levels, the service collections, taking into account the type of BA and EM functionality and the energy-efficient control techniques according to standards (International Standard, 2007; European Standard, 2006).

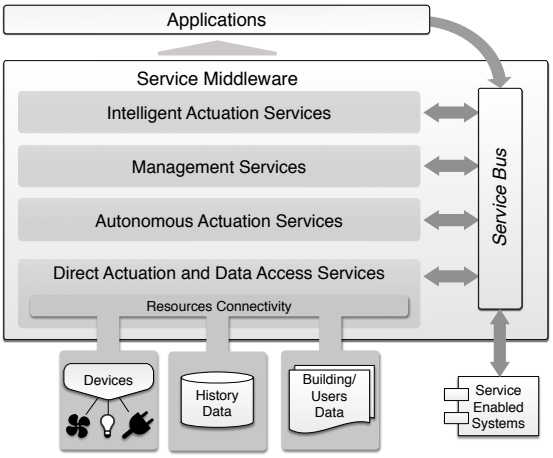


Figure 2: Proposed Service Architecture. The Middleware consists of several service modules which deal and abstract the specifications of each different BAS technology and provide functional services for high-level applications, starting from the field level, then building automation, energy management, and intelligent control.

The *Direct Actuation and Data Access Services Collection* intends to deal with BAS devices communication and it's abstraction. It is also responsible for the devices history data storage, data querying functions, and data fusion and analytics techniques. The *Autonomous Actuation Services Collection* aims to provide some basic functionality actually present in BAS, such as alarms, events, scheduling and scenarios. The *Management Services Collection* aims to achieve a better way to manage the building and the BEMS functions, based on available data models of information. Finally, *Intelligent Actuation Services Collection* provides energy-efficiency control techniques robustly, given the higher service abstraction. These techniques are occupancy-based control, daylight-harvesting, automated blinds control, Heating, Ventilation, and Air Conditioning system (HVAC) control, and some learning techniques in order to take into consideration the user's activities and behaviour.

5 ARCHITECTURE CASE STUDY

The addressed service layer middleware will be applied in a prototype implementation and it's integra-

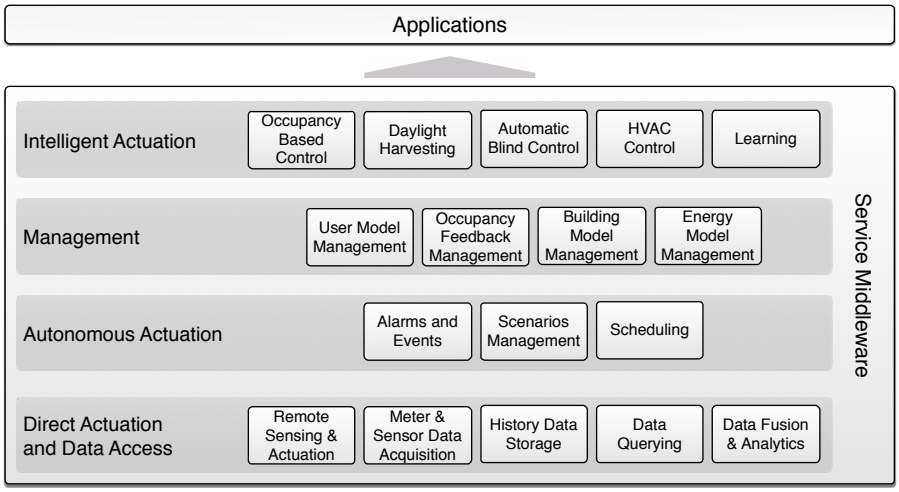


Figure 3: Service collections.

tion with existing BAS technologies already installed in IST building. Automation devices will be installed in office rooms, featuring a number of sensors and actuators, which will be used to implement software modules and services owned by developed middleware platform. This middleware will sustain intelligent automation and energy management applications that will drive the control of various electrical devices inside the office, such as heating, HVAC, and lighting.

In this study, we will not concern with whole functional requirements since they are intrinsic, i.e., the application must operate as any other BEMS solution and the automation devices and services must be fully functional and further developed in OSGi bundles. However, in order to validate the solution presented in this document, non-functional requirements must be validated. Next, we present some of the non-functional requirements that were identified:

- The development of new interfaces and software modules must be simple and not a time-consuming task (empirically measured).
- Deployment of new software modules must not stop the application and they must be available to use immediately.
- Middleware testability and debugging must be ensured.

The solution will be also evaluated according to the code reusability, level of coupling and the relative number of lines of code for the implementation.

There are several proven methods for evaluating an software architecture (Roy and Graham, 2008), such as early and late evaluation methods. Regarding early evaluation, a Scenario-based evaluation method must be applied in order to make sure that the architecture exactly meets all requirements before it's implementation. After architecture implementation, a Metrics-based later evaluation method must be applied in order to proof of compliance with the initial architecture requirements. Presented solutions in related work, were evaluated in similar ways, and we must also use some simulations in order to benchmark and evaluate the performance of final system.

In order to evaluate the user satisfaction, the prototype shall offer a Graphical User Interface (GUI) to the end-user from a handsome display available on the room wall. The display should provide a visualization of consumption curves related with office's HVAC and lighting systems, and even the access and modification of some user profile settings.

6 CONCLUSIONS

Developing software for Building Automation is not an easy task. With the proliferation of Building Automation System (BAS) became almost impossible to integrate several different systems made by different manufacturers. In the document we made a review of existing Building Energy Management System (BEMS) technologies and their main functions. We discovered some lacks in existing systems and we found that the best solution to this problem was to provide a modular layered middleware architecture in order to enable the ability to integrate and extend new Building Automation (BA) and Energy Management (EM) functionality easily. Thus we defined a set of services collections that we believe to be common in all building automation domains, according to existent standards. With this study, we expect to ascertain the best way to define a software architecture for BEMS, in order to the development of their function-

alities is made easier. Chosen technology for the prototype development was OSGi since it provides mechanisms that enforce modular design.

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Analysis and Requirements Gathering of User Interfaces for Home Automated Systems

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Abstract: As Home and Building Automation Systems become more widespread, the need for more natural forms of interaction also increases. However, many of these technologies are brittle and do not adapt to the user's explicit or implicit wishes. Indeed, variety of devices and functionalities required in a smart environment makes it difficult to integrate all controls together under a single UI, making it confusing, overwhelming and hard to operate. Moreover, there are no clear guidance when it comes to designing UI for Building and Home Automation Systems. This document analyses existing User Interfaces for Home Automation Systems to uncover their fundamental aspects of interaction. An action plan will be defined in order to develop the ideal UI. In this plan, studies of previous attempts to improve BAS Interfaces will also be presented.

1 INTRODUCTION

Automation Systems have managed to expand their features to mostly all devices and gadgets. Nowadays, turning a light on, increasing the TV volume or even heating the oven can be accomplished with a single application. As a consequence, more controls are necessary to command each desired feature. Physical interfaces are cluttered, displaying a lack of usability and adaptability. With the increasing ubiquity of interactive computer systems, usability becomes increasingly an important issue. Minor usability problems can scale to having major economic and social consequences (Mayhew, 1999). Whereas in terms of functional requirements systems have been showing evolution (Ghanam et al., 2009), we must give importance to the various aspects of interaction between the user and the application.

Interfaces for Home Automation have tried to focus on responsive behaviour in order to make them more appealing. Human-Machine Interaction is an interdisciplinary area of applied research and design practice. Its key concern is to understand the creation of User Interfaces for machines as experienced and manipulated by human users. It draws many established areas of science and craft: psychology, computer science, anthropology, industrial design (Carroll, 1991).

This document will address the most frequent problems related to Home Automation Systems (HAS) Users Interface, such as Hysteresis, Manual Override, notion of Progress, Completion and much more. In the end, a design proposal will be provided. A description of the procedure that will be used in the creation of a new User Interface (UI) focused on HAS as well as the evaluation method to confirm it's effectiveness.

1.1 Goals

The goal of this paper is to resolve some existing problems related to usability, user friendliness and feature management of Home Automated Systems and build the most complete User Interface.

To implement our idea we have to identify functional requirements (all the features a house has to offer), non-functional requirements (Usability, Accessibility, Portability, etc.) , all the possible modalities (all the devices it can be implemented) and the UI patterns we can apply.

For house features purposes we will split into the following categories: White Goods (everything that has to do with electronic Equipment), Illumination, HVAC, Environmental (analysing external factors that can influence, for example, illumination inside the house) and Security. One of the problems we

will face is how to build a single User Interface for all those categories and still make it user friendly.

1.2 Problem Definition

Home automation and controls provide advanced functionality to homes using distributed control systems. Demand for energy efficient solutions, enhanced security, increased venture capital funding, and greater convenience are some of the factors that have led to the growth of the home automation and controls market. The market is, currently, at the high growth stage of the industry life cycle, and is expected to remain in this phase till 2018.

The majority of existing Home and Building Automation Systems focus on functionality gathering, house features, integrating with external systems or even improving response time. Even though they are significant points, they conceal other requirements that also are of major importance to the proper functioning of systems and acceptance from users.

With this work we propose to resolve the following issues: notion of progress and completion (real-time feedback), Hysteresis and Manual Override. Giving the user a accurate progression state during the course of a requested action allows him to have a real-time knowledge of the state of his request. The same goes to the notion of completion. Solving this problem has a great impact on Home and Building Automation Systems (HBAS) since they can make use of this solution to any kind of request.

Hysterisis is the dependence of a system not only on it's current environment but also on it's past one. Regarding BHAS, we can identify Hysteresis problems when a user wants to perform an action that contradicts a previous one. Solving this problem, we would be not only conserving the system itself but also the physical hardware that could be affected by it.

Manual Override is an action where the control is taken from an automated system and given to the user. The conflict resides in what the system should do, either gives full responsibility to the user, allowing him to fully override any scheduled event or refuses to cede control, making the user less empowered.

Although there are several other issues to be identified, we believe that solving at least these three would show great improvements for Home Automation Systems.

2 CONCEPTS

User Interface is the visual part of computer application through which a user interacts with a software. It determines how commands are given to the computer or the program and how information is displayed on the screen. However, the field that studies how UI's should be designed is much wider than it's definition. In this section we will introduce the concept of Smart homes and Human-Machine Interaction. Both of them will be related with UI designs referencing Ten Usability Heuristics.

2.1 Smart Homes

Smart homes go by several names, including Integrated Control Systems (ICS) and Home Automation Systems (HAS). By any name, these systems are used to control devices around the home. Home electronics and appliances including doors, lights, surveillance systems and consumer electronics are some examples (Humphries et al., 1997). Control Systems can also provide information, meaning, users can find out how much electricity they have used on specific appliances and utilities can read meters remotely (Han et al., 2010). An important goal of smart home research becomes how to appropriately expand system capabilities to produce more control both perceived and actual (Davidoff et al., 2006). To provide mobility, usually, users are able to control with a smart-phone or tablet. However, these systems lack user friendliness and are neither intuitive nor realistic (Wimsatt et al., 2006).

Domestic technologies have been adopted at different rates throughout the years. To better understand the direction smart home technologies are taking and what programmers and scientist believe is the next evolution for HAS (Harper, 2003), it is important that we distinguish the concepts of *time-saving* goods and *time-using* goods (Bowden and Offer, 1994). The first ones are meant to reduce the time needed to complete a task, in order to have more time for yourself. Vacuum cleaners, washing and drying machines are some examples. The majority of these goods took decades to diffuse and all of them are clearly related to household income. As for time-using goods are those which occupy free time and improve its quality by giving the user more to entertain. Television, radio and video are the most common and well-known time-using goods for most people. Unlike time-saving goods, these have spread quickly and showed much less relationship to household income.

The relation between these two goods rely on the time they occupy. The more people spend time using

goods like television or radio, the less they have to complete house tasks. This can be considered the motivation needed to start thinking about smart homes.

2.2 Human-Machine Interaction

Human-Machine Interaction (HMI) is described as the interaction between human users and machines. The abbreviation HMI should be considerably extended to cover the ergonomics challenges presented by the contemporary, highly complex and dynamic human-machine systems. The notion remains a key point with its properties of friendliness, usability, transparency, etc. However, cognitive ergonomics has developed a large number of studies on human automation relationship failures, which concern what is behind the interface (Baecker and Buxton, 1987).

The degree of automation in control of dynamic systems has substantially been increased over the last decades. This is true for all technical systems. High levels of safety, performance and efficiency have been achieved by means of the raise use of automatic control. The need for improved Human-Machine Interaction (HMI) spread proportionally to the degree of automation. Generally, increased automation does not replace human users who are interacting with the machine, but shifts the location of the interface between both. Higher complexity and more sophisticated control structures require a new quality of communication and co-operation between human and machine. From the front line humans operator point of view, machines are not only tools but also possibly autonomous agents and some coherence must be maintained between humans and machines actions on the environment, regardless the interface (Johannsen,).

2.2.1 Usability Heuristics

We can analyse UI's through analysis techniques, computerized procedures, empirical methods and *heuristic methods* (Nielsen, 1994; Nielsen and Molich, 1990). The last one consists in presenting an UI to a number of people that are asked to evaluate a set of usability principles. The original set of heuristics used for several early studies was developed with the main goal of making the method easy to teach (Nielsen and Molich, 1989). In order to normalize the evaluation set of usability principles, Jakob Nielsen defined what is considered to be the Bible of Usability Evaluation:

Visibility of System Status, meaning, the system should always keep users informed about what is going on, through appropriate feedback within reasonable time;

Real-world Conventions should be followed, making information appear in a natural and logical order (words and phrases);

Supporting Undo and Redo is necessary in case users choose system functions by mistake and need to leave the unwanted state without having to go through an extended dialogue;

Consistency and Standards prevent users from wondering whether different words, situations, or actions mean the same thing;

Eliminating Error-prone conditions or showing confirmation boxes before users take an action will help make it clearer;

Minimize the user's Memory Load by making objects, actions, and options visible. Instructions for use of the system should be visible or easily retrievable whenever appropriate;

Flexibility and Efficiency of Use for more experienced users, the system should allow them to speed up the interaction so they can execute the desired task;

Stick with what Really Matters . Dialogue boxes should not contain irrelevant information. Overflow of information might confuse the user and will eventually hide the focus point;

Help users Recognize, Diagnose, and Recover from Errors. Error messages should be expressed in plain language, precisely indicating the problem, and constructively suggesting a solution;

Provide Help and Documentation even though it is better if the system can be used without it. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

2.3 Fundamental Aspects of Interaction with HAS

2.3.1 Feedback Issues

Feedback is the process part of a chain cause-and-effect. Wondering what a software program is doing is a common way to confirm that UI lacks clear information. Feedback principles in a UI needs to be immediate and synchronized with user action. As for Home and Building Automation Systems (HBAS) there are a specific set of responses an UI should give to their users.

Hysterisis is the dependence of a system not only on it's current environment but also on it's past one. This dependence is due to conflicts on internal states.

To avoid conflicts, it's history must be known (Visintin, 1994). We can identify this problem every time a user requests a functionality that is exactly the opposite of the previous one in a short amount of time. Opening and closing blinds and turning the heater on and off are some examples of such problem. To an HBAS it is relevant to determine whether the application should not allow the user to complete his task or simply showing a warning message to acknowledge the user that his request might cause conflicts.

Other kinds of feedback issues come from Progress and Completion of tasks. For the first one we can show the user an accurate progression of the requested action by measuring the average time to complete the activity (Best Effort). Once the average time has passed, a message is shown to the user, confirming the completion of the task. This approach may lead the user in error since we cannot be certain the task is already completed. The second option is to give the Feedback Bus the responsibility of sending and acknowledge (ACK) signal to confirm when the task is completed. The last choice and the most common one, is using a motion sensor in order to get physical feedback. This approach can cause issues if an object is preventing the motion sensor to read correctly.

Manual Override is an action where the control is taken from an automated system and given to the user. When building HBAS, the main goal is to give the user as less work as possible to perform tasks. However, the system should be prepared to deal with exceptions. On extreme cases, giving the machine full responsibility for automations of all features of the house can become an issue. If they follow rules installed by the manufacturer or required by law and refuse to cede control in some situations then the owners of the devices may feel less empowered, alienated and lacking true ownership.

The last two feedback issues are related to Conditions and Energetic Behaviour. The first one is an issue frequently related to temperature. Considering a scenario where an user is using an application connected to all devices in the house, including HVAC, and pretends to turn the heater on. As the temperature rises, the system should be able to control it so it doesn't get uncomfortable to the user (too hot or too cold). Energetic Behaviour relates to how the user deals with his house. The UI should be capable of changing users behaviour in order to save electricity and water.

2.3.2 Control Abstractions

There are many ways users can interact with the system. Each of them can have different results and raise distinct issues. Control abstractions can be distinguish between Spatial, Equipment and Services. For each one of them a different UI should be presented since they possess distinct features.

Spacial requests are what we call Scenarios. They allow the user to change multiple features at the same time in order to create the environment he wishes. Taking an everyday situation such as a user wanting to watch a film, there should be a scenario that is able to dim the living room lights, turns on the tv, turns off any other light and starts the film. Spacial requests involves the whole house and all its features. To represent this control in an UI, besides showing the possible scenarios, the layout should contain the details of each of them.

Controlling Equipments allows the user to make system requests targeted to a specific equipment. The action to be applied to the equipment does not have to be detailed. Requests like dimming all the lights to twenty percent are considered equipment requests.

Requesting for a service is the same as saying that the user wants a specific task to be performed. For example, turning on the lights. These types of services are what make the UI vast and showing too many of these can make the UI less User Friendly and very confusing. It is important that we organise all features with categories so the user finds it easier to request a specific service.

3 RELATED WORK

In this section we will address theoretical studies related to HAS characteristics and their User Interfaces. Firstly we will present the notion of portable systems and remote access. Then we will show some systems capable of controlling various house features with only one UI and in the same section we will discuss customisable UI's.

3.1 Portability and Remote Access

Regarding HAS in relation to portability, typical user interfaces for controlling home systems include computer displays with touch screens, dedicated display devices such as LCD panels with buttons or a touch screen or hand-held remote controllers. All of these examples are devices which are dedicated for control only. The users require extra space and incur extra expenses for them. In some cases, these display devices are installed into walls. In these cases, special installation work is necessary and it becomes very difficult to modify the devices and/or their location. In the case of hand-held remote controllers, the display capabilities are limited and the functions are typically

dedicated to specific purposes such as lighting control. Portability began to matter and attempts where made in order to overcome those drawbacks.

In 1996 a method for menu-driven UI, more particularly, for distributing menus throughout a home, was presented (Fujita and Lam, 1996). In order to make the software portable, functions could be implemented using a personal computers, infra-red, remote controls, home distributed networks and television receivers. This invention was advantageous in a way that menus could be distributed to any place in a home, users could control the home system and outside services from any display location in the home and different menus could be distributed at the same time to distinct display locations.

In 2005, a mobile-based HAS solution was introduced (Van Der Werff et al., 2005). The design consisted on a mobile phone with Java applications, a cellular modem, and a micro-controller. User friendly graphical UI was provided on the mobile phone through applications developed in Java programming language. The controller board resided at home and worked as a home server, which carried out the task of operating and monitoring house appliances. The home server communicated with the remote control via cellular modem.

More recently, a ZigBee-Based Home Automation System was proposed (Gill et al., 2009). ZigBee is a specification for a set of communication protocols used to build personal area networks built from series of small, low powered digital radios (Alliance, 2006). It is based on an IEEE 802.15 standard. ZigBee devices often transmit data over longer distances by passing data through intermediate devices to reach more distant ones, creating a network with no centralized control or high-power transmitter/receiver able to reach all of the networked devices. The decentralized nature of such wireless *ad hoc* networks make them suitable for applications where a central node can't be relied upon.

Another key feature for HAS is the capability for *remote operation*. Considerable efforts have been put into the development of remote control systems for home automation. With the proliferation of Internet, various Internet-based remote control architectures for home automation have been proposed (Al-Ali and Al-Rousan, 2004; Corcoran and Desbonnet, 1997). These systems rely on the Internet as the medium for communication and generally feature friendly graphical user interfaces. Home gateways provide network interoperability, a simple and flexible user interface, and remote access to the system.

3.2 All in One and UI Customisation

Home Automated Systems have been making an effort to control all house features. The standard approach now commonly used is for each device or system in a given environment to be controlled according to a particular methodology which might differ dramatically from other systems (Stein et al., 2000). For example, a home might include a security system, an entertainment system, an environmental control system, and so forth, each with it's own unique interface. By requiring the user to learn several methods of operating each system or set of devices in the environment, it is more difficult for the user to become familiar with the various systems and to take full advantage of all their features. Another drawback associated with this standard approach is that the use of different interfaces may result in an increase in the amount of space taken up in the setting. More and more users want a single application capable of controlling Illumination, HVAC and white goods.

Liu and Xian approached this problem particularly for disabled people (Liu and Xian, 2007). The system was build so as to merge all house features. To enhance the experience, a voice controlled, User Friendly UI was carefully designed, so that user could use not only standard keyboard and mouse, but also the voice to control home environments including lights, TV, radio, VCD/DVD player, fan, and air conditioner. Furthermore, the self-designed software applied home automation control idea to internet access and PC application software access with the features of surfing the internet, sending and receiving emails, using other PC software such as Microsoft Office.

A report by William Wimsatt went further and in addition to gathering features, developed a contextual UI (Wimsatt et al., 2006). Contextual Interface is a product of a design process in which the various interface features are selected to improve the users ability to operate the interface. Examples of interface features that can be controlled include the selection of controls, size, shape and position, background and foreground colour schemes, sounds, as well as the selection of actions that are initiated by operating a control. In most graphical user interfaces these items remain static so that irrespective of the context, a control such as a *start* button, remains in the same place on a display with the same appearance and performs the same function. This invention involved two levels of contextual relevance.

First, the user interface as a whole is contextually sensitive to the elements appearance (e.g., colour, size, font, etc.) and their behaviour vary depending on the context of the control unit (CU). The context of

Table 1: Systems Comparison. Each column represents the dimensions analysed while the lines represent the systems/works mentioned on the previous sections.

	Portability	Remote Access	All-in-One	Custom UI
Menu Driven UI	+	--	+/-	--
Mobile-based HAS	+	+/-	+	--
Zig-Bee	+	+	+	--
HAS for Disabled	+	--	+	--
HAS Contextual UI	--	+	+	+

the CU is represented by state information known to it, including context-specific and global information known to a single or multiple CU's in a system.

And second, individual elements are themselves made contextually sensitive. In a particular implementation, contextual sensitive interface elements include interactive screen elements such that a single screen element can simultaneously display information about the context (e.g., current temperature, sound volume, light level, etc.) as well as implementing behaviour to send messages to a controlled system that can affect the displayed information (e.g., a thermostat, an entertainment system, or a lighting subsystem).

3.3 Discussion

In order to identify the common issues and strengths of each work described during this section, a comparison was made. Table 1 shows the results of the analysis based on the details of each work. To facilitate the comparison, a convention of symbols with different meanings were defined:

"+" the system fully supports the feature to be evaluated;

"+/-" the system partially supports the evaluated feature;

"–" either the system does not support the feature that is being tested or the work does not present any information regarding the evaluated dimension.

Examining the table we can see that each dimension has different results. Regarding portability, we can verify that all of them, excluding the work of William Wimsatt (Wimsatt et al., 2006) (which doesn't present any information related to this dimension), are portable. The systems were built in a way that allows users to access it in different devices. Some of them use infra-red, remote controls and home distributed networks to accomplish this feature. In contrast, almost none of them are customisable.

UI Customisation is the common issue among most systems. When building User Interfaces, systems tend to create fixed layouts that they believe to be ideal, usability wise. To surpass this problem, Contextual User Interfaces was used (Wimsatt et al., 2006). Contextual Interface is a product of a design process in which the various interface features are selected to improve the users ability to operate the interface. Examples of interface features that can be controlled include the selection of controls, size, shape and position, background and foreground colour schemes, sounds, as well as the selection of actions that are initiated by operating a control.

Forcing a user to have a system that controls irrigation, another that controls water and another for illumination nowadays is not viable. Companies understood this problem and made an effort to join all those systems into one, requiring the user to adapt a single UI. According to table 1 we can see that all of them took this problem into account and gather all the functionalities.

The last analysed feature was the remote access. In the last few years, companies have been trying to make their software as accessible as possible, using the network as an asset. According to the table, results vary from work to work.

4 EVALUATION OF EXISTING SYSTEMS

HAS has been growing exponentially in the last years. The proof relies in the various Automation Systems available in the market. The last few years there's been an increase of requests to implement Integrated Control Systems (or Smart homes) and at the same time, an increase of companies capable of providing and supporting those systems. In order to evaluate existing systems we've decided to choose six HAS that stood out among the others: mControl, HomeSeer, Control4, PowerHome2, Vivint and ActiveHomePro.

4.1 Evaluation Method

In order to fairly evaluate the systems we there was a need to define a set of points (or dimensions) of evaluation, each of them containing a set of specific features. For every dimension of evaluation, a system can get minimum score of 0 or a maximum of 5. We decided to also include an "Observations" criteria, that allows the system to gain or loose 0.5 points. If we find features that we did not take into account in our evaluation but are worth mentioning, whether it's good, bad or some detail, it will be considered.

4.1.1 System Features

This evaluation point will take into account house features that the system allows you to control. For evaluation purposes, we consider that are four essential features:

Lighting and illumination of the whole house. The system should also give the possibility to control brightness;

Heating, Ventilation and Air Conditioning(HVAC) The software should be able to control home's heating and cooling system as well as give information about current state;

Motion Sensors allows the system to detect movement or monitor occupancy status throughout the house. This feature, combined with any other, can be very helpful to support other functionalities;

White Goods or whiteware, relates to heavy consumer durables such as air conditioners, refrigerators, stoves, etc., which used to be painted only in white. Despite their availability in varied colours now, they are still called white goods;

4.1.2 User adaptability

The UI has to be clever enough to adapt users demands. In this point, for the software to get the maximum score it has to able to schedule events (timed events) so the user has the ability to prepare everything with no worries. It has to have scenarios. A scenario is a feature that allows the user to control the space around him (Spatial Control Abstraction). They trigger multiple events at the same time with a single button.

The last two points of evaluation are UI Customisation and Session-based application. The first one concerns the UI's ability to be modified. Letting the user customise the main panel, enabling a favourites section/tab are two features to be taken into account. As for the second one, it is related to the capacity of the system to distinguish between different users inside the same house. If each user has it's own username and password the system would be able to collect different types of data, identifying the person that has spent most water and/or energy in the house or even be able to give suggestions based on what it has learned.

4.1.3 Ease of Use, Help and Documentation

Concerning the Ease of Use of an application, we rated each product on its ability to produce an intuitive user interface based on its Commands Organization. If the application uses tabs, buttons with intuitive icons, colour scheme to facilitate the differentiation between functionalities and so on. Overcomplicated processes and clunky interfaces caused systems to rank lower in this category. Another point is the Remote Access. Nowadays it is crucial that the user is able to access the application from anywhere in the world. The most usual devices that should give access are desktop computers, laptops and smartphones. The last point to be evaluated is Voice Recognition. The user shouldn't be obligated to carry his device around the house. Once he is inside he wants to communicate with it in order to satisfy his/her needs. Voice recognition allows that to happen and shows to be an extremely valuable point for this evaluation.

As for Help and Documentation, we ranked each system on the customer service options that it provided, including tutorials, user manuals, online documentation and phone support. Less common features like a live chat option and user forums can also be included.

4.2 Systems Evaluation

4.2.1 mControl v3

mControl was build thinking of all the devices a house can possibly have. This product can control Lighting, HVAC, security systems, IP cameras, irrigation systems, A/V systems, window shades and much more.

This software allows the users to choose from preset scenarios that can trigger multiple functionalities at the same time. Some of them can be automatically initiated if certain conditions are met (Sunset/sunrise events or even timers). Alternatively, you can program your own scenarios.

There isn't, however, any way to customise the UI itself, meaning, buttons layout, main menu preferences. Another flaw of mControl is that it cannot be session oriented (login/logout) and that does not allow us to know for sure who is spending what and at what rate. For example: if the software alerts the user that this week there was an increase of 30 percent on electricity there is no way to know who is accountable for that, making it hard to control or reduce that percentage.

The interface is clean and intuitive: they mostly use tabs to organise commands and abilities. There are already a pre-set role of scenarios that the user can use. These scenarios can be activated through voice recognition functions. The remote access is very useful and a big advantage because it allows the user to access the local panel by using a pc, laptop, a touchscreen device with internet connection, smartphones

or browsers.

mControl is sold in modules. There is a mandatory Base Module that can be extended with Energy Management, Media Control and Professional Modules. Besides providing mobile application to access this software, mControl also is iTunes and Windows Media Center compatible. That means that you can program to turn on your tv or make it part of a scenario.

Help and Documentation is the Achilles tendon of this system. They do not offer interactive tutorials, nor phone support. Besides the user manual, mControl offers email support, online forums and FAQs and live chat option with customer service.

4.2.2 HomeSeer

HomeSeer includes all the features we were looking for and many more. It has a set of scenarios that you can customise and trigger either manually or automatically. You can even include the motion sensors in your scenarios. For example, when you pull your car out of the garage, all the lights turn off and the alarm system is activated.

Just like mControl, HomeSeer also does not allow the user to customise the UI and is not session-based. This system is known for their emphasis on ease of use. In this case, the software separates different functionalities using tabs and colour schemes, making it easier to find features. It also has voice recognition commands, as long as you implement a specific microphone throughout the house and supports remote operations.

The HomeSeer system is compatible with an enormous variety of popular and niche programs. It supports all of the major media management applications, like iTunes, Windows Media Player and Windows Media Center.

As for Help and Documentation, it offers everything we analysed and more. They have a tutorial that you can access easily through their website and a FAQ section. They also give phone support.

4.2.3 Control 4

Like the previous systems, it meets all the requirements of house features we were looking for. It has Audio and Visual control systems to complement. The big contrast between Control 4 and the previous systems is the lack of compatibility with other programs.

Control4 allows to schedule events and create custom scenarios with complex triggers (involving various functionalities from different tabs). Drawbacks: lacks compatibility with other programs, it is not customisable (in terms of UI) and is not session-based.

This system is the first one of our analyses that does not meet all requirements we established for Ease of Use. The command organization is made mostly through colour schemes and their remote access allows you to control the system any part of the world. However, it does not support voice recognition.

Help and Documentation is very poor. It only has User Manual and a FAQ section on their website to help customers in trouble. Does not have telephone, email or live chat support, making this system the worst between all the analysed ones for this dimension.

4.2.4 Power Home

The first one that does not meet all the basic requirements of our system features analysis, PowerHome is still able to cover the following house features: Lighting, Motion Sensors and most of the White Goods.

PowerHome allows the basic of scheduling events and has a pre-set number of scenarios that cover most of the user needs. It also does not allow the user to customize his UI and is not session-based.

The UI it seems to be confusing. They do not separate clearly all the features they provide nor use any kind of understandable scheme to ease the use of the application. It is not User Friendly, it is actually overwhelming and cluttered. The system offers limited support for external modules, and it doesn't have mobile applications. It offers a comparable user experience to HomeSeer, providing a clean and easily understandable interface.

When it comes to help and documentation they do not have tutorials or phone support, however they have a live chat option, user manual and a forum that can respond to almost every doubt you might have.

4.2.5 Vivint

The most impressive part of Vivints home automation system is its integration with their security systems. The Go!Control panel that comes with every Vivint system serves as the central hub for all activity, including announcements of time-based triggers and device activations. You are given more control over your devices through their online control panel. In the web-based application, you can create and modify time-based and scripted triggers for all of your devices.

Vivint is the only one of our analysis that offers something similar to session-based software. As

mentioned before, the point of working with a login/logout system is for the system to acknowledge who did what and provide ways to control the consumption and every kind of expenses of the house. It allows each user to have distinct codes when using the software. With this we have a way to know who spend what and when. The disadvantages of the product are the inability to offer Software Integration and not allowing UI Customization.

It has a very good command organization, using tabs and explicit icons to clearly distinguish between all the features it can provide. The system also provides mobile applications on several platforms that you can use to control your devices from any location with an internet connection, though you cannot create or modify triggers or events from the mobile application. Vivint does not offer voice recognition commands.

In Help and Documentation point, this software is above average. Although it doesn't offer tutorials, besides user manual, FAQ section and phone support, it allows you to clear your doubts or issues through email (email support).

4.2.6 ActiveHome Pro

This system is the product of the home automation manufacturer X10s. Despite the extensive know-how backing the product it presents great lack of compatibility with other programs and devices. When it comes to house features it only includes Lighting and White Goods. There are no motion sensors or HVAC control, making the triggers and scenarios very limited.

ActiveHome Pro includes timed triggers and generic event triggers, like sunrise/sunset events. It is also possible to use events to create scenarios, as with other products. The system does not offer voice recognition or remote access. This lack of remote access is one of the more confusing things about ActiveHome Pro. All scenarios, triggers, programming and management must take place at the console or computer that you set it up on. This drawback significantly damages the usability of the product, limiting to a very narrow set of potential uses.

As for Help and Documentation, it brings every option to the table from email support to a FAQs section to user forums. They offer a vast selection of customer support options.

4.3 Results and Discussion

After the previous analysis it is clear that most of the systems include, either in modules or as a whole package, all the house features we were looking for. We need to take this information into account since our solution will be based on what most system possess.

Table 2: Overall systems comparison. Horizontally, an individual score is presented, according to each dimension of evaluation. the last cell of each line represent the total score of each system. Vertically, the last cell represent the sum of all the points acquired in a specific dimension. Darker cell represents the best dimension and system. Grey cell represent the system and dimension with the lowest total score.

	Points of Evaluation				
Products	System Features	User Adapatability	Ease of Use	Help and Documentation	
mControl	5	3,5	4,5	3,5	16,5
HomeSeer	5	3,5	5	5	18,5
Control 4	5	3	4	2	14
PowerHome	4	2,5	2	4	12,5
Vivint	5	3,5	4	4	16,5
ActivateHome Pro	2	2	1,5	5	10,5
	26	18	21	23,5	

According to table 2, the low scores presented on user adaptability are due to the lack of flexibility regarding UI customization. None of the presented systems offers that option to the customer. Users should be able to customise as they see fit, in order to get to the functionalities they use the most the fastest way. The other reason making this point with an average score is the fact of not being session-based applications. Most of the systems allow the user to access the software remotely. However not all allow voice commands. Tabs seem to be the preferred way to organise functionalities.

Finally, the last point analysed, help and support, showed to be a bit controversial. There are some systems with low scores on system features, user adaptability and ease of use but offer great ways to solve problems. The less the user uses help and documentation, the better he knows how to use the software. This doesn't mean we can ignore documentation or warning messages. We have to let the user know what he's doing in order to avoid making him search for the answers.

5 SOLUTION PROPOSAL

5.1 Action Steps

The research of this document, specially with respect to the conclusions drawn from our analysis of the related work, resulted in a set of requirements and assumptions in which the work is based. Some will still call for the opinion of our target users.

We know that the application is for domestic use, meaning, different age groups will interacting with it. Therefore, the UI should be User Friendly, look familiar to the user and easy to understand. The goal is to respect all the usability heuristics defined by Jakob Nielsen.

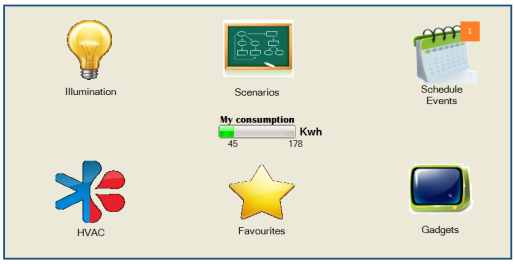


Figure 1: Main panel mockup. From top left: Illumination, Scenarios and Scheduled Events, HVAC, Favourites, Gadgets. In the middle of the screen there is a energy consumption bar where the user can see the amount of power watts spent in the house and the amount he contributed.

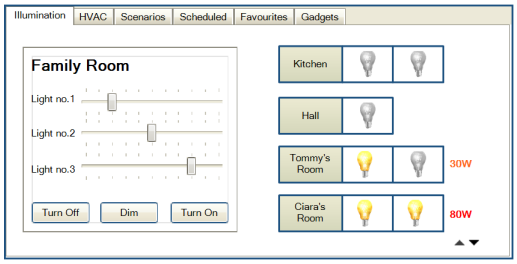


Figure 2: Illumination mockup. On top all the tabs representing main menu buttons. The left side shows all the Family Room lamps and their brightness. Below the three buttons, turn off, dim and turn on, are actions that can be taken only for that compartment. The right side shows all the other house divisions and the intensity of illumination (if any).

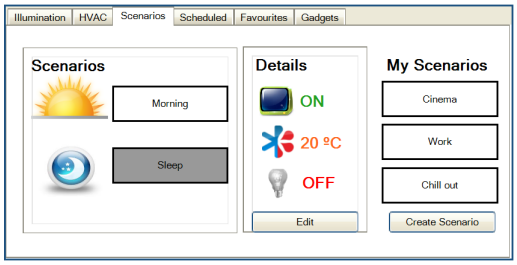


Figure 3: Scenario mockup. On top all the tabs representing main menu buttons. On the left side shows two default scenarios: morning and sleep (selected). In the middle are the specifications of the selected scenario. The right side shows all the custom scenarios created by the user.

Another aspect we have been pointing out is the need to differentiate each user within its own house. This means that, whatever other functional requirements it might have, it has to be **session-based**. Taking into account previous research, this can be achieve with simply making the users register in the system in order to be distinguished.

Other **functional Requirements** will be subject of evaluation: Features like illumination, HVAC and White Goods. The application should also allow users to choose from presets, edit and/or create scenarios. Scheduling events it is also important. Besides that, the application should be able to verify spacial occupation through motion sensors (either inside or outside the house) so it can help regulate Illumination or simply for security reasons.

5.2 User Interface Mockups

To study our solution proposal, we have developed mockups that sketch the final interface. Figures 1, 2 and 3 present three of them.

The first one (figure 1) shows the UI main panel, containing 6 buttons: Illumination, HVAC, Scenarios, Favourites, Schedule Events and Gadgets. In the middle there is what we call a consumption bar where the user can see how much electricity was spent in general (in this case 178Kwh) and, at the same time, how much that specific user spent (45Kwh). If the user scheduled any events, the main panel will present a numeric notification referring to the number of events scheduled that are due to start.

As for figure 2, shows the Illumination tab. This layout can be seen every time a user chooses the Illumination button. On the left side, the UI will present the number of available lights in the compartment the user is (it will be possible thanks to the motion sensors and occupancy verification), meaning, this UI will change according to the room you are in. Besides that, the application will show a status of all lights in the house, whether they are switched on or off and the total power watts of all the lamps.

Finally, 3 buttons will be available for quick action:

1. Turn Off - Turns off all the lights in the compartment the user is.
2. Dim - Dims the lights in order to adjust the brightness.
3. Turn On - Turns all the lights of the current compartment on.

At last, figure 3 represents the layout for the Scenarios button. The UI is clearly divided into three parts: the default scenarios, i.e., the ones already defined by the application itself and present no matter who's the user, details, representing the details of the chosen scenario. In this case we can see that the sleep scenario will turn off all gadgets, turn the Air conditioner to 20 degrees and turn off all the lights. Finally, the my Scenarios part shows the custom scenarios. This part may vary depending on what the user set up. It also allows the user to edit any scenario or create more.

5.3 Evaluation

To validate our solution proposal we have decided two ways to evaluate it: Target users feedback and evaluation metrics.

Target users can be divided in two types: the ones that already had experiences with other interfaces for Home Automated Systems and the ones that never had any kind of experience with this type of systems. The first ones are able to give feedback, comparing it with other systems. Not only they can point out design flaws, but they can also give advice based on ideas from other HAS. As for users that never used interfaces for HAS before, they can give a different perspective, usability wise. Since they do not have any terms for comparison, reviews are going to concentrate on the level of satisfaction and comfort our User Interface offers.

In the previous section of this document, an analysis of existing systems was made. The evaluation was based on the following dimensions: System features (Illumination, HVAC,etc.), user adaptability, ease of use and help and documentation. We are going to use these dimensions and compare the same systems that went through this evaluation.

With this two validations we are capable of validating our solution proposal not only with target users but also with systems that are well rated in the Home Automation market.

6 CONCLUSIONS

Feedback issues regarding User Interfaces for Home Automation Systems were presented. This paper aims to solve some of them, mainly: Hysteresis, Manual Override and Notion of progress and completion.

So far we have studied previous attempts to solve this problem, understood the dimension of it and conducted a study with existing HAS in the market and analysed the results regarding a set of evaluation methods defined by us. Furthermore we designed a set of mockups capable of simulating some of the feedback problems we aim to solve.

However, the proposed approach is yet to be evaluated in real life settings. We believe that the current mockups can be enhanced by a number of ways. For future work we intend to test the designed mockups in order to get users feedback.

We think that our effort in this project is a cornerstone that can inspire the building of more sophisticated and usable UI's for HAS in the near future.

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APOLLON
Using Living Lab Methodologies in the Cross-border Context for Energy Efficiency Pilots

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Keywords: Living Labs, Energy Efficiency, Cross-Border Collaboration, Smart Meter, Real Time Information, User Behaviour Transformation.

Abstract: The APOLLON Project (CIP–ICT–PSP No. 250516) has addressed the challenge of stimulating and measuring energy user behaviour transformation facilitated by ICT solutions to achieve an increase in energy efficiency. Cross-border pilots in four different countries were established and tested common methodologies and practices. The user-driven Living Lab methodology was implemented to achieve faster and more effective results.

1 INTRODUCTION

People's well-being, industrial competitiveness and the overall functioning of society are dependent on safe, secure, sustainable and affordable energy. The EU is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries (EC1, 2011).

Energy efficiency is at the heart of the EU's Europe 2020 Strategy for smart, sustainable and inclusive growth and of the transition to a resource efficient economy. Energy efficiency is one of the most cost effective ways to enhance security of energy supply, and to reduce emissions of greenhouse gases and other pollutants. In many ways, energy efficiency can be seen as Europe's biggest energy resource. This is why the Union has set itself a target for 2020 of saving 20% of its primary energy consumption compared to projections, and why this objective was identified in the Commission's Communication on Energy 2020 as a key step towards achieving our long-term energy and climate goals (EC2, 2011).

Substantial steps have been taken towards this objective – notably in the appliances and buildings markets. Nonetheless, recent Commission estimates suggest that the EU is on course to achieve only half of the 20% objective.

Improvements to the energy performance of devices used by consumers – such as appliances and smart meters – should play a greater role in monitoring and optimizing their energy consumption, allowing for possible cost savings and ensuring that consumer interests are properly taken into account in technical work on labelling, energy saving information, metering and the use of ICT. Consumers need clear, precise and up to date information on their energy consumption.

In future years the deployment of a European "smart grid" will bring about a step change in the scope for gathering and communicating information about energy supply and consumption. This information will allow consumers to save energy. Member States are obliged to roll out smart electricity meters for at least 80% of their final consumers by 2020 provided this is supported by a favourable national cost-benefit analysis.

Smart grids, meters and appliances will allow consumers to choose to permit their appliances to be activated at moments when off peak cheaper energy supply or abundant wind and solar power are available – in exchange for financial incentives. Finally, they will offer consumers the convenience and energy saving potential of turning appliances on and off remotely (Bergvall-Kåreborn et al.) (Holst, M et al., 2011).

2 OBJECTIVES

The work developed in APOLLON in the cross-border pilots targeted the challenges in terms of Energy Efficiency which the European Union is currently facing. It has been stated that to identify and address these key challenges, an ICT-based transformation of the energy sector is needed both in production and consumption. The Energy Efficiency pilots focused on the stimulation of behavioural changes. The aim was to do this by providing real-time updates on energy consumption through Smart meters. (EC3, 2011)

The four Living Labs involved in the experiment were:

- **Botnia Living Lab (Luleå, Sweden)**: Together with Luleå Energy AB, Botnia Living Lab invited 20 households to participate in the test and evaluation of two different visualization technologies aimed at energy saving. The first technology ELIQ focuses on electricity and price while the second technology SABER can measure and visualize consumption of district heating, electricity and hot water consumption.
- **Amsterdam Living Lab (Amsterdam, Netherlands)**: The purpose of the Geuzenveld pilot was to stimulate awareness among citizens and their energy consumption patterns, to make them aware of how to improve their behaviour and thereby to actually save energy. The residents were engaged on an individual and on a collective basis. Another important objective was to gain experience with respect to the implementation of smart meters and energy feedback displays. Over 500 smart meters have been rolled out in the Geuzenveld area. Sixty residents were also issued with a display that is connected to the smart meter.
- **Aalto Living Lab (Helsinki, Finland)**: Together with the building owner and superintendent some of the most vital energy consumption points were mapped out. The building was originally chosen as an energy saving living lab because of the owner's need to mitigate the energy consumption in all the like buildings and, as the chosen building is also the headquarter for Process Vision, it was easy to start testing the different measurement solutions as the immediate vicinity provided quick response times to the needed configurations for the meters themselves. The goal of the Living Lab was to test technical solutions on the metering side, but also, and more importantly, to see how energy savings can be achieved through smart metering and user involvement, in four different use groups at the pilot building.
- **Lisbon Residential Living Lab (Lisbon, Portugal)**: The Lisbon Residential LL is located in a residential block. The purpose of the LL is to implement energy efficiency measures in private households through behavioural change, to test the effect of using smart metering technology and remote management tool software in the reduction of energy consumption and to achieving viable and profitable solutions for energy management and communication.

3 METHODOLOGY

Viewing Living Labs as an environment, several different types of Living Lab environments can exists such as, *Research Living Labs* that might focus on performing research on different aspects of the innovation process, *Corporate Living Labs* that focus on having a physical place where they invite other stakeholder (e.g. users) to co-create innovations with them, *Organizational Living Labs* where members of an organization co-creatively develop innovations, and *Intermediary Living Labs* where independent partners are invited to collaboratively innovate at a neutral arena. Due to the constant development of the concept, other types of Living Labs certainly exist. (EC3, 2011)



Figure 1: Key Components of a Living Lab.

To be able to understand what a Living Lab is, there are some components it should have. The components for a research Living Lab are ICT and Infrastructure, Management, Partners and Users, Research and Approach (see Figure 1). (EC3, 2011)

The *ICT & Infrastructure* component outlines the role that new and existing ICT technology can play to facilitate new ways of cooperating and co-creating new innovations among stakeholders. *Management* represent the ownership, organization, and policy aspects of a Living Lab, a Living Lab can be managed by e.g. consultants, companies or researchers. The Living Lab *Partners & Users* bring their own specific wealth of knowledge and expertise to the collective, helping to achieve boundary spanning knowledge transfer. *Research* symbolizes the collective learning and reflection that take place in the Living Lab, and should result in contributions to both theory and practice. Technological research partners can also provide direct access to research that can benefit the outcome of a technological innovation. Finally, *Approach* stand for methods and techniques that emerge as best practice within the Living Labs environment. (EC3, 2011)

A Living Lab can also have a specific approach to innovation. This approach is built on five key principles. These are: Value, Sustainability, Influence, Realism and Openness and these should permeate all Living Lab operations. (EC3, 2011)

In more detail, the key principles can be described as follows:

- **Value:** The notion of value and value creation in a Living Lab concerns several different aspects such as societal value, economic value, business value and consumer/user value. A Living Lab might also provide insights about how users perceive value. These insights should guide the innovation process to be able to deliver innovations that are perceived as valuable from a societal, economical, business, and a consumer perspective. A Living Lab has the opportunity to create value based on all aspects of the value term
- **Sustainability:** This key principle refers both to the viability of a Living Lab and to its responsibility to the wider community in which it operates. Focusing on the viability of the Living Lab highlights aspects such as continuous learning and development over time. Here, the research component of each Lab plays a vital role in transforming the everyday knowledge generation into models, methods and theories. Other important aspects related to the sustainability of a Living Lab is the partnership and its related networks since good cross-border collaboration, which strengthens creativity and innovation, builds on trust, and this takes time to build up. Also, in line with the general sustainability and environmental trends in society it is equally important that Living Labs also take responsibility of its environmental, social, and economic effects.
- **Influence:** A key aspect of the influence principle is to view "users" as active and competent partners and domain experts. As such their involvement and influence in innovation and development processes shaping and transforming society is essential. Equally important is to base these innovations on the needs and desires of potential users, and to realize that these users often represent a heterogeneous group. While users often are described as drivers and shapers of technology, they still very often are treated as a homogeneous and passive group that carry out activities assigned to them. Hence, one important issue that Living Labs need to manage is how to assure that participation, influence and responsibility among different partners harmonizes with each other and with the ideology of the user influence of the project.
- **Realism:** One of the cornerstones for the Living Lab approach is that innovation activities should be carried out in a realistic, natural, real life setting. Orchestrating realistic use situation and user behaviour is seen as one way to generate results that are valid for real markets in Living Lab operations. However, the aim to create and facilitate realism is an endeavour that needs to be grappled with on different levels and in correlation to different elements such as contexts, users, use situations, technologies, and partners. The principle does not separate between the physical and the online world. Instead it is argued that activities carried out in both worlds are as real and realistic to its actors.
- **Openness:** The principle of openness emphasizes that the innovation process should be as open as possible. The idea is that multiple perspectives bring power to the development process and achieve rapid progress. The openness supports the process of user-driven innovation. In a Living Lab, digital innovations are created and validated in collaborative multi-contextual empirical real-world environments. Openness is crucial for the innovation process in a Living Lab, where it is essential to gather a multitude of perspectives that might lead to faster and more successful development, new ideas and unexpected business openings in markets. However, to be able to co-operate and share in a multi-stakeholder milieu, different levels of openness between the stakeholders seems to be a requirement (Bergvall-Kåreborn et al.).

3.1 Pilot Implementation Methodology

The pilot projects ran in Living Labs localized in Amsterdam, Helsinki, Lisbon and Luleå. They operate in a very fragmented market all over Europe which raises problems and barriers that were analysed during the project. These regional differences are originated by for example: (EC3, 2011)

- Climate differences (Northern countries versus Southern countries).
- Regulatory environments. Different standards. Different levels of deregulation.
- Lack of standards and interoperability.
- Different communication and data transfer standards.
- Different behaviour and cultures.

In order to address these specific issues the Energy Efficiency experiment followed the next 5 steps: (EC3, 2011)

1. Preparation of the pilot - During this phase the Living Labs share best practices and methods for user testing. The Living Labs co-create a methodology for the Energy Efficiency domain and determine what actions to optimize the usage scenario to be implemented for the cross border pilot experiment. The common technologies and research framework to be used are agreed for the four pilots.

2. Experimental setting - The selected technologies are installed in the Pilots under a general usage scenario. This includes a network of sensors, actuators and smart meters connected to wireless interface providing real time information. Users interact with the system and behaviour transformation is carried out. The level of integration of the energy management systems and the interface with electricity utilities depends of local conditions.

3. Testing - Users are facilitated through a participative innovation process. They define their needs and the level of acceptable settings and comfort they consider adequate for their life style and expenditure. These are dependent of their culture, climate and building insulation conditions. Living Lab methodologies are used to gather the user needs and ideas. Users get familiar with the energy management systems and learn from each other. Behavioural transformation approaches are utilised.

4. Evaluation - The evaluation is done continuously and will gather information on:

- Difficulties faced with product integration due to lack of standardization and local regulatory environment (Deregulation availability of real time data, dynamic pricing, etc.);
- Difficulties with the users' culture and their surrounding environments. The setting of control parameters is dependent on the local environment;
- Results on the impact of regulatory environment, climate, culture and behaviour are compared between the different Living Labs. Methodologies and tools to gather results will be assessed to select the most effective;
- Evaluation of the benefits of using cross border methodologies for co-creating and co-testing Energy Efficiency products.

4 TECHNOLOGY DESCRIPTION

In the way of involving end-users in the living lab experiment, different levels of visibility for energy measurement were given in the different Living Labs. All four Living Labs have installed different metering solutions. Also the different metering systems are controlled by different management systems and from these management systems the measurements are shown thru different portals: (Oja et al., 2012)

- **Lisbon:** The users were provided with an easy-to-install meter that from the first minute displays energy consumption, thus the user was aware of its consumption right from the beginning. The solution envisaged for the pilot could be easily rolled out, since it was only necessary to set up a distribution list, supported by a customer service line, and the users can easily, by themselves, install the equipment.
- **Luleå**: Metering solutions from two different local vendors were installed, and both of these vendors had their own solution for showing the measured data to end users. Those users that had the KYAB solution installed could follow-up on their energy consumption through a web portal. Those end-users that had the ELIQ solution installed had the possibility to view their consumption from a home display.
- **Helsinki**: The users in were able to view the energy consumption thru an excel report that was updated hourly to the intranet site viewable to all, also they had the possibility to view the consumption thru an extranet site called eGeneris that showed the energy consumption also on hourly basis.
- **Amsterdam**: The users had access to two kinds of real time energy displays: Onzo display and the GEO display, that real-time interacted with the

smart meter and provided information on energy consumption to the user.

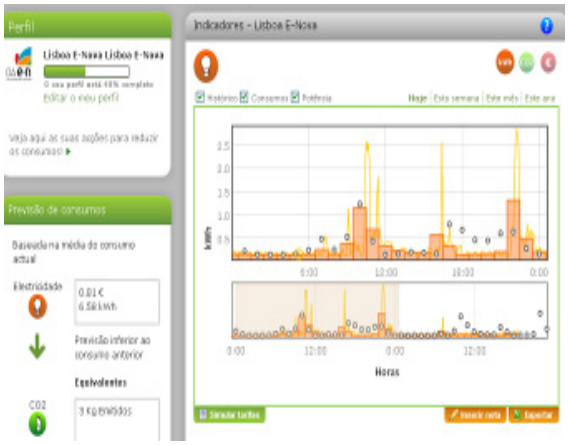


Figure 2: Energy display at Lisbon.



Figure 3: Energy display at Luleå.

5 RESULTS AND DISCUSSIONS

Within the energy efficiency experiment there has been in place during the Apollon project four different LLs in four different countries: Finland, Sweden, Netherlands and Portugal. All the four countries had a different basis for energy consumption because of the different climate conditions and what borders these conditions set for energy efficiency. Legal entities as well as national energy players set demands to mitigate energy consumption as well as lowering/shifting of consumption peaks. The Living Labs are in most part similar except for the Finland pilot that is located in a higher voltage office building when in the other Living Labs the pilot is of low-voltage metering point; namely private homes. (Oja et al., 2012)

From the four different Living Labs few key issues have risen above others in terms of user involvement and notification. The most flagrant issues in energy saving is the avenue with which the users are notified of their energy consumption and therefore are incorporated in the process of energy savings also on how to keep them engaged long-term. End users are most likely to change their consumption habits to greener ones if they have a good knowledge on what their usage has been before, what this usage means in terms of minutes and euros as well as clear objectives on what the consumption could be and with what means this could be achieved. (Oja et al., 2012)

Users demonstrate an interest at the start of ICT use and interaction, but interest tends to decrease in time if users are not engaged and challenged on regular intervals. Hence, energy efficiency information workshops are essential to raise user awareness, provided messaging and language are appropriate to the audience involved. With this in mind cross border activities are vital in sense of fresh ideas and common methodologies for interpreting the user behaviour changes. (Oja, R., et all, 2012)

The results of the co-operation can be seen in the good results in energy savings of the four living lab pilots: (Oja et al., 2012) (Gonçalves et al., 2012)

- **Helsinki**: Average 9% (increase of energy usage 4% to decrease of 24%)
- **Luleå:** Average 9% (5-12% decrease of energy usage)
- **Amsterdam**: Average 6% (4-8% decrease of energy usage)
- **Lisbon**: Average 15% (9-20% decrease of energy usage)

6 CONCLUSIONS

6.1 Cross-Border Collaboration Experiences & Evaluation

The most sustainable part of Cross-border collaboration and its evaluation is the collaboration between the Living Labs, who share most of the interests and whose strategic focus does not shift as rapidly as does the corporate side. Also, research collaboration is very much linked to most Living

Lab activities and sharing research findings add value for those partners. Public sector partners such as municipalities or regional innovation agencies are there to support and facilitate rather than to take part in the project operational side. (Launonen, P. et all, 2012)

6.2 Benefits

International cooperation benefits from exchange of experiences and lessons learnt from the partners, allowing the results of an initiative developed elsewhere to be appropriated and worked upon in other projects. This allows a convergence of resources, leveraging European-wide available assets (scientific excellence, technologies, methodologies, tools, experimental facilities, Living Labs, user communities) and avoids double work while achieving the same results. (Launonen et al., 2012)

A European level initiative can more broadly assess a wider range of topics, methodologies and technologies, count on a wider network of stakeholders and reach a far bigger audience and so prompt results on a totally different scale from those achieved if the experiments are solely conducted at the local level, which, due to a lack of economies of scale and budgetary constraints, would of necessity be deficient and incomplete. (Launonen et al., 2012)

Each pilot has its own specific target users but uses common methodologies, allowing for generalization of findings to other Living Labs. Working at the European level is complementary to city initiatives, fostering public collaboration in the form of city's cooperation to enhance impulse and build upon each city's strengths and expertise, providing also the basis for harmonization in areas where this is both essential and beneficial in advancing and initiating follow-up studies. (Launonen et al., 2012)

Benefits for Research and business are:

- Knowledge transfer
- Business matching & partnerships – SMEs and Large Enterprises
- Technology testing and validation, market and feasibility testing

6.3 Challenges

The challenge for public organizations and non-profit private entities, which seek to contribute to sustainable development by systematic and continuous improvement of the energy and environmental performance of the city is to implement a continuous improvement process involving all of the city's key stakeholders in a holistic and quantifiable way which results in a measurably better energy and environmental performance of the city. The cross-border activities consisted of several such cases, all with the purpose to test and evaluate new technologies for energy saving and behavioural change in terms of energy consumption, all striving to share experiences, methods and tools among their sites and to provide business opportunities for their SME communities. (Launonen et al., 2012)

The challenge for SME's is to take the advantage of being in permanent touch with up-to-date technologies, from different companies, in the field of energy metering, with partners from different European countries, sharing ideas and forming business alliances. The greatest challenge is the absence of a single uniform European Energy service market for consumers. There are different industry legacies, regulatory environments, standards and supporting instruments for each individual European country. (Launonen et al., 2012)

6.4 Partners in the Project

Available public funding for SMEs helps when it focuses on RDI issues close to markets, since their development cycles are very short. LLs should aim to provide 'same type services' for SMEs in each location. (Launonen et al., 2012)

In this experiment Local Authorities were municipality representatives, energy companies owned by local authorities and energy agencies. So local authorities drive the local energy policy and support local SME community for piloting. Local energy management systems are an asset in achieving local energy consumption optimization, facilitating the delivery of a balanced supply system and an optimal integration of demand storage means. The residential level created by e.g. the Lisbon pilot promotes the reshaping of energy consumption patterns by smoothing peak hours' consumption and implementing management procedures that allow transfer of consumption to off-peak hours, settling of dynamic baselines of consumption according to energy supply conditions, combining grid needs with dynamic accumulation sources and strategies that shall be addressed within the energy management arena for the installations evaluated. This methodology, commonly used at a higher level than the municipal can be easily replicated to the municipal level. (Launonen et al., 2012)

Municipal Energy agencies are the link to the energy test bed. Their unique position allows them to be the bridge between local authorities, SMEs and Universities, positioning such a consortium to be the real framework that motivates the LL methodology. Municipalities can appropriate results and draw up new policies and legislation both at the urban planning and urban management level, exploiting APOLLON results towards a more sustainable approach to the urban environment. (Launonen et al., 2012)

6.5 Research

In this experiment there were two Research Institutions as partners; Helsinki Aalto University and Luleå University of Technology. For research institutions in this experiment, the focus has been to do research on how to stimulate users to change their energy consumption behaviour by means of new technology and by means of tasks that stimulates their use of the implemented technology.

In this experiment we have been able to elaborate with methods and tools for user behaviour transformation. For instance, one aspect of the experiment has been to have done a longitudinal study with user involvement for a longer period of time. Here it has become obvious that it is difficult to involve users and to keep them engaged for several months. One way that we have tried to stimulate their engagement has been to give them assignments that they should carry out, with the objective to stimulate use transformation and adoption of the innovation and to stimulate the users to change their behaviour. By this mean, it is observed that the users do change their energy behaviour to some extent, and they do also become more knowledgeable in the area of energy saving. (Launonen et al., 2012) Another focus area has been facilitation of systemic innovations and orchestration of open innovation networks in the energy efficiency domain.

The added value for Living Labs has been the increased knowledge in the area of energy savings. This has led to new project initiatives, business models, products and services. The project initiatives will in turn increase the collaboration between partners around Europe. Another aspect of added value has been a strengthened collaboration with local SMEs who have not been involved with similar projects before. (Launonen et al., 2012)

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Participatory Design of Scenarios for Future Service Implementation
The Case of Smart Campus Project: ICT based Services for Energy Efficiency

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Keywords: Service Design, Participatory Design, Energy Efficiency.

Abstract: Energy efficiency in public buildings is a fundamental goal for both public and private institutions. Its achievement depends on different factors such as the policy of the institutions but also the behaviour of the buildings users and the selections and availability of integrated technologies and monitoring systems. All these elements require the coordinated activity of many stakeholders with common goals and shared vision of the desired solutions, able to take into account needs and constrains of all the people involved. The paper describes the participatory design process applied in the Italian pilot of Smart Campus EU project to design ICT based services scenarios to reduce energy consumption in university campus buildings. It describes the scenarios' development process and discusses the results obtained and the positive implications of having the stakeholders involved right from the context research phase. This process is more and more used in Service Design projects in order to increase the possibilities of success for the following prototyping and on field implementation of the solutions. The paper is a contribution to the practice of participatory design of complex services.

1 INTRODUCTION

Reducing energy consumption is a major challenge nowadays and this is especially important in cities where the majority of the world population is currently living and where more and more people will concentrate in the next decades. Moving from the first attempt to agree a common understanding of the concept of sustainable development at global level, reported by the Brundtland Commission in the late 80's, the movement towards sustainability has done important steps forward in the last years. The European Union recently adopted the Energy and Climate Package (http://ec.europa.eu/clima/policies/package/), a set of legislation and directives that aim to ensure the European Union (EU) meets the set climate and energy targets for 2020. On this basis the EU member states have committed to the 20/20/20 goals reducing greenhouse gas emissions by 20% from 1990 levels, increasing the use of energy from renewable sources by 20%, and improving energy efficiency by 20%.

In order to reach these targets, the building sector is a key area. This sector is a big consumer of energy and has on the other hand a great potential for interventions aimed at reducing its consumption. This is mostly true considering buildings used for services, where different activities are performed and where common policies and interventions can significantly reduce energy waste.

Improving energy efficiency in public buildings is a challenge since it depends on many factors, such as external climate conditions, structure and materials of the building itself and activities carried out. The users' behaviour towards the use of energy is also a key factor to be considered, since everybody has a different perception and sensitiveness towards the use and value of energy. Indeed the way people use Heating, Ventilation and Air Conditioning (HVAC), lighting and appliances has a great impact on a building's energy consumption.

2 SMART CAMPUS PROJECT AS A TESTING ENVIRONMENT

"Smart Campus. Building User-Learning Interaction for Energy Efficiency" (Smart Campus) (http://greensmartcampus.eu) is a European project funded by the Competitiveness and Innovation Framework Programme 2007-2013, with the aim of

achieving a 20% reduction in energy consumption in public buildings, through the development and installation of ICT based services at pilot buildings in four European universities. These services will be integrated with the energy management systems present in the pilot buildings and provide guidance that will lead to user behavior transformation towards more energy efficient practices. The possibility to actively interact, in a dynamic way, with the buildings energy management systems, gives users the possibility to control the environmental conditions of their workspaces in a way that until now has not been possible, becoming aware of their energy consumption habits in the process. At the same time the energy management systems learn and adapt to specific user routines. This way the users learn how to better use the spaces of the buildings thanks to the installation of sensors and technologies allowing them to interact directly with the surrounding environment.

The project is carried out in four pilot locations in the partner-country campuses (Italy, Portugal, Finland and Sweden) and actively involves students, professors and university staff in the development of the field activities. The aim of the pilots is to work on the criticalities observed and to reduce the energy consumption by enabling a mutual learning process between the building and its users and to facilitate the application of the same solutions to other university campuses.

3 DESIGNING SERVICES WITH A PARTICIPATORY APPROACH

Service Design is a relatively young discipline that moves from different traditions such as design for sustainability, interaction design and business sciences (Manzini, 1993); (Pacenti, 1998); (Mager, 2004=; (Meroni and Sangiorgi, 2011). Especially following the 'interaction paradigm', explored by Pacenti, the perspective assumed to design a service is the one of the user, detecting all the points where he/she gets in touch with the service during his/her journey across it. All these "touchpoints" are the elements (products, communication elements and processes) that need to be designed in order to assure the best experience and results in its use.

Before getting to the full design of all these interaction elements, especially when dealing with complex solutions involving many stakeholders, project scenarios are defined, aiming at creating a shared vision taking into account their different needs and behaviors. This is mostly true when the stakeholders and final users become active players in the solution development and in its adoption.

In the last decade the approaches to deal with services projects has changes significantly (Sanders and Stappers, 2008). In fact the perspective assumed by the User Centre Design method that looks at the users as "object" to be observed in their use of a service or product has been slowly changed. In the Human Centred Design concept proposed by IDEO (http://www.ideo.com) or in the Community Centred Design approached used by Meroni and the POLIMI Desis Lab group when dealing with social innovation initiatives (Meroni, 2008); (Cantù et al., 2012), the users become "subject" in the project development process, becoming active players in the detection of the problems and in the design of the solutions they will be using. Even if the user remains at the center of the project this is a radical change in its role, transforming him/her in co-designer of the future solution.

This new perspective has significant implications in the way designers work. In the Design discipline tradition the designer was the inventor, the creative person with a technical and cultural knowledge supporting the creation of a new product for the market. When dealing with services, characterized by intangibility, heterogeneity, inseparability and perishability (Lovelock and Gummesson, 2004), the user experience become the key for the success of the service solution. This, as a consequence, brought the attention on the users perspective in the design process and required service designers to become 'facilitator' in involving them in the early phase of the solution design. In this process the users are involved in collaborative activities where designers support their participation to with face to face meetings, workshops and specifically designed tools and format.

Looking at recent service design research projects (e.g. *Feeding Milan. Energies for change* project, MedeaLab's *living labs* in Malmo, *Life 2.0* EU project) it is possible to recognize that the people involved into the development process are not just final users of the services. In fact to develop an innovative service, entirely self-sustainable after designers work ends, it is important to involve the potential stakeholders right from the first phase of context analysis and scenarios' definition. This allows local actors to have voice, raising their needs and pointing out their potential role in the future solution (Cantù and Rizzo, 2012).

From a design perspective the theoretical

reference used for discussion in this paper is Participatory Design (PD). This is an approach that is used in all the design process moving from the collaborative definition of the project scenarios to the service idea - the concept - and continues with its testing and implementation together with the stakeholders, and concludes with the service ready to be used.

In order to develop this process, the methodology adopted in the Smart Campus project pertains to PD as defined by the Scandinavian school (Ehn, 2008); (Bjögvinsson et al., 2010); (Emilson et al., 2011). The authors look at PD as a movement "from designing "things" (objects) to designing Things (socio-material assemblies)" and they argue that "this movement involves not only the challenges of engaging stakeholders as designers in the design process, as in "traditional" Participatory Design (i.e., envisioning "use before actual use," for example, through prototyping), but also the challenges of designing beyond the specific project and toward future stakeholders as designers (in other words, supporting ways to "design after design", i.e. after the conclusion of the design process for the specific project). And they see this movement "as one from "projecting" to one of "infrastructuring" design activities" (Bjögvinsson et al., 2012, p.102).

As previously mentioned this means that the work of designers in this process ranges from engaging non-designers in envisioning and co-designing future service ideas, to involving potential stakeholders in the process, aligning their interests and empowering them to create self-sustainable services after the end of the design project.

In the Smart Campus project PD is applied right from the beginning with the aim of co-creating the digital services scenarios with the users and decision makers at local scale, thus ensuring higher sustainability of the solutions and better user requirement identification. This will be eventually translates into higher success rate of behavior transformation and long term adoption of the proposed solution.

This paper aims at giving a contribution to the design practice in the field of PD, describing the outcomes of the Smart Campus project scenarios' definition, whose effective sustainability will be verified with the conclusion of the EU project.

4 PARTICIPATORY DESIGN OF SERVICE SCENARIOS AT POLITECNICO DI MILANO PILOT

Milan pilot is located in the campus Leonardo of Politecnico di Milano. Inaugurated in 1927, over the course of the decades the campus has been expanded to encompass new campuses and given rise to a real and genuine university quarter commonly dubbed "Città Studi" (City of Studies). Specifically the pilot will be implemented in one of the biggest building of the Leonardo Campus: "La Nave" (The Ship). This is structured in two main functional areas: the classrooms used by the students and professors and the department rooms. This building was selected as it is one of the most representative for its double function, offering at the same time the opportunity to interact with a wide range of different users; moreover it is already equipped with technologies that collect data on costs of operation, maintenance, surfaces, volumes and consumptions and it has a significant potential in terms of reduction of energy consumption.

This paper describes the participatory process that defined how different kinds of users behave in the spaces of the pilot building with good and bad performances in term of energy consumption. Moreover it reflects on how these information were collaboratively transformed into future ICT services and solutions aimed at reducing energy consumption in the building.

The work was structured the same way in all the country-partner pilots, conducting a context analysis to define:

- Personas and "as is" scenarios
- "To be" scenarios and pilots requirements

Personas is a tool that represents a stereotypical description of the main classes of users that will be involved in the project and that will benefit from the pilots implementation in terms of behavioural changes towards a more efficient use of energy in the universities pilots buildings. "As is" scenarios are short storytelling describing the main situations where bad behaviours of the building users generate high energy consumption. From these tools "to be" scenarios are generated describing future situation where ICT based services support the users in having more energy efficient behaviour and where energy is saved due to partially automated systems. This work concludes with the definition of the users requirements to build the Intelligent Energy

Management System supporting the new services in all the pilots.

The following paragraphs will describe how the main stakeholders and professionals were involved right from the initial phases of the project, describing their role and collective contribution to the development of the services to be. The "to be" scenarios, jointly with the elicited users requirements, will be used in the second phase of the project as the starting point for the pilot real implementation.

4.1 Collaborative Design of "As Is" Scenarios: Users, Spaces and Problems Setting

In Milan the people involved in the design of the project scenarios were both users and more in general stakeholders of the Politecnico system. Here below a short description of each actor involved is provided, jointly with its main role in the process:

a) *Politecnico di Milano institution.* The university was involved right from the initial phase related to the writing of the proposal and was constantly updated during the development of the research project. Polimi participated to the selection of the building for the pilot project thanks to its knowledge in terms of energy management of the entire system and gave its endorsement and support. The objective of the Smart Campus project is in fact in line with the university policies in terms of reduction of energy consumption.

b) *Students.* The research team conducted a set of activities in parallel with the students from the *Urban Planning Studio* and *Interaction Design for PSSD Course* in the School of Architecture and the School of Design. The courses activities carried out focused on users' observation and interviews, adopting an ethnographic approach to investigate how people behave in the pilot spaces and allowed to bring the peculiar students perspective as users of the building in the project (table 1).

The work done during the courses, permitted to: highlight different classes of users described then as personas; describe the areas of the building with the major energy loss; detect the bad behaviours of students and professors; develop initial service ideas to overcome the problems detected.

c) *Professors.* Professors were involved through interviews and informal discussions. They contributed to highlight the current use of the offices spaces, not visible to the students, raising the awareness of the improper use of the energy in those spaces and outlining possible solutions.

Table 1: Tools used for context analysis in Milan pilot.

Tool	Description of the tool in use	Duration and frequency	Technologies/ Materials	Profile of the participants	Main results
FIELD OBSERVATION	- Observation of the users of the building during the interaction in different time of the day (classes hours, group work, breaks) - Visit of the building and the heating management spaces with the Polimi technicians	December 2012	Photos, notes	Students, professors, Polimi's technicians	- Critical behaviors causing excessive energy consumption - building's heating and lighting infrastructures
INTERVIEWS	Interviews with students and professors regarding their perception on the quality of the lighting and heating in the building Interviews with technicians and the chief of the heating management offices' responsible	December 2012 (students and professors) January-February 2013 (technicians and administrative)	Face to face interviews	Mainly students and professor	Discrepancy between the negative effect of a specific behavior and its perception by the users Users are not aware of the characteristic of the building and its infrastructure.
SURVEYS	Both multiple choices and open questions to collect specific information and unexpected inputs	December 2013	Face to face	Students	Information regarding the use of the spaces, usability issues and the perceived efficiency of the building.

From the first analysis on the consumption monitoring system and from the on-field observation with the energy managers and the students, a first mapping of the pilot over-consumption areas and the users' most significant negative behaviours has been drawn, eliciting spaces for a significant improvement in the energy efficiency management. The pilot areas where the main critical behaviors were detected are the classrooms, both during the lectures and during the group study, corridors, where the students have brakes during the day and professors' offices, where it happens that heating and lighting systems are turned on even when the rooms are not used.

From these problems, and using the personas generated, a set of "as is" scenarios, similar to the one reported in table 2, were generated.

4.2 Defining "To Be" Scenarios for Future Implementation

"As is" scenarios were used to define the energy managers perspective and were then translated into "to be" scenarios (table 2). This process was possible thanks to a joint work with managers and technicians who supported the pilot designing the system architecture, including sensors and logics.

d) *Energy Managers.* The energy managers of the building were key actors to be involved to understand the effective impact of the observed bad behaviours on the energy consumption. They

supported the data collection of the building performances and the understanding of the logics behind them.

e) *Technicians and app developers.* Professionals out of the Politecnico system participated to collective workshops and individual meetings and gave support in translating the users (students and professors) point of view into technical requirements and features needed from the system to solve the problems emerged. Properly supported by the research team, especially service designers, they actively collaborate to the definition of the "to be" scenarios, merging the description of the future solutions from the point of view of the users and the one of the other stakeholders.

"To be" scenarios have been detailed during a local workshop following these steps:

1. Analysis of all the materials and data collected during the context observation (personas and scenarios);
2. Elaboration, on the basis of the results of the step 1 of ideas of possible solutions for the users represented by the personas and for the problems represented by the "as is" scenarios;
3. Design of "to be" be scenarios as suggestions for energy saving solutions in the pilots building and service ideas and functionalities on which to build up the Smart Campus pilots requirements.

Table 2: Example of the evolution from "as is" scenario to "to be" scenario (taken from Smart Campus project deliverable 2.2).

AS IS SCENARIO 1: Working home having a room in the Politecnico.	**Technical description**	**TO BE SCENARIO 5: 3 temperature levels in the faculty rooms**
Main character: Alessandro, a FULL professor at the Politecnico di Milano **Secondary characters**: Students and colleagues Alessandro is a Full professor in Planning at the Politecnico of Milano, school of architecture. He has a studio in la Nave building one of the most famous Politecnico buildings since it was designed by a famous Italian architect. He likes very much that space but he doesn't come there often, only one or twice per week when he needs to meet his students or some colleagues with which he carries on projects. In fact Alessandro lives out of Milano in the surroundings and he prefers do not travel during the week but to stay home, for this reason his computer in the office is always on. In this way he can access it remotely for every files he might need. The only thing that he feels not comfortable with his office is the control of the heat during winter-time as well as that of the air conditioning in summer. In fact his office is equipped with a fan coil that has a hand based control system. The problem that Alessandro sees is that if he turns off the fan coil his office is always cold in winter and hot in summer. To solve that problem Alessandro always leaves the fan coil on.	The rooms of teachers have problems related to their orientation North or South. The rooms facing north have very little lighting and require artificial light constantly. The rooms facing south have a strong radiative load, which requires the constant use of curtains on the windows. The rooms are heated by forced air systems (fan coils on the floor or channelled vents with supply and return); the temperature is regulated by means of a room thermostat. The use of metal channelled vents to distribute hot air in the rooms is the most critical, because the hot air tends to stratify on top and to be short-circuited by the pick-up duct, often too close to the outlet nozzle. Furthermore, the air flow is often oversized, so those who frequent the rooms often "play" with the thermostat turning the plant "on" or "off" even in very short times, which is the index of a really bad plant management	The regulating system has three temperature levels: - 14°C, minimum temperature of the room (during an extended absence of people); - 16°C, medium temperature of the room (when there are no people in the space); - 20°C, higher temperature of the room (when there are people using the space). People presence is controlled by a presence sensor or, preferably, by the professor, researcher or PhD candidate who have the right to access by interacting with the APP. When someone enters the room the fancoil starts reaching the 20 °C temperature. When the sensor does not detect presence in the room the temperature tend to reach the 16 °C, (under this level the fancoil turn on again to prevent an excessive temperature reduction). If the professor knows that the room will be not used for an extended arch of time he can access the APP and indicate the period in which the room will be not used so to allow an extra saving of energy. In this case the room will be not heated up to the reaching of the lowest level of 14 °C.

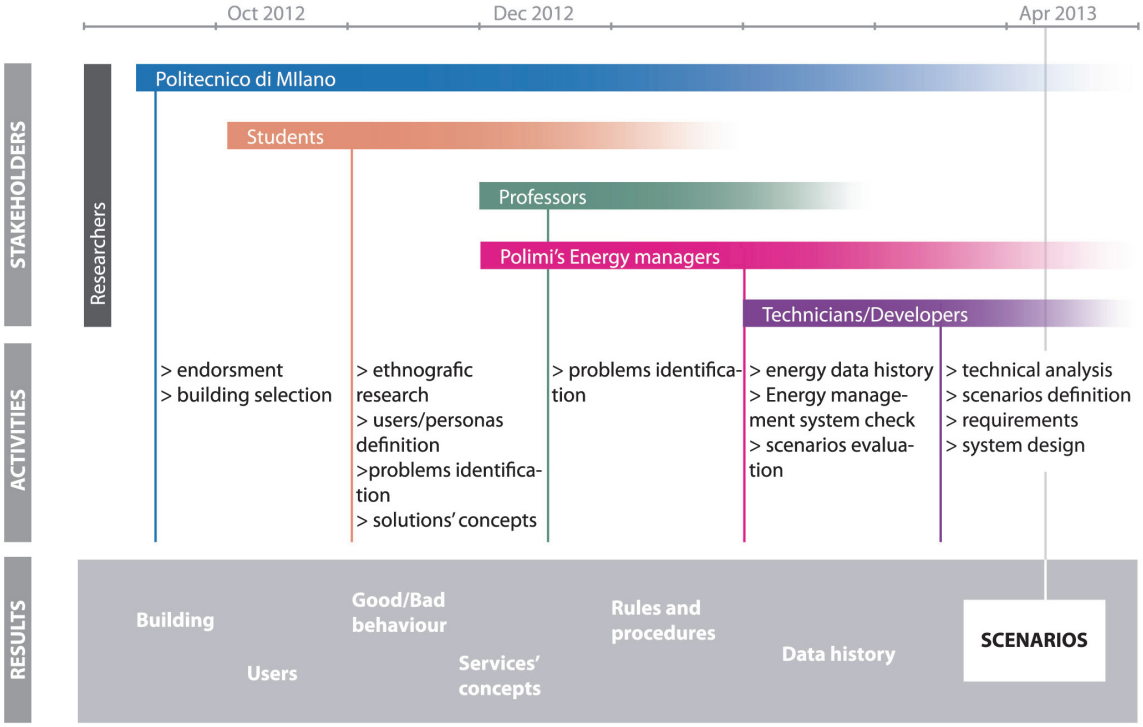


Figure 1: The participatory design process.

The dialogue and work done with the technicians moreover permitted to foreseen the effective impact of the solution further evaluating the 5 scenarios generated. The latter were translated into users, systems and functional requirements by other project partners and will be then implemented for the piloting phase in the classrooms, corridors and offices.

4.3 Main Achievements

All the 5 actors aforementioned (a-e) were involved in the design process as they represent different perspective on the project that needed to be taken into account for the development of effective solutions. The activities done by the research group through the repeated interactions with them led to the collection of the following information that were finally translated in the scenarios "to be" (figure 1):

- the detection of the building for the pilot project;
- the main users typologies involved;
- the everyday practices that users conduct in the pilots sites that mostly affect energy consumption/saving in the building;
- the rules and procedures applied by Politecnico di Milano to regulate the use of the building with respect to energy consumption/saving;
- the historical data on energy consumption of the building;

As a synthesis of the contextual research process 3 main things were outlined within the scenarios:

1) ICT based services for students and professors aiming at User Behaviour Transformation towards a more energy efficient use of the building spaces;
2) Automated solutions to save energy depending on the users behaviours;
3) Interfaces for energy consumption monitoring and management;

5 STAKEHOLDERS PARTICIPATION IN SERVICE SCENARIOS DESIGN

Energy efficiency in public buildings is a fundamental goal for both public and private institutions. Despite that its achievement depends on different factors such as the policy of the institutions but also the behaviour of the buildings users and the selections and availability of integrated technologies and monitoring systems. All these elements require the coordinated activity of many stakeholders with common goals and shared vision of the desired solutions, that are able to take into account needs and constrains of all the people involved.

In the Smart Campus project these conditions clearly emerged right from the fist phases of work, where the dialogue with the Politecnico institution started. As the project evolved it emerged the need to involve new actors in order to set the condition to create the "socio-material assemblies" argued by the PD Scandinavian school.

Moving from these considerations the research group decided to start working with the students in order to have a bottom-up perspective on the uses' behaviour in the spaces, to discuss them later on with the professors, energy managers and the institution. The definition of a set of bad habits (i.e. causing excessive energy consumption) by the students, and the generation of draft service ideas to solve them, were used as material to start involving professors in the research. The latter supported the understanding of the classrooms use but also became slowly aware of their bad behaviour in the offices spaces as well contributing to define new areas for intervention. This process started the engagement in the project of the professors more committed to the topic, preparing their participation to the following piloting phase. On the other hand the continuous dialogue with the energy managers of the university permitted to have a direct feedback on the emerging ideas, letting the researchers evaluate their effective feasibility.

The participation of all the actors mentioned and the co-design workshops and activities carried out allowed to have a holistic perspective on the problems in order to define well-articulated, innovative and realistic design. In the definition of the "to be" scenarios the designers work was to collect and integrate feedbacks, insights and suggestions from all the people involved, merging the knowledge provided by technical partners with the users perspective.

In this first phase of the Smart Campus project the idea was to "projecting", preparing the ground for future involvement of local actors in the following "design after design" process, that is the "infrastructuring" work where all the elements to implement the solution need to be included and where the "alignment" of their interest is the basis to create a partnership to run the solution in the future.

6 CONCLUSIONS

The paper discusses the process of building scenarios for ICT based services with the collaboration of users and stakeholders. This approach raise more and more interest both in public and private sector in order to develop effective solutions really adopted by the users. This holistic perspective to contexts analysis and problems detection is more and more used by Service Design to develop projects aimed at solving real problems and producing more sustainable solutions. In this field traditional tools used for research are adapted and re-designed to meet the need of involving individuals or groups into a co-generation process, supporting the inclusion of non-designers into the design process but also aligning the interest of potential stakeholders in the solution implementation.

Moving from the experience achieved in previous projects, and taking into account the Smart Campus scenario building work, it appears evident the need to start right from the beginning to include potential users and stakeholders in this process. We can refer at the process of Service Design as divided in two parts: the design of the service concept and its prototyping and real implementation with local stakeholders. In both the phases, when the service concept needs to be defined and when the future ownership of the solutions generated is not yet determined, PD approach seems to significantly increase the possibility of success for the service to be.

PD is promising to develop services with the highest level of acceptance and adoption by their users and promoters. Nevertheless the experience achieved up to date indicates that in high complex condition involving different stakeholders on relevant topics, such as energy consumption, the success of the service can not be certain.

The work done so far in Smart Campus to collaboratively build the project scenario will be the basis for the follow up of the project. Here designers' work will focus on the development of the services concepts, defining the detail of the users' journey through the service and which will be the touchpoints used to interact with the system. Then a strong effort will be addressed to the 'alignment' of the stakeholders' interests during the piloting and prototyping of the solutions, designing-after-design (Bjögvinsson, Ehn & Hillgren 2012).

This paper is a contribution on how services' scenarios can be designed using PD. The future outcoms of the alignment and prototyping phase will integrate the results achieved, verifying the effectiveness of the PD approach towards the implementation of the services to be.

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Energy Discourses in Europe
Legitimation of EU Energy Efficiency Policy

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Keywords: Energy, Discourse, Legitimation, EU.

Abstract: The production and use of energy is an important factor in European politics and science. However, we know little about the discussions that influence how scarce financial resources of governments and organizations are directed to different projects and action related to energy strategy of EU. Therefore, this paper studies the discourses that underlie the 'energy talk' of EU decision makers. This is important because discourses are resources that are employed to legitimate governmental and organizational aims and decision, such as new energy saving projects and policies. This paper is based on discourse theory that acknowledges that discourses change understanding of social situations, which also makes discursive activity a form of political activity (Hardy & Phillips 1999). However, there are multiple and contradictory meanings and realities existing in an organization, or in any discursive space (Hardy 2001) and discursive actors are commonly embedded in multiple discourses (Hardy & Phillips 2004). The study will be based on interviews with EU Members of the Parliament. The results are likely to reveal local and EU-level discourses that influence establishing of new energy policies and projects on EU-level and this way affect organizations and business in Europe.

1 INTRODUCTION

Production and use of energy on the level of EU is a business area that has a significant effect on the economy and wellbeing of all European citizen in their daily life. Energy related decisions on EU level require negotiations in which MEPs play a central role in a way how they create and join certain energy related discourses and how energy related issues are framed and defined as important or less central in the negotiations. These discourses are resources for the legitimation for energy policies and also for EU as an institution. Legitimation is needed for sustaining the support of the constituents, such as business organizations and citizens. Despite the importance of this phenomenon we lack knowledge on the discourses that are central in the 'energy talk' of EU decision makers. Therefore this paper studies the discourses related to energy policy making in EU with the help of critical discourse analysis and interviews of MEPs as empirical material.

2 DISCOURSES ON ENERGY

Discourses have been studied in many different fields and disciplines in social sciences. Consequently, there hardly exists an unambiguous definition of 'discourse'. However, in Critical Discourse Analysis (CDA), that is the methodological approach we take in this paper, it has become customary to define discourses as interrelated collections of texts that construct social reality and produce a particular way and version of representing 'the world' (Fairclough, 1993, 2005). From the CDA perspective, discourses are also understood as social practices. That is, they are not merely 'empty rhetoric' disconnected from other social action, but instead inherent parts of different social and material practices that (re)construct our social structures and relationships (Fairclough, 2005). Texts are integral to the creation of meaning, but they do not function individually or independently; instead, meaning is created from collections of texts— or discourses—that evolve from the ongoing production, distribution, and consumption of individual texts. (Maguire and Hardy, 2009). Discourses provide a language for talking about a topic and also knowledge about a topic (du Gay, 1996: 43). They are socially constructed, not just descriptive. From discourse perspective there is no single "truth". "Truth claims"

on the other hand are embedded with certain worldviews, judgments and preferences (e.g. Carvalho 2007) that are expressed through discourses. Discourses shape the way in which we can speak and act on a domain (Reed, 1998) and therefore they contribute to institutionalization. Power is a central in discourses. Power in discourses is related to 'subject positions' and 'bodies of knowledge'. Subject position can be based on bureaucratic or socially constructed contemporary position. High subject position gives possibility to legitimately, meaningfully and powerfully to speak for something. Where as the bodies of knowledge relate to the power of discourses to normalize certain ways of thinking and acting. Individuals that produce, distribute and consume texts can this way change institutions. (Maguire and Hardy, 2009)

Discourses related to energy policies and environmental issues have lately raised the interest of many scholars. After the 'linguistic turn' in the social sciences the constitutive role of language became focal which made researchers to pay attention to the discursive processes involved in the management of science and policy (e.g. Hajer, 1995). In studies conducted in Great Britain and South Africa the discourses of energy security and climate change were found central in energy policy discussions (Rogers-Hayden et al., 2011; Rafey and Sovacool, 2011). The construction of the discourses however varied by different groups, leading to for example to 'naturalization' of new clear new build or focus on lack of energy diversity (Rogers-Hayden et al., 2011). In this kind of situations competing movements engage in discursive debates—or framing battles—over the interpretation of the problem and the necessity and nature of solutions (Hoffman, 2011). This is related to the construction of 'interpretive packages' or frames (Gamson and Modigliani, 1989) that are interpretations of 'truth' in which the issues are not just defined but also put together with broader values. For example in the case of climate change as the phenomenon is so complex that there is no 'one professional logic' the credibility the person interpreting the discourse becomes central. (Lefsrud and Meyer, 2012). Usually negotiating such complex issues causes 'us' versus 'them' struggles, or in-group and out-group distinctions (Gamson, 1992) between different groups in the negotiations. Groups that have different reasons for supporting certain discourse can also implicitly form 'discourse coalition', that is, link up with people that have same goals although different understanding of the issue (Lefsrud and Meyer, 2012; Gray and Stites, 2011)

An important perspective is also how common definitions such as climate change are discursively framed in the policy negotiations. As a cultural issue, climate change engages embedded values around issue categories related to religion, economics, risk, freedom, national security, and others (Hulme, 2009). Boykoff (2008) noted that British newspaper articles on climate change were predominantly framed through weather events, charismatic megafauna and the movements of political actors and rhetoric, while only few stories focused on climate justice and risk. The news were usually also brought up with tones of fear, misery and doom. In policy making public discourses and media play a significant role in producing, maintaining and creating discourses. "Depictions of the world in the media result from a series of choices such as whether an issue will make the news, the highlight it will be given, and who is going to speak for it. Operations of codification of the issue into media discourse are directed by the perceived interest and social impact of a topic, as well as other "news values," economic considerations and editorial lines. " (Carvalho 2007) Interestingly for example in the case of climate change the scientific knowledge behind the phenomenon was presented as uncertain in US, certain in Germany where is in Britain the readings of uncertainty varied between newspapers. (ibid)

One of the few studies on this area is a study by Kratochvil, P. and Tichy, L (2013) about the discussions around EU-Russian energy relations and noticed that these discussions were dominated by the discourses of integration, liberalization and diversification.

3 LEGITIMATION

Legitimation is closely related to policy-making as policy-makers must turn to scientists and experts to justify their lines of action (Lefsrud and& Meyer, 2012). For policy-makers in various organizations and different organizational actors, legitimation and gaining legitimacy is crucial (Deephouse and Suchman, 2008; Meyer and Rowan, 1977). More specifically, legitimation is a fundamental process in organizational 'birth' and 'existence' (Deephouse and Suchman, 2008). In addition, organizations and organizational actors engage in legitimation for responding to social, institutional practices and for constructing themselves as conformant 'citizens' in the generally accepted cultural worlds (Meyer and

Rowan, 1977). As a concept, legitimacy can then be defined as "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Suchman, 1995: 574).

Building on these premises, it can be said that legitimation is very much an interactive process. That is, by utilizing various substantive and symbolic practices, organizations and organizational actors constantly legitimize themselves in relation to other actors, organizations, and institutional, cultural environments (Meyer and Rowan, 1977). In addition, there are multiple factors that affect the ways in which the external constituents 'judge', and for their part, 'construct' the legitimacy of an organization (Kostova and Zaheer, 1999). Moreover, the legitimacy of a particular organization can be increased or decreased by the legitimating activities of other players in the field (ibid.).

However, for the purpose here, it is crucial to understand that as legitimacy is socially constructed, discourses are fundamental for legitimation (e.g. Kostova and Zaheer 1999; Berger and Luckmann 1966). This has then lead researchers to examine more closely the discursive practices and processes constituting legitimation. For example, in the context of international mergers and acquisitions, Vaara et al., (2006) have examined different kinds of discursive strategies used in legitimating such activities. As another example, Suddaby and Greenwood (2005) in their seminal study focused on the rhetorical strategies that contribute to legitimation. On the other hand discourses can also work for abandoning previous legitimized and institutionalized practiced through deinstitutionalization. Deinstitutionalization can be started by an internal or external actor in the organization. Changing a discourse at the macro level will cause reconfiguring of power/knowledge relations in the organization and its context. (Maguire and Hardy, 2009)

Yet, despite these advances in increasing our understanding of the discursive practices involved in legitimation, it is clear that we still lack understanding of the specific discursive struggles involved in the process of legitimation (cf. Mumby 2004; Zelditch, 2006). In this paper we study legitimation of EU energy strategy from discourse perspective.

4 CRITICAL DISCOURSE ANALYSIS

In this study our methodological analysis is based on Critical discourse analysis. In spite of the existence of a variety of approaches to Critical discourse analysis (CDA) (see e.g. Fairclough and Wodak, 1997), focal in these approaches is that CDA appreciates the centrality of language (Alvesson and Willmot 1992, 2003) and focuses on the relationship between discourses, power, and domination, (Alvesson and Deetz 2000; Fairclough 2005). It is called 'critical' because it does not only concentrate on lingual perspective but it also questions taken-for-granted assumptions and perspectives of our social order, institutions etc. (Alvesson and Willmott, 1992). More specifically, the purpose of CDA is to examine and unravel the ways in which discourses shape and are shaped by (unequal) power relationships; how these are socially constructed, maintained and changed (Fairclough and Wodak, 1997). In addition, CDA can be seen both as a theory and a methodology (Wood and Kroger, 2000).

Also, central to CDA is the aforementioned understanding of the relationship between discourses and their cultural, economic, historical and political surroundings. Consequently, in CDA discourses and discursive practices are tightly coupled with their social contexts (Alvesson and Deetz, 2000). Building on these premises, CDA can be said to focus on examining the (power) effects of discourse in their wider socio-cultural contexts (e.g. Fairclough, 1995, Grant et al., 2001). In this way, CDA builds on social constructivism (Berger and Luckmann 1966; Grant et al., 2001) as discourses are seen not only to 'mirror' some existing 'reality out there' (Alvesson and Kärreman, 2000; Hardy, 2001), but instead construct a particular version of 'reality' in general, and particularly, a 'reality' in terms of power relationships between actors. Therefore, from this perspective, discourses are not simply language or a medium for transmitting knowledge between social actors (Wood and Kroger 2000). Instead, in conjunction with other social and material practices, they are fundamental in constructing the structures and relationships between organizations and organizational actors (Fairclough, 2005). Hence, in CDA the focus of research is in how discourses relate to the other social and material practices within a particular social context, and how these together uphold or change existing power relations within that context (ibid.)

Following from this, inherent is that in CDA the purpose is to make explicit that different 'truths' about a particular social structure can exist in different discourses. Often in social contexts, over time one 'truth' – i.e. one discourse – has become dominant over others (Fairclough, 2005). Consequently, this benefits certain groups and their interests over others (Alvesson and Deetz, 2000). It is also common that this dominance has become taken for granted and 'invisible' for the central actors in the social context. From this perspective, CDA attempts to unravel these taken for granted discursive structures, and bring forth the other discourses and 'truths' alongside the dominant ones and this was reduce out pre-structured limitations of thinking (Alvesson and Deetz, 2000). Moreover, it can be said that the purpose in CDA is to highlight that societal and organizational actors have a high degree of latitude in selecting the ways in which 'truth' is represented, and also that different discourses can be utilized to challenge the dominant ones for changing existing discursive, social and material structures (Fairclough, 2005; Heracleous, 2004).

Following from this, for example, Mumby (2004) has pointed out that from the CDA perspective, organizations and organizational actors are often engaged in dialectical, discursive struggles of power and resistance. That is, as multiple, often contradictory, discourses exist in a particular social context, organizations can be seen as political sites where different groups utilize different discourses for promoting one's own position over others (Hardy 2001; Mumby, 2004; Phillips and Hardy, 2002). Hence, organizations become discursive sites of power and resistance struggles, where groups discursively attempt to gain privilege for the version of 'truth' and 'reality' that benefits them selves (e.g. Hardy, 2001; Zoller and Fairhurst, 2007; Mumby, 2004; Hardy and Phillips, 2004).

Thus, in this study CDA offers a perspective that, firstly, enables us to look at the complementary but also contradictory discourses that struggle and produce the political reality that forms the basis of European energy strategy; and secondly, enables us to see the power relationships that are influential in this political and societal context.

5 EMPIRICAL MATERIAL

The empirical material for the critical discourse analysis is going to be collected by interviewing EU Members of the Parliament. The Interviews will be both face to face interviews that will be transcribed verbatim but also e-mail interviews, all together 30 interviews. Publicly available written documents of ITRE (Committee on Industry, Research and Energy) of European Parliament will also be used as a background information.

6 POTENTIAL FINDINGS

The results are likely to reveal local and EU-level discourses that influence establishing of new energy policies and projects on EU-level and this way affect organizations and business in Europe.

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SHORT PAPERS

GreenNet
A Centralized Hardware Resources Optimization Tool for Energy Conservation

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Abstract: Students in higher education institutions have a great contribution in exploring possible areas of research in their field that will have an impact in the society where they belong. The emergence of this so-called "Green Computing" in the fields of Computer Science and Information Technology exposed the awareness of the students to do their part in promoting energy conservation in the institution, thereby initiating the said awareness in the classroom which will later on expand in the outside world. With variety of constraints to consider such as sufficient budget to replace old computer units to green-compliant units to support the programs' academic requirements would not be the first priority. The idea of developing a software tool to aid in reducing energy consumption in the computer laboratories came into realization. This software tool to reduce the power consumption of the computer units in the laboratories was initiated by the students as a research project. Furthermore, the application of an optimization technique that influences the power consumption of a computer unit was also considered. Testing and evaluation of the said software tool is on-going and once results were generated, this will help lessen the energy expenditure of the school.

1 INTRODUCTION

The world-wide issues on environment protection, climate change and global warming are becoming prevalent. Even in universities around the world, several researches are initiated to help solve or at least contribute to the possible solutions addressing these concerns.

With the advent of smarter technologies today and its widespread use, a challenge on how to responsibly use it must be considered. The fact that utilizing these technologies requires energy, reducing its energy consumption can contribute to energy conservation. Computers, for instance, the technology that has become so dominant in businesses, institutions, households and almost anywhere can be used in an efficient way thereby unconsciously promoting caring for the environment.

In higher education institutions, students have a great contribution in exploring possible areas of research in their field that will have an impact in the society where they belong. In the computing field, one research area that students explored and initiated is the so-called "green computing". The idea was built from the concept of how this emerging "green computing" associates to the Computer Science program, students, faculty and the institution. Based from the observations made by faculty and students on how computers are used in the institution, the notion to develop software or program to efficiently and responsibly use the computers in the institution ascended. It was observed that the simple task of setting up the power adjustment in the computer of a certain user was ignored and taken for granted by user of computers. Aside from that, the simple turning off of the computer when not in use for long period of hours was not practiced by most of the student-users in the campus. Continuously ignoring those simple tasks contribute a lot to power consumption of the institution. When these simple tasks of setting the power saving mode of each computer and turning off of the computers after use and during vacant hours will be performed by all computer users, a lot of energy will be saved and a lot of power will be reduced. This leads to the idea of developing a tool to automatically perform those simple tasks. Firstly, this paper aimed to determine

the level of awareness of faculty members, students and staff about green computing. Secondly, how can a software tool be designed and developed to integrate the "green computing" concept like energy conservation and lastly, how can this developed software tool be evaluated relative to its impact on power consumption reduction.

1.1 Scope and Limitation

The study integrated two (2) modules: the centralized power adjustment module and the computer hardware resources' optimization module. In the first module, the administrator has the ability to change the power adjustment settings of all computers connected in the network. Although each computer has its own power adjustment module that can easily be adjusted, most users are not aware that the simple step of properly adjusting it has a great impact in reducing the energy consumption of the computer. In this module, the adjustment settings can be performed in an easy manner with less time and effort. One of the important information needed in this module is the schedule of classes in the computer laboratories.

The second module pertains to the optimization of the computer hardware resources such as Central Processing Unit (CPU) and hard disk drive (HDD). The module includes identifying the capacity and used resource of each hardware component. CPU optimization will be included since this resource contributes to the total energy consumption of a computer system. A notification will be given to users regarding the status of the usage of these resources. Once notification was given, an optimization strategy will be suggested by the system if there is a need to optimize the hardware resource.

Both modules will include the generation of reports. Reports on the utilization statistics can be generated by the system, uptime and downtime percentages as well as status of the computer hardware resources of all the units connected to the network. However, the study will not cover the computer units used by faculty and staff in the different offices as it focuses on the computer laboratories of the institution. In addition, the system will only run in the Windows operating system.

1.2 Significance of the Study

The study will benefit the academic institution as this will serve as the mechanism to further improve its energy conservation program. The system will have a huge impact on the school's expenditure on energy. More so, a big responsibility of each member of the entire academic community on protecting the environment through energy conservation will be realized. This will also become a very significant highlight in the achievement of the College and its students as this will promote the responsible and efficient use of technology. This study will also serve as future reference on related research in the field of green computing.

2 LITERATURE

The literature cited provided benefits to the improvement of the study. Concepts on energy conservation, green computing and networking were considered.

Green computing is defined as the study and practice of designing, manufacturing, using and disposing of computers, servers and associated subsystems such as monitors, printers, storage devices and networking and communication systems efficiently and effectively with minimal or no impact on the environment (Murugesan, 2008).

Since green computing associates with the technologies used today and that these technologies rely on power and energy to function, ways on how the energy will be conserved will contribute to environment protection.

Tidal (2007) stated that energy conservation is an approach of preserving and getting better our lifestyle with less energy consumption. The author also mentioned that if corporations place energy conservation as their top priority, it will contribute a lot to green community.

As discussed in the research made by Gartner (2013), the number of personal computers (PCs) in use surpassed 1.7 billion units in 2012 and will top 2.1 billion units by year end 2015. This only means that more and more computers cause the unnecessary production of greenhouse gases every year. Gartner also mentioned that the contribution of information technology (IT) to greenhouse gases is more than 2% and emissions tied to computers are comparable to greenhouse gasses produced by all the world's airplanes.

With the large production and utilization of computers worldwide, its effect to the environment can not be underestimated. Promotion of responsible and efficient use of computers must be taken into consideration. In this area, students took part on how this can be encouraged.

3 METHODOLOGY

The researchers employed the descriptive and software development methods of research. Interviews and surveys were conducted to determine the level of awareness of the faculty, students and staff about green computing. Interviews with people in the institution who advocate energy conservation were also conducted to further solicit information on the different energy conservation programs of the institution and significant feedback on how to improve the proposed software tool. Furthermore, focus group discussions and brainstorming were set to bring into light the design concepts for the proposed software tool.

In software development, the rapid prototyping model was used in the study. This model helped the researchers increase effective communication with the stakeholders and understanding of the proposed software tool.

3.1 Subject of the Study

The researchers conducted interviews to the head of the Physical Plant and Facilities' unit, staff of the Management Information System (MIS) unit of the institution as well as to the college laboratory staff. Survey questionnaires were distributed to the following respondents: fifteen (15) faculty members, one hundred seventy six (176) students and two (2) college staff.

3.2 Programming Language

The researchers used Visual Basic.Net to design and develop the interface of the system. For the database, MySQL was utilized by the researchers to maintain the records of the necessary information needed by the system.

4 RESULTS AND DISCUSSION

Presented in this section are the results derived by the researchers.

4.1 Level of Awareness of the Faculty, Students and Staff about Green Computing

Table 1 shows the summary of the level of awareness of faculty, students and staff about green computing.

Table 1: Level of awareness of faculty, student and staff about green computing.

Level	Faculty	Students	Staff
Strongly Aware	0%	2%	0%
Aware	80%	50%	50%
Not Aware	10%	28%	0%
Strongly not Aware	10%	20%	50%

As shown in Table 1, more than half or 80% of the members of the faculty are aware of the concepts about green computing while for the students, 48% are not aware about the concepts of green computing. For the staff, 50% are aware about the concepts of green computing. The result of the survey only shows that there is a need to promote the green computing because though majority of the faculty members are aware, it is important that students as well as staff must be properly informed.

4.2 Design and Development of the Software Tool

The developed software tool has two major functions: the centralized power adjustment module and resources optimization module.

4.2.1 Centralized Power Adjustment Module

Our computer unit has its own power adjustment module that can be set individually by the user to adjust its power saving capability. The ability of this module is that the computer administrator has the authority to modify the power adjustment settings of either individual or all computer units connected to the network in an easy manner. There is no software tool yet in the institution that can do the centralized or network-based power adjustment configuration. With a large number of computer units and its capability to use the existing network set-up of the institution, this module can easily modify the power adjustment settings of all computers in the network.

In addition, the module provides automatic shutting-down, restart, hibernate and sleep modes for all computer units based on the laboratory class schedules. For example, if there is no laboratory class at 3:00 pm to 6:00 pm at a certain day, the program automatically turns-off (or depending upon the set mode by the administrator) all the computers in the laboratory to save energy. This is applicable to those schedules without classes for a week. The program is also very useful in the case that students forgot to turn the units off and if there are succeeding vacant periods because the program does the turning off of the units automatically or as set by

the administrator. Figure 1 shows the centralized power adjustment module.

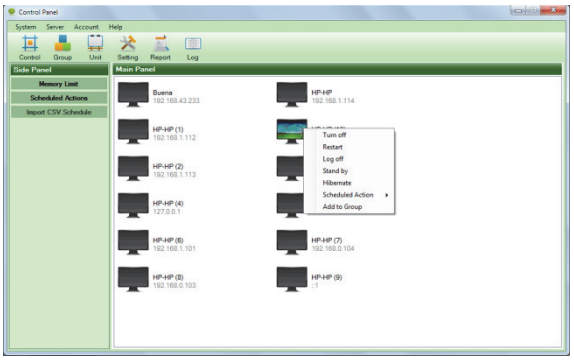


Figure 1: Centralized power adjustment module.

Shown in figure 1 are the options that can be selected by the administrator to configure the power adjustment for individual or all computer units. The module is divided into three (3) sections: control, side and main panels. The control panel contains the following sub-menus: system, server, account and help. The side panel which is in the left portion of the form includes the following sub-menus: memory unit, scheduled actions and import (CSV) schedule and the main panels displays the computer units connected to the network. The administrator can change the power settings of each computer by right-clicking at each computer icon in the main panel. Under the system sub-menu, the administrator can access the following sub sub-menus: control, group, unit, settings, report and log.

Figure 2 shows the server sub-menu.

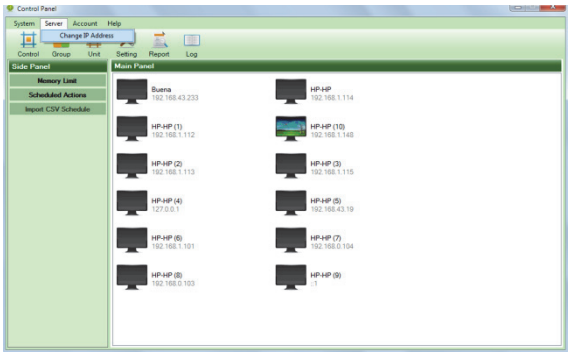


Figure 2: Server sub-menu.

Shown in figure 2 is the server sub-menu which contains the change Internet Protocol (IP) address sub-menu. In this sub-menu, the administrator can modify the IP address of each computer connected to the network.

Figure 3 shows the account sub-menu.

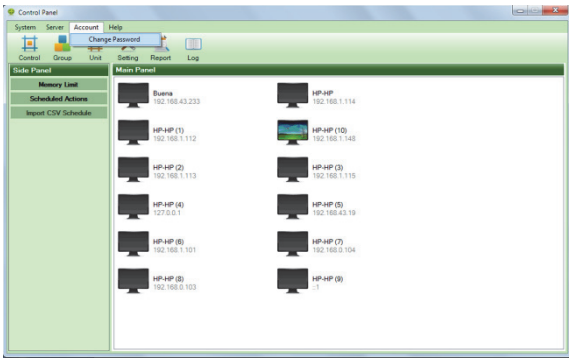


Figure 3: Account sub-menu.

Shown in figure 3, is the account sub-menu where the administrator changes the password of each computer unit. Only the administrator can change the password of each unit for security purposes.

Figure 4 shows the report on computer specifications.

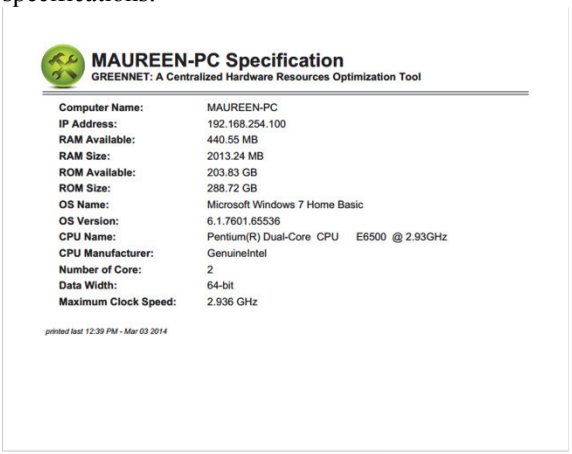


Figure 4: Computer specification report.

As shown in figure 4, is the sample report displaying the computer specification. This report will guide the administrator to adjust the appropriate settings or limits in the hardware resource optimization module.

Another important component in the development of the system is the database structure. Table 2 presents the database structure for computer units in the client side.

Shown in Table 2 is the database structure for the computer unit in the client-side. The structure is used to store the information about the computer including its status. Each field name consists of the field type, length and description.

Table 2: Database structure for the client-side computer unit.

Field Name	Type	Length	Description
clientId	int	11	Primary key
ipAddress	varchar	30	Holds the IP address of a computer
Computer_name	varchar	100	Holds the computer name
OSFullName	varchar	100	Holds the OS full name of the computer
OSVersion	varchar	100	Holds the OS full name of the computer
RAM_Available	double		Holds the avaialbe RAM
RAM_Total	double		Holds the total amount of RAM
CPU_Name	varchar	50	Holds the name of the CPU
CPU_Number Of Cores	varchar	20	Holds the CPU core number
CPU_DataWidth	varchar	20	Holds the data width of the CPU
CPU_MaximumClock Speed	varchar	100	Holds the maximum number of clock speed
status	varchar	20	Holds the status of the computer
lastUpdated	varchar	20	Holds the last update data of the client
controlStatus	varchar	20	Holds the control status of the computer

4.2.2 Resources Optimization Module

This module includes the identification of the capacity and used space or resource of the computer memory and HDD components of a computer unit.

In this module, the administrator can set the limit of the memory and HDD that would be available to users to save the energy needed by the computer to function. The researchers found out that the more we use the computer hardware resources, the more energy it will consume. By limiting the component's capacity, only the application programs needed by the user on that particular period of time can be loaded and will result to faster processing and reduced time consumed by the unit. In the case that the system encounters the limit specified in the computer unit, the module will send notifications to user suggesting ways on what to do to optimize the use of the computer. The module is capable of determining which in the opened applications are not being used frequently by the user. After identifying which applications can be closed since it is not being used, the program will display the notification to the user.

Both modules are capable of generating reports for the uptime and downtime of computers, utilization statistics and status of the computer resources connected to the network.

4.2.3 Formula Used

In order to derive the energy saved by computer with GreenNet, the formula below was used:

Energy consumption (with GreenNet) = EGN

Energy consumption (without GreenNet) = EoGN

Energy Saved =ES

$$ES = EoGN - EGN \quad (1)$$

4.3 Result of the Evaluation of the Developed Software Tool

Several tests are still conducted to determine if the developed software tool can aid in power consumption reduction of all computer units in the laboratories. An initial test conducted is presented below:

Table 3: Test Case using the Power Meter connected to two (2) computers.

Test Description: *Time/ Duration:* 9:03 AM to 6:12 PM *Opened Application:* Chrome, Ms Word, Excel *Initial power reading in W:* 1000480 Wh	**Computer with Greennet**	**Computer without Greennet**
Total Uptime Hours	6.02 h	9.15 h
RAM Usage	815.86 MB	809.72 MB
Wattage consumed/hour	39.87 Wh	39.87Wh
Wattage consumed during the set time span	240 Wh	364.78 Wh
Energy Saved	124.78 Wh	

As shown in table 3 is the result of the test conducted by the researchers. The difference in the total uptime hours was the result of the automatically shutting-down of the computer with GreenNet assumed it was set in the schedule that there is no laboratory class from 3:04 pm to 6:12 pm. The computer without GreenNet that was not turned-off continues to consume power until 6:12 pm. The result showed that in case computers were not turned-off during the vacant period and power adjustment was not set prior, it will continue to

consume power. The difference of 124.78 watts per hour per computer is considered to be the energy saved when GreenNet will be installed to computer laboratories. Hence, the developed system can help reduce the power consumption in the computer laboratories of the institution. This in turn will be of great help to institution in reducing its expenditure for electricity.

Table 4: Test Case using Digital Power Meter connected to five (5) computers.

Test Description: *Time/ Duration:* 12:25 NN to 8:25 PM *Opened Application:* Applications used by the scheduled regular class	**Computers with Greennet**	**Computers without Greennet**
Total Uptime Hours	6.00 h	8.00 h
Energy consumed during the set time span	309 Wh	637.4 Wh
Energy Saved	328.4 Wh	

As shown in table 4 is the result of the test conducted by the researchers using the digital power meter to achieve more accurate and exact results. The difference in the total uptime hours was the result of the automatically shutting-down of the computers with GreenNet assumed they were set in the schedule that there is no laboratory class from 6:25 pm to 8:25 pm. The computers without GreenNet that were not turned-off continue to consume power until 8:25 pm. The result showed that in case computers were not turned-off during the vacant period and power adjustment was not set prior, it will continue to consume power. The difference of 328.4 watts per hour for five (5) computers is considered to be the energy saved when GreenNet will be installed to computer laboratories.

Table 5: Test Case on Measurement of Energy Consumption of Computers with Open Applications using Digital Power Meter connected to two (2) computers.

Criteria	**Computer 1**	**Computer 2**
Total Uptime Hours	1.00 h	1.00 h
Open application	None	Blender, Photoshop, Netbeans
Energy consumed during the set time span	204.2Wh	232.1 Wh

As shown in table 5 is the comparison of the energy consumed by computer unit with and without open applications. The result showed that the when the computer is running more software applications, it consumes more energy than those with no or limited running application. Based on the observations made by the researchers, most of the students in the computer laboratory classes are using software applications which are not required in a particular class set on that scheduled. Therefore, by limiting the capacity of the computer resources to the requirement or need of the particular course only in a given period of time, faster processing will be achieved as well as more energy will be saved.

5 CONCLUSIONS

Based from the results of the study, the faculty, students and staff of the institution are not strongly aware about the concepts of green computing. The institution may initiate programs to increase the level of awareness of its faculty, students and staff about the concepts of green computing. More so, the developed software tool for energy conservation has the capability to centrally manage the power settings of all computer units and optimize the use of computer resources to lessen power consumption to help conserve energy and lastly, the developed software tool can aid the institution to reduce its power consumption thereby reducing the expenses for electricity.

6 RECOMMENDATIONS

Based from the conclusions drawn from the study, it is recommended that the study can be extended in all the computers used within the organization including the administration. Furthermore, additional computer resources can be included in the optimization module and seminar or training programs can be proposed to raise the level of awareness of students and staff.

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Adaptive STM32F4 Microcontrollers
Case of Flexible Smart Meters[*]

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Keywords: Microcontroller, STM32F4, Reconfiguration, Smart Meter, Smart Grid, Software Agent, Modeling and Verification, Simulation.

Abstract: The research paper deals in theoretical level with flexible and adaptive microcontrollers following the well-known industrial technology STM32F4. It is applied in the practical level to a Smart Meter SM which is developed at Cynapsys for future generations of Smart Grids. A reconfiguration scenario in theory is assumed to be any flexible operation allowing the addition-removal-update of OS tasks in order to adapt the microcontroller to its environment according to user requirements. It is assumed in practice to be any addition-removal-update of new services to-from SM such as the energy consumption, the remote information reading and power shutdown, the stabilization of the delivered power, the management of new power provider offers, the sale of energy and finally the peak consumption management. We propose an agent-based architecture for a STM32F4 device where a hierarchical software agent is defined to control the environment evolution before applying local reconfigurations for a required flexibility of the microcontroller. We model the agent by using nested timed automates, and design the whole architecture to manage all possible reconfiguration forms. The agent-based architecture is totally implemented and applied to SM, and a simulator X-SM is developed for the evaluation of this paper's contribution.

1 INTRODUCTION

Microcontrollers, STM32 F4 are special-purpose computer systems designed to perform one or few dedicated functions often with real-time computing constraints in order to control physical processes in the real world. The requirements in the development of microcontrollers are increasingly growing in term of flexibility and agility (Vyatkin et al., 2005) (Pratl et al., 2007). The most promising directions to address these issues is the reconfiguration of one of the most used microcontrollers in the world which is the STM32 F4 to be autonomous as a new challenge, STM32 F4 represents 45% of the microcontroller market, and provides users a number of annexes integrated component, it allows the addition of devices, such as the management of LCD displays. This functionality refers to the process of modifying the software as well as hardware structure and behavior of the system during its execution. Being reconfigurable is important for reacting fast to sudden and unpredictable requirement changes or perturbations with minimum cost and risk. Several interesting academic and industrial research works have been made in recent years to develop reconfigurable control systems (Gehin and Staroswiecki, 2008).We distinguish in these works two reconfiguration policies: static and dynamic reconfigurations such that static reconfigurations are applied off-line to apply changes before the system could starts (Angelov et al., 2005), whereas dynamic reconfigurations are applied dynamically at run-time. Two cases exist in the last policy: manual reconfigurations applied by users (Rooker et al., 2007) and automatic reconfigurations applied by Agents (Al-Safi and Vyatkin, 2007)(Theiss et al., 2009). We are interested in software reconfigurations, and assume that all the

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reconfigurations are applied automatically by an internal module of the microcontroller that should be kept autonomous as much as possible. In the case of a manual reconfiguration, we assume that the reconfiguration agent interacts with user to execute there requests. This controller is assumed to be a superset of OS software tasks such that only a particular subset is loaded at run-time to implement it under user constraints. A reconfiguration will be any automatic operation allowing the addition, removal and update of tasks at run-time. We propose a new module named Embedded Control Module ECM to handle software reconfigurations of the microcontroller. This module is a superset of sub-modules that manage all possible reconfiguration scenarios such as the addition, removal or update of tasks at run-time (Zhang and Wang, 2010) (Pfeffer and Ungerer, 2004) (Chauhan et al., 2009) (Otero et al., 2006). We propose a UML-based model for this ECM which plays a key function inside the autonomous microcontroller. We apply this contribution by assuming the case of electric meters following the STM32 technology of microcontrollers. We consider in particular the smart meter developed at the German-French Company Cynapsys located in Tunisia. This meter supports the classic task dealing with the computation of the energy consumption. Nevertheless, the company plans to add new functionalities that allow these meters to be autonomous and smart. The remote shutdown of the electric power when the bill is not paid, the stabilization of energy, the remote reading of data or display of news, the management of peaks, the management of renewable energy or the remote negotiation between the provider and the clients, will be new original services to be added to the microcontroller of the planned Smart Meter in order to enhance the performance of the devices and optimize the energy management. All these original services to be considered as OS tasks will be handled by the ECM that adapts the device according to user requirements by adding or removing or updating tasks at run-time. The planned smart meter will be a new challenge for Cynapsys in Tunisia to guarantee services with high qualities and with low-costs. We specify these services as well as the ECM according to the model checker by using the tool UPPAAL which is used to simulate the new meter (Alur and Dill, 1994) (Bengtsson et al., 1996). We propose also the implementation of the STM32 smart meter and show the experimentations that we did at Cynapsys to evaluate the whole contribution. The organisation of this paper is as follows. The next section analyzes the Background and a detailed description of the Reconfigurable Embedded Systems, the STM32 Microcontrollers and Current Smart Meters. Section 3 is dedicated to the description of the Smart Meter at Cynapsys Company and describe new challenges and solutions. Section 4, proposes reconfigurable STM32 microcontrollers where we formalize, model and design their behaviors followed by a detailed modeling of our system modules by using UML Diagrams. Section 5 proposes the new original Smart Meter at Cynapsys where we detail their verification, design and implementation. Finally Section 6 concludes this work. Our approach is original by implementing new services in the Smart Meter to manage production and the optimisation of the consumption at Real-Time.

2 BACKGROUND

In this section, we present an overview on reconfigurable embedded systems, the STM32 microcontrollers family and the current used smart meters.

2.1 Reconfigurable Embedded Systems

An embedded system is reconfigurable if it changes its software or hardware behavior at run-time according to user requirements. The software reconfiguration is any operation allowing the addition, removal or update of software tasks that implement the system to encode corresponding functions. The hardware reconfiguration is assumed to be any operation allowing the addition, removal or update of hardware components according to user requirements. An addition or removal can be of memory, of data-event inputs-outputs, or of a new network for communication. The update of hardware components can be the modification of the processor speed. The constant growth of the complexity afferent and necessary to the management of embedded software systems makes reconfiguration autonomy increasingly important. The challenges include both the model design level and the environment level of runtime support. According to(Boukhannoufa, 2012), real-time systems can be large, distributed, and have a dynamic environment. This requires the introduction of various modes of operation and reliability techniques to ensure its operation and maintainability. Moreover, these dynamic changes of architecture and behavior have a negative impact on the temporal characteristics of systems that require a special study on the ability of adaptive behaviors to ensure the hard real-time constraints imposed to the systems. These adaptive behaviors amplify the complexity of developing real-time systems. According to (Wang et al., 2010), the new generations of embedded control systems are addressing new criteria such as flexibility

and agility. To enhance their operations, the embedded control systems should be changed when random disturbances happen or when improvements of the performance should be applied and propose a dynamic low power reconfigurations of real-time embedded control systems that should respect hard real-time constraints and perform modifications of the periods and deadlines, modification of the worst case execution times (WCETs), and finally the removal of some tasks to minimize the energy consumption in order to adjust the behavior of the processor. According to (Kramer and Magee, 1985), the authors propose a reconfiguration model based on the dynamic incremental modification and extensions. In this work, the required properties are determined by languages and their execution environment. In (Thramboulidis, 2004b) (Thramboulidis, 2004a), the authors propose a new vision for the reconfiguration of distributed control applications. The main objective is to bridge their works on software engineering (*eg.* UML) to IEC 61499 (J.H.Christensen et al., 2005). In (Zhang et al., 2013) the authors present a reconfiguration architecture for real-time distributed control systems. Specifically, the low-level control of the physical components which is shown with the handling of real-time requirements. The main contribution of this work is to define a reconfiguration request that interacts with the application under reconfigurations through three interfaces. More specifically, the modification interface provides its role based on a set of key reconfiguration services identified in a previous work (Zoitl et al., 2010). Our contribution is to provide an original approach for the automatic and manual agent-based reconfiguration model for STM32 F4 microcontrollers implementing original services for low power management.

2.2 STM32 Microcontrollers

A microcontroller is an integrated circuit that brings together the essential elements of a computer: CPU, memory (ROM for program RAM for data), peripheral units and input-output interfaces. Microcontrollers are characterized by a higher degree of integration, lower power consumption, lower operating speed, and reduced cost compared with versatile microprocessors used in personal computers. Microcontrollers are widely used in embedded systems such as auto engine systems, remote controls, home appliances and mobile phones. The STM32 technology of 32bit Flash microcontrollers based on the ARM Cortex processor is proposed to provide a 32bit product range that combines high performance, real-time capabilities, digital signal processing, and low-power, low-voltage operation, while maintaining full integration and ease of development. The different STM32 microcontrollers, based on an industrial standardization with a large choice of tools and software, make this family of STM32 the ideal technology for small projects and for entire platform decisions. To apply our reconfiguration approach, we opted for the choice of a STM32 card type STM32 F4 Discovery which is based on STM32F407 Cortex M4 controller with 1MO Flash and 192KO RAM. The STM32F407 family is based on the high-performance ARM Cortex-M4 32-bit RISC core operating at a frequency of up to 168 MHz. The Cortex-M4 core features a floating point unit (FPU) single precision which supports all ARM single precision data-processing instructions and data types. It also implements a full set of instructions and a memory protection unit (MPU) which enhances application security. This card uses power from the USB bus or from an external 5V power supply, a 3-axis accelerometer LIS302DL, two buttons and a micro USB connector (STMicroelectronics, 2013). The use of STM32 F4 cards is the first approach in the field of reconfigurable microcontrollers, in terms of originality, our scientific paper is characterized by the application of different types of architectural, scheduling and data reconfiguration in order to add new services at runtime to the operation of the Smart Meter developed at Cynapsys.



Figure 1: STM32 F4 Discovery Card.

2.3 Overview on Current Smart Meters

According to (S.Depuru et al., 2011), a smart meter is an advanced energy meter that measures the consumption of electrical energy, provides additional information compared to a conventional energy meter.

A smart meter is a counter that automatically registers and communicates data on electricity consumption, it is divided into two main categories: traditional meters (the old electromechanical meters) measure only the total electricity consumption and Smart meters measure the amount of electricity consumed and the time of consumption, they automatically transmit data to providers by using a wireless communication technology (Ahmad, 2011) (Hoenkamp and Huitema, 2012). The price of electricity with these data may vary during the day, giving houses a new way to manage the costs of their consumptions. You could, for example, choose to reduce your consumption during the most expensive time (peak or normal) and partially use electricity during off-peak hours, during which it will be cheaper. Investigations conducted in Tunisia have for the moment appear incomprehensible bill increases in number. These Meters are intelligent and used to regulate the energy delivery in peak of consumption periods, for example the French Electricity Distribution Network ERDF has with the Smart remote Meter Linky, the ability to change their rates from one minute to another, according to the consumption of international prices electricity (ERDF, 2009). In Cynapsys, we propose a new strategy to add the original proposed services to the old developed Smart Meter which was a remote control example of a DC motor. This last represents one of the end devices that can be used at home or a building. The communication with the Energy Counter is established by means of wireless communication protocol ZigBee. The Energy counter module allows providing information about the average of the energy consumption of all the elements connected to it. In addition it permits to get the real-time consumption of the home or building via ZigBee protocol. Today the deployment of Smart Meters should allow a better understanding of the positions of power consumption and thus save money. Monitoring real-time also opens the door to energy billing in real time, but also to the differentiated based billing electricity demand (peak load). Into this research we will enhance the behavior of the electric meter by the services described above in order to make it more intelligent. Intelligence brought many advantages for the customer and energy companies. Starting with a bill which can be calculated on the basis of real consumption, interventions carried out remotely (without constraint of appointment) including stabilization of the varying voltage and regulating consumption by micro-cuts in periods of high consumption known to peak loads. Consume less power and better is the goal of our study. These optimizations will be applied to the electric meter developed by Cynapsys. The intelligence provided to the meter is by adding new services that provide an immediate benefit to the counter in real-time. Smart meters equipped consumers should not pay an estimate bill but they consider real power consumptions. This new generation of meters can display power consumption and remote meter reading. Thus the consumer can also save money by better monitoring its power consumption. The use of smart meter certainly makes life easier for users, thanks to its new services such as the automatic control of electrical devices at home and the regulation of supply and demand through remote micro-cuts in order to not exceed a fixed consumption threshold. Our paper consists of two novel approaches, the first is a theoretical approach to enhance the electric meters with new original services, and in the second we propose a practical approach by proposing the X-SM Simulation tool.

3 ADAPTIVE SMART METERS OF CYNAPSYS COMPANY: NEW CHALLENGES AND SOLUTIONS

At the German-French Company Cynapsys, the current research paper is applied to a well-developed STM32-based electric meter for the remote control of home end devices. The meter encodes a main counter module ECM to provide the real-time energy consumption of any connected device to it by using a Zigbee-based protocol. In addition to this classic function, we propose to enrich the meter with original services such as the remote shutdown of power, the remote reading of the energy consumption from the meter to the provider, the smart stabilization of power by using renewable energy that we assume available at home, the display of the energy consumption for users at home, the smart management of promotions to be offered from the provider by relatively activating or deactivating home end devices when the price of power (per hour) is low or high, the sale of energy to the provider when the available renewable energy is enough, the smart peak management by deactivating home end devices during peak times, and finally the management of news to be sent from the provider about the network status in the next weeks or months. These optimizations will be applied to the electric meter developed by Cynapsys. Note that all these services will not be loaded together on memory in order to not overload the memory by the applications and the tasks that will not be executed. Thus, the system preserves all its resources to treat most substantial services. Except the main service dealing with counting,

we assume that each another will be loaded on memory when needed at run-time. Reconfiguration in our approach keeps the system available, increase operating efficiency and especially without remarkable performance degradation. We propose a model of dynamic automatic reconfiguration, or possibly manual to be executed through a decision module that handles these cases in real-time. The current paper deals with the theoretical level of the STM32 Microcontroller to be assumed flexible and autonomous. Each service is assumed to be implemented by an OS task. The system is then implemented by a superset of tasks such that only one subset implements it at a particular time after a well-defined reconfiguration scenario. The paper deals in the application level with this Smart Meter of Cynapsys to be enriched with these new services. Each addition-removal of a service on the smart meter corresponds to a reconfiguration scenario. The services and the tasks in our approach are executed according to the priority to be assigned and based on the importance of the operations as the remote power shutdown that must be executed upon his arrival. We denote in the following by:

- T_1: the main software task that measures the energy consumption by reading directly and not by an estimation of consumption. This task has the highest priority,
- T_2: the software task allowing the remote shutdown. The meter we conceive is remotely programmable and equipped with a remote switching device called "AMM" (Advanced Meter Management). This service is crucial in the case of non-payment of bills,
- T_3: the software task allowing the remote reading from the smart meter to the power provider and remote users,
- T_4: the software task allowing the stabilization of the delivered power from the provider by using if possible (if the input load is decreased at run-time) the renewable energy that we assume available at home,
- T_5: the software task allowing the display of information on the meter which is equipped with a digital displayer,
- T_6: the software task allowing the management of promotions to be offered from the provider, this task informs users by SMS and emails about these offers,
- T_7: the software task allowing the sale of energy to the provider when the available local energy is enough, this task informs users by SMS and emails,
- T_8: the software task allowing the management of peaks by using useful information to be sent by SMS and emails from the provider,
- T_9: the software task allowing the management of all news to be sent from the provider about the network status. This task informs users by SMS and emails.

The proposed tasks are considered as a new generation of energy production and consumption. They represent a solid medium for effective management of the power across the electric Smart Meter which is the entrance of the smart grid.

4 THEORETICAL CONTRIBUTION: RECONFIGURATIONS OF STM32F4 MICROCONTROLLERS

We aim in this section to dynamically reconfigure a STM32 microcontroller which is assumed to be implemented by a set of independent OS tasks. The goal is to adapt its behavior at run-time to its environment according to well-defined user requirements. A reconfiguration scenario is assumed to be any dynamic operation allowing the addition, removal or update of tasks to-from the microcontroller. We propose an Embedded Reconfiguration Module to be denoted by ERM that controls the evolution of the microcontroller's behavior and considers also user requirements to apply run-time reconfigurations. The ERM is assumed to be encoded in three hierarchical software levels: (a) Architecture Level (to be denoted by AL), (b) Scheduling Level (to be denoted by SL), and (c) Data Level (to be denoted by DL). We define in AL, all the possible software architectures that can implement the STM32 microcontroller at run-time. An architecture in AL is a set of OS tasks that perform control activities. A reconfiguration scenario can change the software architecture of the microcontroller by adding or also removing OS tasks. For each architecture in AL, we need to define an execution model of the corresponding tasks. A scheduling is then defined in SL to affect a priority to each task. For each architecture and for each scheduling of the corresponding tasks, we define also in DL all the possible corresponding values of data to be handled at run-time. Thanks to this hierarchical structure, the ERM can handle all possible reconfiguration scenarios of a STM32 microcontroller, our approach is original because no previous work did the same hier-

archical architecture on STM32F4 to handle reconfiguration scenarios.

4.1 Formalization of Reconfigurable STM32 Microcontrollers

Let *Sys* be the STM32 microcontroller that can be reconfigured at run-time to adapt its behavior to its environment. We denote by Γ_{Sys} the big set of all the possible tasks involved in the different implementations of the system *Sys*, which is implemented at any particular time *t* by a subset ξ_{Sys} which represents the set of tasks involved in a particular implementation $\xi_{Sys} \subseteq \Gamma_{Sys}$. We model the architectural level *AL* of *ERM* by a finite state machine S_{AL} such that each state of S_{AL} corresponds to a particular implementation at architectural level.

$$S_{AL} = (\Gamma_{Sys}, O, \delta), \text{ such that,}$$

- O is a set of n states in S_{AL} ($O = \{S^i_{AL} / i \in 1..n\}$),
- δ is a state-transition function $\Gamma_{Sys} X O \rightarrow \Gamma_{Sys} X O$

A reconfiguration scenario $R^{i,j}_{AL}$ is a transition from a state S^i_{AL} corresponding to particular subset of tasks ξ^i_{Sys} to a state S^j_{AL} corresponding to particular subset of tasks ξ^j_{Sys}. In this scenario, we assume run-time operations allowing addition-removal of tasks to adapt the system *Sys* to its environment. For each state S^i_{AL}, we define in the second hierarchical level(Scheduling Level *SL*) a particular state machine to be denoted by S_{SL}. Each state in S^i_{SL} defines a particular scheduling of the subset of tasks ξSys. This scheduling affects a priority to each task in order to get a deterministic execution model of the microcontroller *Sys*. We denote by $\Psi(\xi_{Sys})$ the set of all possible execution models of tasks of ξ_{Sys} at the Scheduling Level.

$$S_{SL} = (\Psi(\xi_{Sys}), P, \beta), \text{ such that,}$$

- P is a set of m scheduling states in S_{SL} ($P = \{S^i_{SL} / i \in 1..m\}$)
- β is a state-transition function $\Psi(\xi^i_{Sys}) X P \rightarrow \Psi(\xi^i_{Sys}) X P$

A reconfiguration scenario $R^{i,j}_{SL}$ at Architectural Level AL, is a transition from a state S^i_{SL} to another state S^j_{SL} of S_{SL}. The reconfiguration of the microcontroller *Sys* in the third hierarchical level *DL* can be the update of data. We define for each state S^i_{AL} of S_{AL} and also for each state S^j_{SL} of S_{SL} a new state machine S_{DL} where each state corresponds to new values to be affected to data of tasks belonging to ξ_{Sys} under the scheduling S^i_{SL}. Let $\Upsilon(\xi_{Sys})$ be the set of all possible values of data for the tasks of ξ_{Sys} under the scheduling S^j_{SL}.

$$S_{DL} = (\Upsilon(\xi_{Sys}), Q, \beta), \text{ such that,}$$

- Q is a set of l data states in S_{DL} ($Q = \{S^i_{DL} / i \in 1..l\}$)
- β is a state-transition function $\Upsilon(\xi^i_{Sys}) X Q \rightarrow \Upsilon(\xi^i_{Sys}) X Q$

A reconfiguration scenario $R^{k,h}_{DL}$ is a transition to change the values of data from a state S^k_{DL} to another state S^h_{DL} of S_{DL}. We denote finally by $Config_{i,j,k}$ a configuration of the STM32 microcontroller *Sys* to be implemented by the subset of tasks ξ^i_{Sys} under a well-defined scheduling corresponding to a state S^j_{SL} in S_{SL} with particular values of data defined in a state S^k_{DL} in S_{DL}. A reconfiguration scenario to be denoted by $Reconfig^{u,v,w}_{i,j,k}$ of *Sys* is defined then as any run-time operation allowing the adaptation of the microcontroller from a configuration $Config_{i,j,k}$ to a new one $Config_{u,v,w}$. The originality of our approach is distinguished by a specific formalization of the scenarios as possible reconfigurations and the exclusivity of the application of our original ideas to the Electric Smart Meter.

4.2 UML-based Design of Reconfigurable STM32 Micro Controllers

To implement the different run-time reconfiguration scenarios of the STM32 microcontroller *Sys*, we propose in Figure 2 a UML class diagram that designs both the Embedded Control Module ECM and also the different OS tasks belonging to Γ_{Sys}. Our class diagram consists of a ECM class that plays a very important role in our reconfiguration approach. This class manages all the interactions in the system, it is related to the classes AL, SL, DL which respectively represent the architectural reconfiguration level, scheduling reconfiguration level and data reconfiguration level. We have also four other classes: Provider Interface, User Interface, Equipment Interface and Task. The Task class represents all the tasks included in the different implementations of our system. The user interface class represents all the customers of our system. The Equipment Interface class, includes all devices connected to the counter. Finally, the Provider Interface class manages the relationship with the electricity supplier.

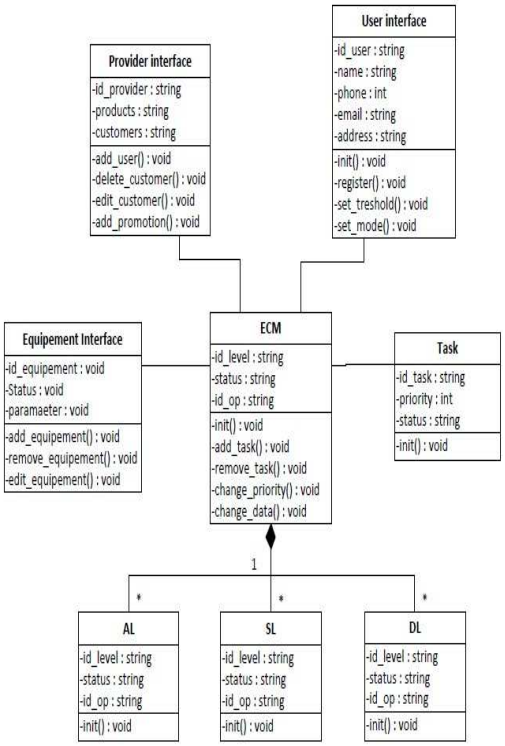


Figure 2: UML Class Diagram of an Adaptive STM32 Microcontroller.

5 PRACTICAL CONTRIBUTION: CASE OF NEW SMART METERS AT CYNAPSYS

In this section we present the practical contribution of our approach.

5.1 Timed Automata Models

We describe in Figure 3 the different state machines encoding the ECM of the STM32-based Smart Meter. The state machine encoding the Architectural Level is composed of four states:

- Counting the energy consumption
- Regulation of the energy
- Promotion negotiation
- Remote shutdown of the electricity

The first state Counting corresponds to the system's implementation $\xi^1_{Sys} = \{T_1, T_3, T_5, T_9\}$ when the main task T_1 is active as well as the tasks T_3, T_5, T_9 that allow respectively the remote reading, the display and the management of news. The second state Regulation corresponds to the system's possible implementation $\xi^2_{Sys} = \{T_1, T_4, T_5, T_9\}$ when the main task T_1 is also active as well as the tasks T_4, T_5, T_9 that allow respectively the stabilization, the display and the management of news. The third state Negotiation corresponds to the system's possible implementation $\xi^3_{Sys} = \{T_1, T_5, T_6, T_7, T_8, T_9\}$ when the main task T_1 is active as well as the tasks T_5, T_6, T_7, T_8, T_9 that allow respectively the display, the management of promotions, the sale of energy, the management of peaks, and finally the management of news. We describe also in the scheduling level the different possible execution models of tasks encoding each state in the architectural level. The scheduling *Sched*1 of the state Counting executes the main task of counting T_1 each time it executes T_3, T_5 and T_9. The precision of counting is high in this case. The scheduling *Sched*2 of the same state Counting reduces the precision by executing T_1 two times in a trace of execution. The precision of counting is low in *Sched*3 that executes T_1 only one time. We describe in Data Level the periodicity of each trace of execution in the second level. In this case, *Sched*1, *Sched*2 and *Sched*3 are respectively executed periodically each 100*ms*, 300*ms* and 500*ms*.

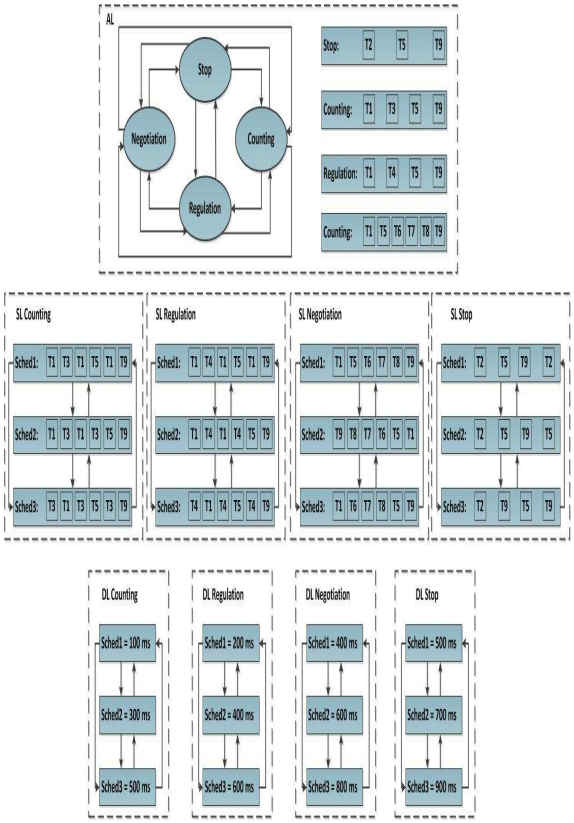


Figure 3: State Machines of the Embedded Control Module that handle the reconfigurations of the STM32-based Smart Meter.

The design of reactive systems must comply with logical correctness: ”the system does what it is supposed to do” and timeliness: ”the system has to satisfy a set of temporal constraints”. The smart meter should respect the notion of time such as if a power interruption is requested it should execute this task immediately, then it can reactivate the electricity due to the existence of functional constraints such the payment of bills or the passage of a period of high consumption. We model and simulate the different state machines of ECM as well as the different assumed tasks by using the well-known model checker UPPAAL in order to check the behavior of the adaptive smart meter after each reconfiguration scenario. According to (Palshikar, 2004), model checking is the most successful approach that’s emerged for verifying requirements. We describe in Figure 4 the model of the second task T_2 allowing the remote shutdown of the smart meter according to the formalism Timed Automata. The meter we conceive is remotely programmable and equipped with a remote switching device called ”AMM” (Advanced Meter Management). This service is crucial in the case of non-payment of bills, the deployment of a team to ensure power cuts today becomes useless.

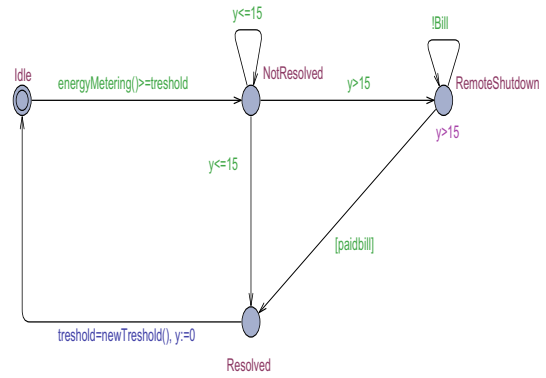


Figure 4: Model of T_2.

The voltage variation is defined in relation to other disturbances that can affect the electric network. It is generally defined as a decrease followed by an increase (sometimes the opposite, but less frequently) of the electric intensity. We describe in Figure 5 the model of the task T_4 allowing the stabilization of the consumed energy. The operation of stabilization is based on the use of the stored energy derived from green renewable sources. In the case of voltage fluctuation the battery is checked in the state BatteryCheck and the compensation process begins.

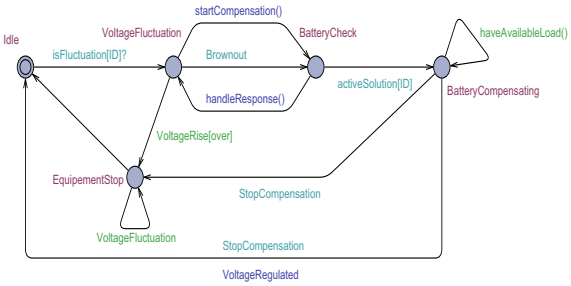


Figure 5: Model of T_4.

5.2 Implementation of the X-SM Simulation Tool

The simulation is a mandatory step for the final deployment of any system to be represented by a model. In our research work, a simulator is developed for the simulation of all these services that encode the electric meter of our company Cynapsys. We developed an environment X-SM for the simulation of a STM32F4 based smart meter. Our tool is essentially a program that allows the counting (a)the total power consumption of all devices that are connected to the electric meter, (b) the execution of any remote shutdown of the electrical energy in the case of exceeding the threshold of consumption, (c) the management of promotional offers proposed by producers,(d) and finally the stabilization of the energy variation. The main interface of our tool presents the different services offered by the Smart Meter and the various devices connected to it. To test the microcontroller, we assume three types of devices: a lamp, a refrigerator and a boiler with their characteristics and parameters such as the device name, the power, the device state (on or off), the priority, the shutdown condition, the output number (identifier) and the period of use.

The power consumption counting service, oper-

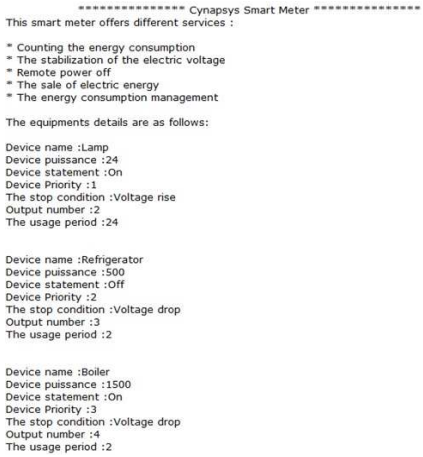


Figure 6: Tool Main Interface.

ates in real-time and provides the equivalent amount of the consumed quantity. It stills compared to the fixed consumption threshold as shown in the figure below.

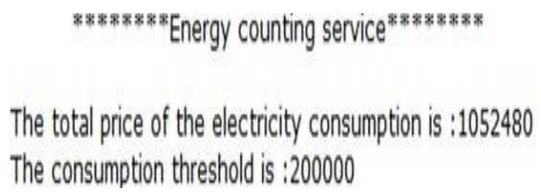


Figure 7: Energy Counting Service Interface.

The remote shutdown service interface informs the user by SMS and email, that the consumption threshold is exceeded. It performs the shutdown operation and changes the state of the device from On to Off. The user is informed in parallel about the electricity shutdown so that he can pay his unpaid bills, or rationalize his energy consumption.

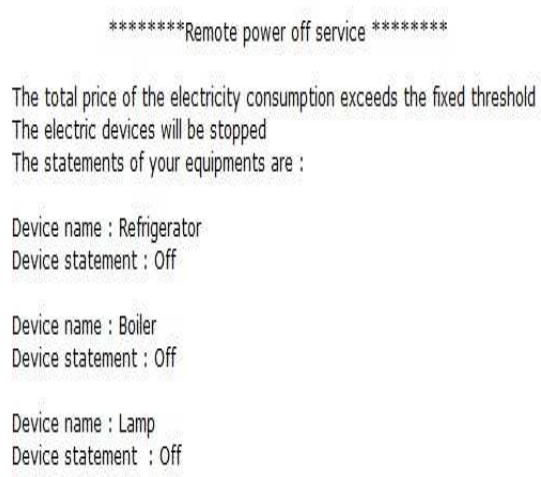


Figure 8: Remote Shutdown Service Interface.

The voltage stabilization is a capital service, it helps to maintain the electrical equipment in the house against voltage variations that can damage them. The interface of the tool detects a variation and identifies its type, whether it is an increase or decrease in voltage. It informs the user by SMS and email that a shutdown must be performed. After the Shutdown the system pass to the compensation solution by using the amount of energy stored in the batteries produced from supposed renewable sources at home.

Below the management peak consumption service interface proposed by our environment X-SM, a peak energy consumption is generated by a strong demand for electricity and an imbalance in supply and demand. The smart meter allows smooth management of these peak periods through an anticipation mechanism.

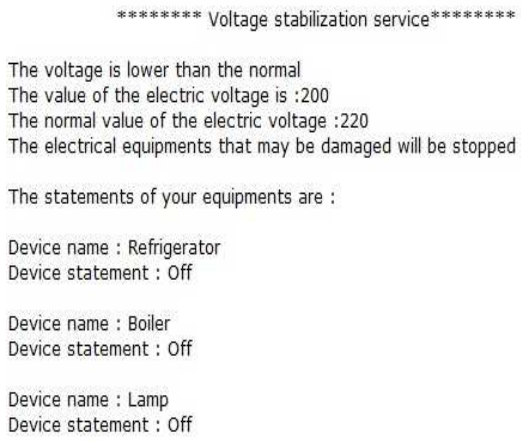


Figure 9: Voltage Stabilization Service Interface.

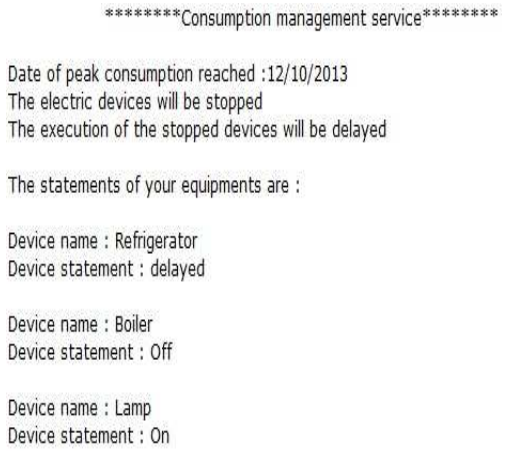


Figure 10: Peak Consumption Management Service Interface.

After crossing the period of peak consumption, the user regains his normal operating mode. The stopped devices will resume there normal executions. The system of anticipation / reaction offers an innovative solution that provides a huge gains and preserve the equipment in houses, which can be damaged by sudden and unexpected cuts. Below the end of the peak consumption interface.

5.3 Experimentation

The figure 12 shows a comparison between the results obtained before and after the contribution of our proposal. We assume that the daily consumption of electricity in regular time is estimated at 4 KWH. During peak consumption this value should not exceed 2 KWH per day. The reconfiguration applied to our electric meter, gives rise to direct cuts that should not exceed the fixed amount of electricity.

After connecting the STM32 F4 card to our X-

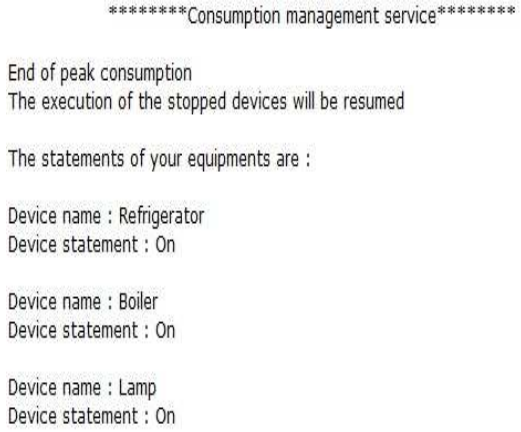


Figure 11: End of Peak Consumption Service Interface.

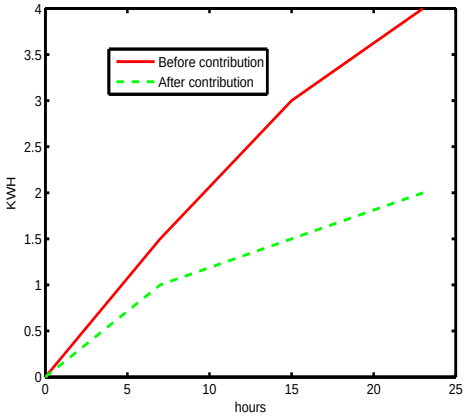


Figure 12: Peak Consumption Management Service.

SM simulator, the data acquisition is performed via a communication and information collecting protocol. Our simulation environment shows the reaction of the electric smart meter face to the detection of voltage variation. The reconfiguration process enables the service of voltage stabilization via the compensation through renewable production sources and electrical equipment shutdown, so they are not damaged.

6 CONCLUSIONS

This paper deals with an agent-based dynamic reconfiguration of a microcontroller solution. Our approach is started by a complete study of the actual electric meter in the field of energy development and applied to the Cynapsys developed smart one. The reconfiguration agent allows the embedded systems to change its software or hardware behavior at runtime according to user requirements or environmental changes. We propose in this work an embedded

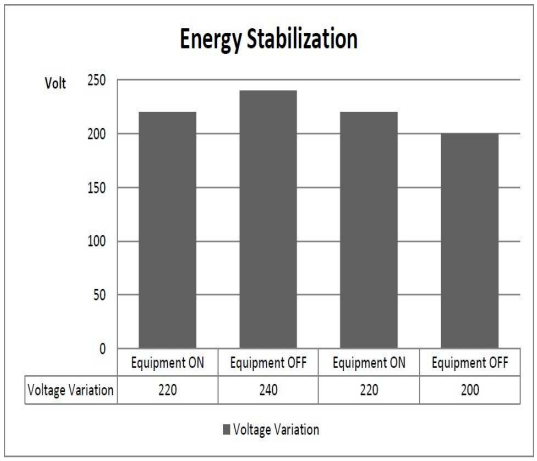


Figure 13: Energy Stabilisation Histogram.

reconfiguration of the microcontrollers following the STM32 F4 technology the well-used in the world. To manage the reconfiguration process we propose an agent-based architecture, composed of the architectural level, Scheduling level, and data level. We present a detailed formalization, verification of nested state machine models and a software design version which is based on UML Class Diagram before the development of complete simulation tool applied to the Smart Meter developed at the German-French company Cynapsys. The proposed approach is original and is distinguished from the related works in this field, the product will now proceed to the production and marketing by the company Cynapsys. we will focus more in the future on the communication between electricity providers and smart meters, we will give more importance to the electricity metering based on the real consumption of the consumer, deploy this prototype in a smart city and finally the massive industrialization of this innovative product.

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New Software Solutions for Low-power Management of Green Smart Homes*

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Keywords: Microcontroller, STM32F4, Reconfiguration, Smart Home, Smart Grid, Software Agent, Modeling and Verification, Simulation.

Abstract: The research paper deals with new Green Smart Homes which offer original services such as the optimal power consumption, peak management, and home power selling while assuming an available home green energy. We propose a Master-Slave based architecture following the well-known industrial technology STM32F4. A microcontroller Slave Agent is proposed for each selected Home Device to control its local consumption, and a unique microcontroller Master Agent is proposed to control the whole architecture. The goal is to optimize the use of green energy, to minimize the consumption costs by exploiting the offers from providers and also the peak times. We model these services by using the model checker UPPAAL, and propose UML design diagrams for this architecture. A visual simulator of this STM32-based architecture is developed and applied to a case study proposed by Cynapsys.

1 INTRODUCTION

Home automation consists in the management of our equipments based on new technologies and also in the proper use of information. If it is properly used, the home automation can make real energy savings and be part of a sustainable development of the future electricity networks. Home automation presents itself as an alternative to reduce energy costs, increases intelligence at homes by the mean of sensors and actuators, as well as maintaining the power grid by the balance of supply and demand. To make life easier, Home Automation is an obvious choice, it allows to design a green grid, which is based on renewable energy and to encourage innovation through the latest discoveries in the field of high tech. In recent years, several studies about the automation were conducted; the most important proposes an approach that is based on the diversification and the decentralization of energy production sources and the development of a platform that enables the exchange and communication between different types of interconnected networks (Torbensen, 2008). Inspired by (Abras et al., 2008) home automation systems can be combined with Multi-Agent Systems for the home energy management and the adaptation of the consumption to the available green energy resources as well as the development of new algorithms for emergency and anticipation mechanisms. Among the used communication solutions at home automation systems, Internet, ZigBee or Bluetooth have been proposed to control households from an remote location by using visual interfaces and web applications. (A.Vichare and Verma, 2012)(Gill et al., 2009)(R.Piyare and M.Tazil, 2011). we are interested in this research in optimal home electricity management through the creation of new modern Home Automation Services. We propose an original reconfigurable home automation system Model which allows the dynamic change of the daily behavior at run time according to user requirements and energy constraints. The reconfigurable model of our approach consists of the execution and the control of three runtime services: a Power Consumption Management Service which is used to manage and control the power consumption of equipments at home. It adapts the energy demands to production

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systems through an action plan predefined by the user. The second service consists of the Management of the green low power distribution which is based on the decentralization of production through the use of renewable sources in low-voltage networks. This energy is stored in batteries and used according to a specific management and consumption policy. This service also allows the user to manage sales promotional offers, it may as well buy energy during discount periods, store it and use it when prices are inflated. Finally we propose the third peak management service which allows to manage high consumption periods by deactivating directly the equipments or delaying there execution. This service also allows to compensate the difference between the production and the consumption thanks to use of green energy that we assume stored in batteries. These original services meet exactly the different requirements of the modern and smart electricity grid. We propose a Multi-Agent based architecture to offer these services. It is composed of: (a) City Information Agents to gather the useful information for the distribution and the use of electrical energy, (b) City Master Agents that control Home Master Agents which supervise Home Slave Agents to be responsible for the operation of the electrical equipments at homes, and finally (c) Home Storage Agents to be deployed for the monitoring and the exploitation of renewable energy produced and stored in batteries at home. An original Master/Slave architecture is hierarchically proposed in the current paper to manage Information, Storage and the proper use of green electricity. This architecture is guided by a communication protocol that manages the exchanged messages between the different agents in order to perform the services discussed above. This optimal protocol allows the management of renewable energy, management of consumption peaks and management of electricity consumption. We also propose the formalization of these services and the design of the software with UML diagrams. We verify the whole architecture by proposing timed automata models, and apply UPPAAL for model checking(Alur and Dill, 1994),(Bengtsson et al., 1996). We aim to verify functional and temporal constraints since our system is strict and does not tolerate faults and mismanagement of used data and information. The study of our approach leads us to develop a simulation tool to be named X-SH which is an original product for the power management in smart homes. The paper's contribution is applied to a real case study provided by Cynapsys in order to discuss its advantages. The rest of this paper is organized as follows, the next section presents the state of the art of Smart Homes. Section 3 presents the Case Study of Cynapsys that will be assumed as a running example in this paper. Section 4 proposes the Multi-Agent Master/Slave architecture followed by a formalization of the problem and the proposed services, the UML design and the verification of timed automata models, The Simulation tool X-SH. Finally section 5 concludes this research works.

2 BACKGROUND

We present in this section an overview on Home Automation Systems, System Reconfiguration and Master/Slave Agent based architecture.

2.1 Home Automation Systems

Nowadays, the research works in the field of home automation systems have a unique direction to look for luxury, comfort and the mixture between daily tasks and new technologies. The authors in (AlShu'eili et al., 2011) propose a new approach for voice recognition based wireless home automation system to control all lights and electrical appliances at home or offices by using voice commands, they propose a verification test based on the voice recognition. However, this approach is weak against identity theft and imitating the voice of the house's owner, so anyone can take control of the home. According to (Nunes, 2010), an architecture for a home automation system is given, which has a distributed nature, very modular and can easily be expanded in size and functionality. The authors present two types of constitutive modules interconnected through a network. The proposed approach consists of Supervision Module (SM) and a Control Module (CM) to be interconnected by a Communication Network, a simple system with an Action/Reaction mechanism. In (Debono and Abela, 2012), the authors present an implementation of a home automation system through a central FPGA controller as a simple solution whereby the user control devices by employing a central field programmable gate array (FPGA) controller to which the device and sensor are interfaced. The control is established by using a communication with the FPGA from a mobile phone through its interface. A design of a networked monitoring System for home automation is presented in (Song et al., 2007). The system consists of a base station, a home server, wireless sensor nodes and smart user terminals such as PC and PDA. A ZigBee-Based Home Automation System is developed in (Gill et al., 2009). the authors present a flexible and low cost home automation infrastructure. The home's low data rate, control and monitor-

ing needs are catered by using ZigBee. the authors in (Ha, 2009), try to present a dynamic integration of ZigBee home networks into home gateway by using OSGi service registry. The proposed architecture is divided into two layers of ZigBee home networks; physical and logical interface. A realization of home remote control network based on ZigBee is described in(Shunyang et al., 2007); the authors present the ZigBee as an emerging wireless communication technology with low cost and low power characteristics.

2.2 Reconfigurable Embedded Systems

We assume that an embedded system is reconfigurable if it changes its software or hardware behavior at run-time according to user requirements. The software reconfiguration is any operation allowing the addition, removal or update of software tasks that implement the system to encode corresponding functions. The software reconfiguration is assumed to be any operation allowing the addition, removal or update of hardware components according to user requirements. An addition or removal can be of memory, of data-event inputs-outputs, or of a new network for communication. The update of hardware components can be the modification of the processor speed. We are interested in this paper in software reconfigurations. We distinguish two reconfiguration policies: static and dynamic reconfigurations (Wang et al., 2010). Static reconfigurations are applied off-line to implement changes before the cold start of the system (Angelov et al., 2005), whereas dynamic reconfigurations are dynamically applied at run-time.(Seokcheon, 2010)(Hu et al., 2011) Two cases exist in the latter: manual reconfigurations applied by users(Rooker et al., 2007) and automatic reconfigurations to be applied by intelligent agents (Seokcheon, 2010)(Khalgui et al., 2011).

2.3 Master/Slave Multi-agent Architecture

According to the authors in (Megherbi and Madera, 2010), the Master-Slave architecture is described as the most popular and widely used architecture in the distributed systems. Master software nodes assign each slave node for a specific amount of work, and once the slave has completed its task, it reports the results back to the master. In (Nwana et al., 1996), the authors propose a coordination model in software agent systems, based on Master-Slave architecture, the master agent plans and distributes fragments of the plan to the slaves. The slaves may or may not communicate among themselves, but must ultimately report their results to the master agent.

2.4 Contribution: New Services for Smart Homes

According to the study of these research works proposed in Smart Grids, Home Automation Systems, Multi Agent Systems, and Reconfigurable Embedded Systems, we find that the researches carried out: do not respond exactly to the requirements of the modern world, do not consider the exponential growth of the energy consumption, and do not follow the new technical and technological progress. These works are simple, wobbly, and too generalizing. Indeed they lacked precision and intelligence. We propose in the current paper a new Master/Slave Multi-Agent architecture in order to: (a) decentralize the control, (b) guarantee the determinism, (c)and reduce the number of messages circulating in the network. This original architecture allows: (a) the management of the energy consumption, (b) the management of peak period, (c) the use of renewable green energy to be stored in batteries, (d) and the management of the promotional offers from providers when the prices are down.

3 CASE STUDY: CYNAPSYS HOME AUTOMATION SYSTEM

We present in this section the Cynapsys Smart Home (to be denoted by CSH) which was maintained as the reference case study of our company in the current project. We assume a house to be composed of six rooms and a garden. Each home area is supposed to be controlled by a STM32 F4-based electronic equipment for the optimal daily energy consumption (STMicroelectronics, 2013). CSH ensures serenity and control of ambient lights, appliances and access. The Proposed CSH provides automated blind controls to open or close, and to be based on times or light and heat levels. An integrated cooling and heating system to optimize the energy use through pre-determined scheduling or temperature controls, as well as the management of the smart meter to control electricity consumption in real-time and the promotional offer of the energy providers. We propose a control irrigation system and pool pump operation management and finally the integration of new green renewable energy production sources to be composed mainly by wind and solar panels that we store in home batteries. The CSH shows many interests: (a) the billing service, (b) the conservation of energy, (c) the

peak management, (d) and the use of renewable energy. Figure 1, provides a description of CSH that we assume as a running example in this paper.

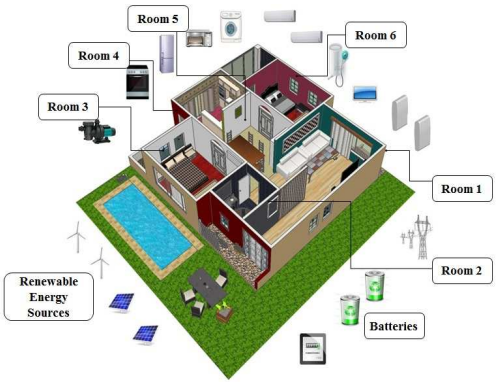


Figure 1: CSH case study.

We propose the characteristic of the CSH equipments in the table below with real values about the energy consumption, the frequency of use and the priority of each device.

Table 1: Electrical Equipment Characteristics.

Equipment	P	UF	CA	Pr
Combined Fridge	100 W	Continuously	875	2
Air Conditioning	150 W	5 H/day	450	2
Washing machine	940 W/C	3 cycles/week	135	1
Microwave	500 W	1.5 H/Week	36	1
Boiler	2000 W	80L/day	400	1
Heating	60 W	Continuously	345	2
Pool Pump	1500 W	5H/day	750	1

Where:
P: is the equipment power (watt)
UF: is the equipment usage frequency
CA: is the equipment Calculated amount (KWH)
Pr: is the equipment Priority.
The data presented above will be used in the implementation of our proposed new services such as the management of peak demand or help the user to rationalize its energy consumption and pay less. In this section, we propose a novel idea which is based on the classification of household tasks into two broad categories, the first category contains the permanent tasks, *i.e* the daily tasks that have the highest priority such as: radiators and heater. The second category contains temporary tasks that can be delayed, such as television, washing machine, dishwasher and iron. We will assume that we have three tariff zones in a day as described in Table II: (a) from midnight to 8am, (b) from 8am to 16pm is a middle zone and (c) from 16 pm until midnight. The first zone is used for the normal consumption and we attribute coefficient 2 to this period. The second one is characterised by a consumption peak and has the high coefficient equal to 4. The last one is a medium zone with consumption coefficient equal to 3.

Table 2: Pricing zones.

	Normal Zone	Peak Zone	Medium Zone
Time Slot Time Slot	00.01 to 8am	8.01am to 16pm	16.01pm to 00.00
Coefficient	2	4	3
Price Mill/KWH	130	260	195

In the following, we will present the advantages of using three tariff zones for both continuous and partial time tasks.

- For a continuous task, for example refrigerator:
  - With a unique tariff (peak zone): The annual consumption in Tunisian Dinar is equal to:

$$875 * 0.260 = 227.5\ TND/Year. \quad (1)$$

  - With three tariff zones: The annual consumption in Tunisian Dinar is equal to:

$$(875 * (0.130 + 0.260 + 0.195) \div 3) = 170.6\ TND/Year. \quad (2)$$

- For a partial time task, for example the pool pump:
  - With a unique tariff (peak zone): The annual consumption in Tunisian Dinar is equal to:

$$(750 * 0.260) = 195\ TND/Year. \quad (3)$$

  - With Normal tariff zone: The annual consumption in Tunisian Dinar is equal to:

$$(750 * 0.130) = 97.5\ TND/Year. \quad (4)$$

In the first case, we notice a gain in the bill equal to $(227.5 - 170.6)$ TND. In the second one, the user choices the cheapest pricing zone and can earn the half of the price $(195 - 97.5)\ TND$.

To test the peak management service, the electricity daily consumption estimation during a summer day is as follows (using Table I):

$$(2.4 + 0.75 + 0.45 + 0.11 + 1.09 + 7.5) = 12.3\ KWH/Day. \quad (5)$$

The available energy during peak consumption period is equal to 2 KWH/Day. So in this case, the requested value is equal to 10.3 $KWH(12.3 - 2)$. We propose to deactivate the less priority equipments during peak periods. So we will only keep the refrigerator and air conditioning and the daily consumption will be equal to:

$$(2.4 + 0.75) = 3.15 KWH/Day. \quad (6)$$

Compared to the provided value, we still need 1.2 KWH to meet the daily electricity lack. We assume that we have domestic batteries to store energy

produced by renewable sources. The used batteries are divided into two parts. The first part uses 70% of the available capacity for optimizing the production. The second part uses 30% to solve the peak consumption problems. For example, if the battery available amount of energy is equal to $4KWH$, we have to use only 30% of this amount, which is equal to $1.2KWH$

After using our idea, we we

re able to avoid a peak consumption by delaying the execution of some lower priority equipment and compensate the remaining value through the use of renewable energy available in the battery.

4 MULTI-AGENT BASED SOLUTION

In this section, we propose a Multi-Agent based Architecture, for our CSH to control and manage the domestic energy consumption. Our architecture consists of a one Home Master Agent controlling a number of Slave Agents corresponding to their equipments. We have also Storage Agents functioning together with the Green Agents for the production and the storage of the green renewable energy.



Figure 2: Multi-agent based architecture.

4.1 Agents Description

In this section we will introduce the various agents used in our approach. We have four kinds of agents:

1. ***Home Master Agent.*** It controls and optimizes energy consumption and encourages the use of the green renewable sources. It coordinates between all the Slave Agents controlling their corresponding equipments.
2. ***Home Slave Agent.*** They control the electrical equipments by stopping and resuming their functioning through a mechanism of Sensors/Effectors,
3. ***Green Agent.*** They control the production of the renewable energy sources,
4. ***Storage Agent.*** They control storing in batteries the energy produced by green renewable sources, to be used in the case of peak consumption.

4.2 Agents and Services Formalization

In this section we propose a formalization of the agents and the original services used in the contribution.

4.2.1 Formalization of Agents

Let

- $Sys_{CSH} = \{MA, \xi_{SA}, \xi_{GA}, \xi_{STA}\}$ be the Cynapsys Smart Home Multi-Agent based System composed of a Master Agent MA, N Slave Agents SA, M Green Agents GA and finally K Storage Agents. Let:
- $\xi_{SA} = \{SA_1, ..., SA_N\}$ be the set of Slave Agents for the control of rooms,
- $\xi_{GA} = \{GA_1, ..., GA_M\}$ be the set of Green Agents,
- $\xi_{STA} = \{STA_1, ..., STA_K\}$ be the set of Storage Agents,
- $Sys_e = \{e_1, e_2, ..., e_n\}$ be the set of electrical equipments.

4.2.2 Agent's Parameters

Let $MA = \{ID, EC, ASL, NLV\}$ be the Master Agent list of parameters, where:

- ***ID***: the Identifier of the agent composed of a String,
- ***EC***: the daily estimated energy consumption,
- ***ASL***: the Available Stored Load energy,
- ***NLV***: the Needed Load Value used in the case of peak consumption and daily production management.

Let $e_i \in Sys_e$ where e_i has:

- ***ID***: be the Identifier of the electrical equipment,
- $EC(e_i)$: be the daily estimated consumption of the electrical equipment,

Let $sa_i \in \xi_{SA}$ where sa_i has an ID, an NLV, and and a set of equipment Sys_e to control.

- ***ID***: be the Identifier of the Slave Agent,

- $NLV(e_i)$: be the Slave Agent Needed Load Value corresponding to the equipment e_i.

Let $ga_i \in \xi_{GA}$ where ga_i has an *ID* and a *DPV*

- ***ID***: the Identifier of the Green Agent,
- ***DPV***: the Daily Production Value.

Let $sta_i \in \xi_{STA}$ where sta_i has an *ID* and a *STV*

- ***ID***: the Identifier of the Storage Agent,
- ***STV***: the Stored Value.

4.2.3 Formalization of Services

The intelligence in power systems spreads starting houses, through intelligent cities to arrive at a smart grid.

Let:

- P_e be the equipment power amount,
- P_G be the general available energy.

Our system should always satisfy the following equation:

$$\sum_{i=1}^{n} ECe_i < P_G \quad (7)$$

let:

- Pr_t be the total price of the energy consumption,
- Pr_i be the price at the instant i,
- C_i be the consumption at the moment i,
- Pu_i be the unit price of the KWH at the moment i,
- $Pr_i = C_i * Pu_i$,
- Tr_c be the Consumption Threshold.

Our approach must satisfy the system represented by the equation below, which consist of using the three tariff zones, $i \in [0,1,2]$ where zero corresponds to the first tariff zone, one for the second one and two for the third one:

$$Pr_t = \sum_{i=0}^{2} Pr_i \quad (8)$$

The problem is to find the right formulas of energy consumption during the appropriate periods to minimize the total cost.
The equation is therefore to establish an optimization relationship having the form:

- $MinPr_t$,
- $Pr_t < Tr_c$.

Let:

- EC be the estimated daily consumption of a house,
- ECe_i be the estimated consumption of a single device e_i per day.

The estimated daily consumption is given by the following equation:

$$EC = ECe_1 + ECe_2 + ... + ECe_n = \sum_{i=1}^{n} ECe_i \quad (9)$$

Let:

- Pv be the Peak Value provided by the energy producers,
- STV be the available capacity in the battery.

In the case of a peak detected by the energy producer, the power source become the battery in case of presence of sufficient load. In our approach, we have 30 % of the capacity of our battery remains untouchable, this part is dedicated to solving the problem of peak consumption as described in the equation below:

- $Pv = 0.3 * STV_i$,
- STV_i be the stored value of the Storage Agent i.

4.3 Service Protocols

In this section, we propose a Service Protocol to coordinate all used agents in the implementation of the different proposed services.

Algorithm 1: Green Energy and Storage Device Management.

foreach $ga_i \in \xi_{GA}$ **do**
  $STV_i = \sum_{i=1}^{n} DPV_i$
end
// The Sum of the Daily produced Value provided from different green renewable sources represents the Stored Value used in the Peak Management Service.
foreach $sta_i \in \xi_{STA}$ **do**
  $STV = \sum_{i=1}^{n} STV_i$
end
if $Date == Date\_Peak$ **then**
  $Pv = STV * 30 \div 100$;
  //The Peak Value represents 30% of the available capacity on the Battery
end

The next algorithm deals with the management of the interaction and the communication between the used agents used in order to handles the power consumption optimization.

4.4 Timed Automata Models

In this paper, we propose a global approach for the design of adaptive reactive systems, i.e. systems that dynamically adapt their architecture depending on the

Algorithm 2: Home Master Agent and Home Slave Agents Energy Management.

Init
$Date <> Date\_Peak$
$State = Enabled$
while $Date = Date\_Peak$ **do**
  foreach $sa_i \in \xi_{SA}$ **do**
    if $Priority == 1$ **then**
      $State == Disabled$
    end
    if $NLV <= Pv$ **then**
      MA Sends a $giveSolution(MA, STA)$
    else
      foreach $sa_i \in \xi_{SA}$ **do**
        $State = Disabled$
      end
    end
    if $Event == PromotionalOffer$ **then**
      MA Sends $Store(MA, STA)$
    else
      foreach $sa_i \in \xi_{SA}$ **do**
        if $(Priority == 1)$ *And* $(Zone <> NormalZone)$ **then**
          $State = Disabled$
        end
      end
      if $Pr_t >= Tr_c$ **then**
        foreach $sa_i \in \xi_{SA}$ **do**
          $State = Disabled$
        end
      end
      $State = Enabled$;
    end
  end
end

context. We use the timed automata formalism for the design of the agent's behavior to check and verify functional and temporal properties of our inter-agent communication protocol. This allows their evaluation regarding logical correctness and timeliness, thanks to model-checking and simulation techniques. According to (Palshikar, 2004), model checking is the most successful approach that's emerged for verifying requirements. The idea is that by ensuring that the model satisfies enough system properties, we increase our confidence in the correctness. As follows we present a Timed Automata Model for the example of agents that we propose in our approach. We model the Home Master Agent with its two main important services: Distribution and Peak Management which has been described above. The Home Master Agent is responsible of the whole house control by supervising a set of Home Slave Agents which in their turns are responsible of the home's electrical equipments. Figure 3 shows the timed automata model of the Home Master Agent.

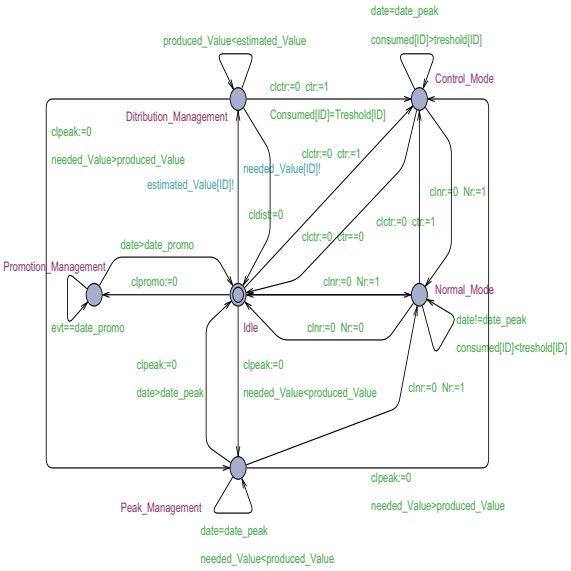


Figure 3: Home Master Agent Timed Automata.

This automata consists of different states related to the different operations of the Home Master Agent. The default mode is the normal mode, however, the transition to the control mode is activated by: (a) the arrival of preemptive events, (b) functional constraints related to exceeding consumption threshold, (c)the arrival of a peak load, (d)time constraints related to power management across shutdown, (e) and activation of equipments to consume intelligently and during specific periods. Figure 4, shows the transaction of distribution management, which is an important service in our theoretical approach. The decentralization of the distribution in this work is a major asset for ensuring optimization, maintaining the network and the integration of renewable sources for the energy generation. The reactive system upon detection of failure or the arrival of a new promotional offer from the provider. In this case, we verify the amount of renewable energy to be available in the battery. Following the application of the formulas given above, our system decides if the new source of energy an be used or not. Our reactive system will be efficient in this case while respecting imposed time and ecological constraints.

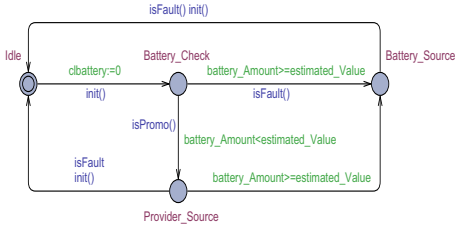


Figure 4: Distribution Management Service Timed Automata.

The proposed approach allows the management of peaks by using useful information to be sent from the provider. Figure 5 describes the mechanism of energy management during peak periods. Our goals: (a) the minimisation of the energy consumption during these periods, (b) take into account environmental impacts and cost of energy productions, (c) optimisation of the overall energy generation plan by anticipating consumer demands while ensuring comfort, (d) taking into account resources and environmental constraints, (e) and better control of consumption and local distribution. The management of high consumption periods is based on the use of compensation for energy requests through house storage devices to be connected essentially to green production sources. The system is converted to a control mode after the arrival of a peak load event. The source of production becomes a local battery after the checking of its capacity. This is done with a specific management policy with efficient calculation methods to guarantee green and low cost energy for users.

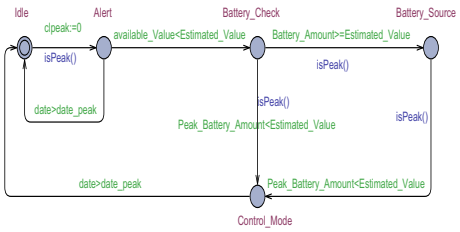


Figure 5: Peak Management Service Timed Automata.

4.5 Implementation

4.5.1 UML Modeling

We propose a UML model to implement the software version of our home system. Figure 6, shows the class diagram ”Home Automation System” (abbreviated by HAS) that represents the whole Multi-Agent architecture. This class manages all interactions in the system. It is related to the provider interface class which allows interaction with energy producers, and the user interface class which allows manual accesses of users into the system. An Agent class is proposed to represent both Home Slave Agents and Home Master Agent through an inheritance relationship. Figure 6 shows the whole class diagram.

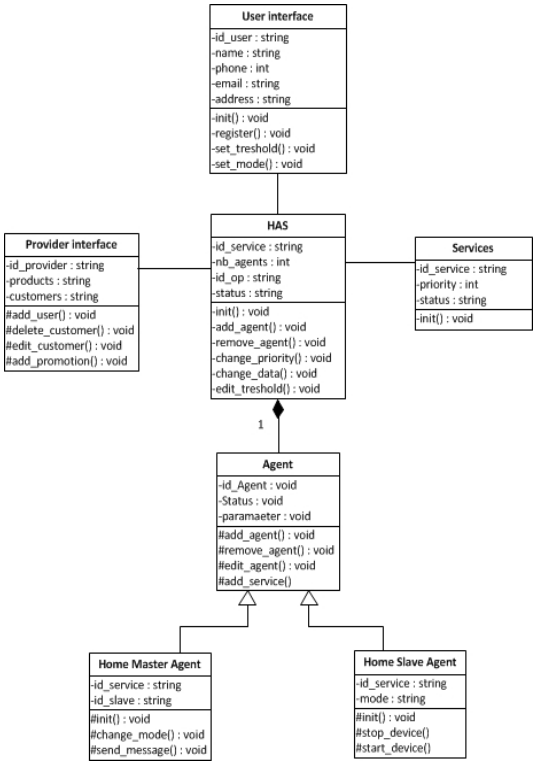


Figure 6: Home Automation System class Diagram.

4.5.2 X-SH Simulation Tool

The simulation is mandatory for the development and deployment of our system model. This model represents the main characteristics of the selected physical, abstract system or process. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training and education. In this section, we present a tool to be called X-SH that we developed at Cynapsys for the electrical energy management. This tool simulates the services that we describe above by using real-time data collection.It reacts to various changes of the electrical network. This tool can be used by both users and producers for the estimation of the daily energy consumption in order to optimize the use of green sources, manage peak periods, manage offers from producers. After the authentication interface to be used for a required security, the main interface appears to include the various offered services that we describe above: (a) Equipments Management service, (b) Consumption Management service, (c) Consumption Threshold service, (d) and Sale Management service (Figure 7).



Figure 7: Main Interface Energy Management Tool.

In Figure 8, we show the equipments management interface. The households are controlled by the Home Slave Agents. The X-SH Simulation tool allows the addition of new equipments, removing or changing priorities according to periods of use and operation modes.

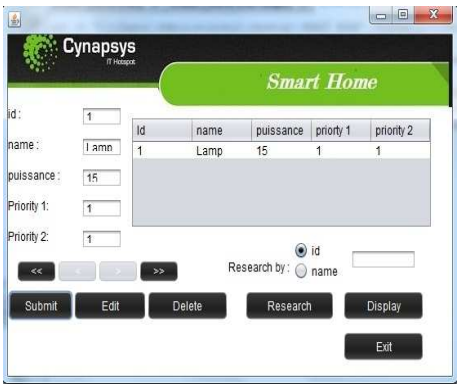


Figure 8: Equipment Management Interface.

Figure 9, shows the consumption management service which is provided by our simulation tool X-SH. The interface informs the users about the values of the estimated consumption for a period and the actual daily consumption.

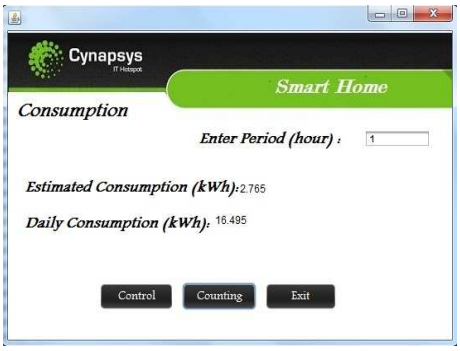


Figure 9: Consumption Management Interface.

In Figure 10, we show the consumption Threshold management Interface. This service allows to avoid the energy waste or loss as fixed by users. In the case of exceeding Threshold, we are directly informed about the passage of the home to the control consumption mode.

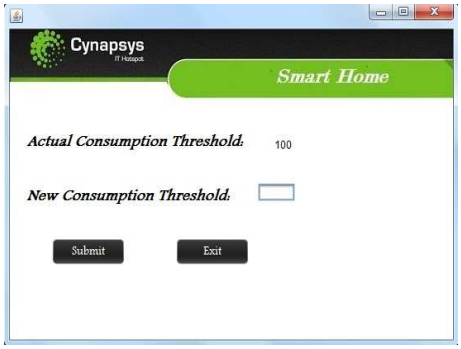


Figure 10: Set Threshold Consumption Interface.

The last service proposed by our consumption management tool X-SH consists of the management of the provider promotional offers (Figure 11). In the case of lower prices, the user can change its production source from the battery to the provider. We consume less in this case and can help to preserve energy that we store in the batteries for future uses, management electric failures, and management of peak periods.



Figure 11: Sale Management Service Interface.

4.5.3 Contribution Analysis

The testing of our simulation tool at Cynapsys helped us to better assess the gain of the proposed approach. Thanks to this contribution, the management of the power consumption shows a remarkable gain that costs 50 TND = 227 TND - 170 TND before the application of our approach and after (1 Euro = 2.2 TND in January 2014). This gain is very important for any Tunisian family in the medium society class. (Figure 12).

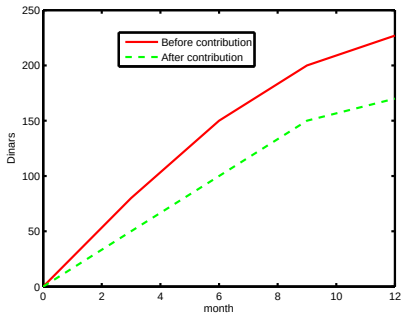


Figure 12: Comparison between the energy consumption before (Red) and after (Green) the contribution.

We propose also in Figure 13, the test of the thresholds consumption service that we did at Cynapsys. We note that during the same period, the user can consume energy intelligently by considering the priority of each equipment and the production of renewable energy from batteries. The consumption should not exceed the fixed amount.

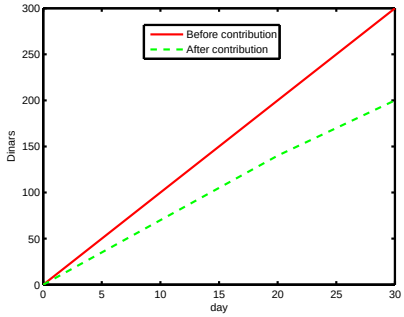


Figure 13: Comparison between the energy consumption without threshold (Red) and with threshold (Green).

Finally we propose in Figure 14 a histogram showing the use of renewable energy in our approach. We choose a summer day, which is characterized by a high consumption of electricity and an alert of peak from the provider. We applied an optimal management of the energy with the participation of the renewable sources that costs 38.09%.

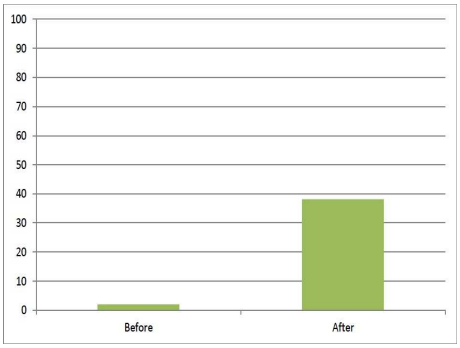


Figure 14: Green renewable energy participation.

5 CONCLUSIONS

This paper deals with a new Multi-Agent architecture for Smart Homes, which propose, new services for users such as: (a) Peak Management, (b) Promotion Offers Management, (c) Consumption Management. We offer a Home Master Agent that controls the whole architecture, interacts with the energy provider, coordinates with home users in order to optimise the green energy that we assume available at home. A Home Slave Agent is proposed for the local control of each equipment. We propose a communication protocol between these agents to support all the services that we propose above. Since the architecture that we propose is real-time and based on concurrent operations, we propose timed-automata models for these agents and verify their correctness by using UPPAAL. We developed a simulator X-SH which can be used by both home users and providers in order to estimate and manage the daily consumptions. This tool was tested at Cynapsys and some experimental results are exposed in this paper. In our future work, Cynapsys plans the real commercialisation of this product. We are planning in this case to finish the complete deployment of this simulator as well as Agents on microcontrollers following STM32F4 technology. The real commercialisation and distribution is planned for the end of 2014.

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