

Hybrid Approach for Mobile Couriers Election in Smart-cities

Fadi Al-Turjman
Dept. of Computer Engineering,
Middle East Technical University,
Northern Cyprus Campus,
99738 Kalkanlı, Güzelyurt, Mersin 10, Turkey
fadi@metu.edu.tr

Abstract—In this paper we propose a hybrid heuristic approach for public data delivery under ultra-large-scale smart-city settings. In this approach, public transportation vehicles are going into election process to be utilized as Mobile Couriers (MCs) that read public Access Points (APs) data loads and relay it back to a central processing base-station. We also introduce a cost-based fitness function for the MCs election in the smart-city project which forms a real implementation for the Internet of Things (IoT) paradigm. Our cost-based function considers mobile resource limitations in terms count, storage and energy. Extensive simulations are performed and the results confirm the effectiveness of the proposed approach in comparison to other heuristic approaches with identical objectives.

Keywords- Mobile Courier, Path Planning, Internet of Things, Cost-functions, Smart Cities.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have evolved from supporting application-specific deployments such as habitat monitoring, health care, and retail supply chains [7], to enabling multiuser platforms that simultaneously support multiple applications operating in a large-scale Internet of Things (IoT) environment [12]. Smart cities are examples of such applications that support multiuser access on a multi-application platform. However, the ability to handle multiple users simultaneously with different requirements on the data delivered, in terms of attributes such as latency, reliability, and throughput, as experienced in a smart city, has not received sufficient research attention. That is because the use of WSNs to enable smart environment applications is still in the experimental stage. Moreover, the complexity involved in handling heterogeneous traffic flows in the underlying sensor network results from multiple requests with diverse user requirements simultaneously. To address this complexity, we propose a novel architecture that consider the use of mobile smart devices, called MCs [10]. We propose a Hybrid Genetic-based Path Planning (HPP) approach that minimizes the *total number of required MCs* and *their associated travelling distances* while collecting data in a smart city setup. Since every MC is usually associated with a predetermined route in the city, we use the *MC* and *route* count interchangeably in this article. Consequently, we will be looking for the least route count to be used while serving the distributed smart nodes in city. However, this shall be achieved while maintaining also the least travelled distances by the MCs (i.e., shortest length for the total chosen routes) in order to reduce cost/energy consumption. Thus, the targeted problem can be stated as follows: *Given a set of MCs with a limited storage and predetermined routes, find the minimum MCs count while maintaining the minimum travelled distance and traffic load constraints.* To solve this multi-objective problem, we are using a hybrid meta-heuristic approach based on Genetic and Local Search

(LS) algorithms.

The remainder of the paper has been organized as follows. Section II reviews related work in the literature. Section III provides the system models and problem description. In Section IV, we provide the details of the proposed HPP approach. Next, we elaborate more on the HPP via a use-case in Section V. The proposed framework is verified and validated in Section VI via extensive simulation results. Finally, we conclude our work in Section VI.

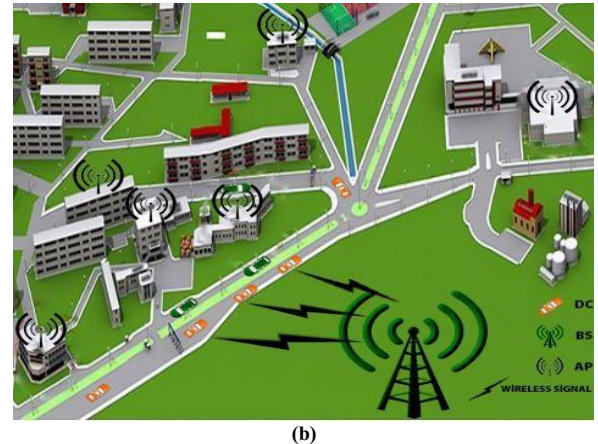
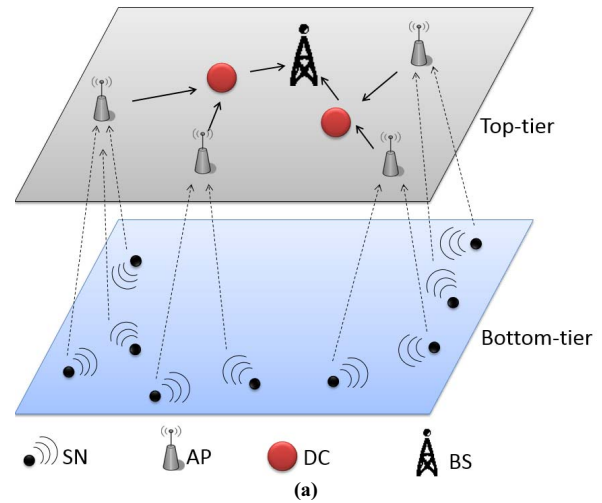


Fig. 1. (a) Two-tier hierarchical architecture, and (b) Data gathering in smart city via DCs.

II. RELATED WORK

Recently, Public Sensing (PS) paradigms started to render itself as an effective tool in the field of Smart-cities [10][12]. In such paradigms, the sensing process is performed by deploying a number of sensors that are used to collect and send data periodically about the smart city variables (e.g., temperature, humidity, traffic conditions, etc.). The sensors send the data to the processing center via a wireless link. To be able to collect precise data about a certain sector, it is required to employ a number of mobile MCs and efficiently utilize their path of interest. Mobile MCs were proposed in [8], assuming centralized knowledge and decisions made at the BS. It was shown that using MCs extends the network lifetime compared to conventional WSNs using static Sensor Nodes (SNs) only. In fact, MCs were used earlier in [8] and [9]. Unlike the aforementioned MC approaches, GA does not break easily and is robust towards the noise [5]. Each chromosome contains information, and the population means a big data for the current generation. GA can be seen as a parallel searching approach due to searching for a set of candidate solutions in a population of current generation simultaneously. Since GA is a powerful and robust optimization technique, it has numerous successful applications to real-world problems inside image processing, robotics, medicine, biology and more. The applicability of GA, as an artificial intelligence technique, comes from the fittest among chromosomes along/over consecutive generations for solving a problem. As the generations continue, each chromosome, that represents a potential solution, will become more suited to its environment. Thus, it will be possible to obtain successful results. GA has a big potential for solving path planning and such problems. In [5], GA was applied to find the optimal path effectively while reducing the path cost with shorter computation time and smaller number of generations in a static environment with known obstacles. In [6], authors utilized GA for the problem of offline point-to-point autonomous mobile robot path planning. On the other hand, authors in [7] used GA to calculate optimized paths in path planning for autonomous mobile robots (mobile MCs) where a robot is represented by its coaxial coordinates in the targeted environment. Although GA is randomized and uses random search, in fact it directs the search into region of better performance within the search space. Genes from good chromosomes propagate throughout the population so that it is expected to handle better offspring than parent. For this work, we have mainly focused on our meta-heuristic algorithm that consists of GA and 2-opt LS algorithm to improve the search for more optimized solution in a very competitive time complexity.

III. SYSTEM MODELS

In this section, we discuss the main system models we assume in realizing our HPP approach.

A. Network Model

In this paper, we consider a multi-tier WSN framework with three main components: 1) the Base Station (BS), 2) Mobile Courier (MC), and 3) the WSN Access Point (AP) in a smart city (see Fig. 1). In a telecommunication network there is either one BS or multiple BSs. In this paper, a two-tier hierarchical architecture is assumed as a natural choice in large-scale applications, in addition to providing more energy-efficient solutions. The lower layer consists of sensor nodes that sense the targeted phenomena and send measured data to the APs in the top-tier, as shown in Fig. 1 (a). Usually these sensor nodes have fixed and limited transmission ranges and do not relay traffic in order to conserve more energy. The top-tier consists of APs and MCs which have better transmission range and communicate periodically with the base station to deliver the measured data in the bottom-tier. Also, at the top-tier of our proposed architecture, we decide on the data-packets

size and the order of the targeted intermediate nodes, each has a load, to be delivered to the BS.

B. Energy Model

The energy supply of a mobile MC can be unlimited or limited. When a MC has an unconstrained energy supply (rechargeable or simply have enough energy relative to the projected lifetime of the APs), the placement of MCs is to provide connectivity to each AP with the constraint of the limited communication range of APs. When the energy supply of MCs is limited, the allocation of MCs should not only guarantee the connectivity of APs but also ensure that the paths of mobile MCs to the BS are established without violating the energy limitation. In this research we assume a fixed and limited power supply at the MCs. In addition, we assume the exact communication power consumption model used in our previous work [8].

IV. HPP APPROACH

In characterizing the network architecture, in the entire working area, we use a set of locations that belong to a number of devices (APs). We use some vehicle routing problem (VRP) instances from the literature as location information, and therefore we know the locations and the distances between the deployed devices (nodes). To minimize the total energy of the network, we try to minimize both the total number of MCs that needs to be used for servicing all the devices in the network and the total travelled distance by MCs especially for large environments. Minimization of energy consumption is an essential metric in smart cities. We now propose our HPP framework to optimize the cost, calculated by MC count and travelled distance, in a smart-city setup.

A. Path Planning

The idea of this section is to formulate the path planning of MC's navigation from the start to the target [14][15]. These locations are same and called Base Station (BS). Visit locations do not need to be specified, because for each sample we know the locations; and assume the environment is known. We focus on determining optimal routes with minimum route distances for each one. In addition, we consider that each device location is a target for related MC on its route. The path planning consists of two major stages: The assignment of the devices in the network to the related MCs and the specification of the orders of nodes at each route. We remark here that this *fitness function* represents the procedure that evaluates the quality of a population in GA by calculating the fitness values for each chromosome. Where *fitness value* represents the suitability of a chromosome for the found solution and it represents the ability of that chromosome to compete with other chromosomes in our genetic-based approach. This fitness function helps actually in directing the search space to find chromosomes that cover all APs interested in exchanging their data loads, and then it finds the shortest path with the least possible MCs.

V. USE-CASE

In this section we elaborate more on our proposed HPP approach via a typical delay-tolerant communication scenario in rural areas where people and/or public transportation can reach but the infrastructures of WiFi/cellular networks are not deployed. We assume discretized rounds per which our scheme selects routing paths based on locating the most suitable DCs passing through these paths. This is determined according to minimum travelled distance and DC's available storage capacity constraints calculated from the top-tier of the proposed architecture from the BS down to APs. In Fig. 2 we illustrate an example where three cities' APs: A, B, and C, respectively, have established at some point of time one or more connecting paths, through some DCs, to one BS in the country. Note that each DC path

has its end-to-end storage capacity and travelled distance characteristics as speculated by the HPP approach given in the format (capacity/distance) in Fig 2. These characteristics are based on routing table exchanges between DCs and the APs. The HPP approach aims at selecting the paths (shown in dashed-lines) that guarantees minimum total travelled distance without violating the DC capacity constraints. The decision of utilizing these DCs depends on its resources which are stored, as well, at the AP's routing table. For example, assuming that AP in city *A* in Fig. 2 has to transmit packets with a data-load that requires a minimum DC capacity of 100MB, the HPP detects two different paths connecting *A* to the BS. Both of them obey the capacity constraints, and the one amongst these two which provides the minimum total travelled distance is ultimately chosen. It will be also able to serve the AP at *B* as the remaining storage of that DC is still satisfying the capacity constraint. And then the second dash-line (route) passing by city *C* will be utilized to deliver its corresponding data.

VI. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed HPP against pure GA and the modified 2-opt LS algorithm. To use GA without LS, we set the mutation probability to 0. Also in order to use LS without GA, we set the crossing-over probability to 0. We execute our demo 100 times for each experiment and take the averages of the results. Detailed description of our experimental setup is given in the following section. We assume a network of vehicles in a smart city, where MCs are a subset of the moving public transportation vehicles. We assume up to 100 total APs with one BS. For some experiments we keep data traffic or MC capacity fixed, and for other experiments we use the values in [5].

A. Performance Metrics and Parameters

In this research, we assess our proposed HPP in terms of three main metrics:

1. **Cost**: is the fitness value computed by the fitness function and it represents the cost for each extra vehicle utilized in the smart-city).

In the following, we also list the varying parameters in this section experiments:

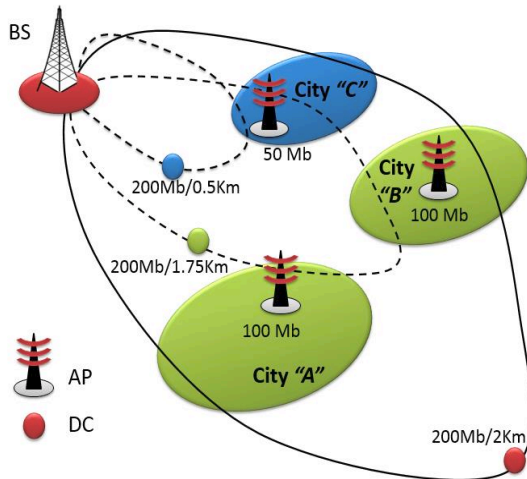


Fig. 2. A use-case scenario for a group of cities under one BS control.

1. **Load**: is the amount of data to be delivered from a smart node (or AP) to the BS via a MC.
2. **Capacity**: is the maximum storage capacity for the utilized MCs measured in Mbytes.

B. Simulation Results

Simulation results are shown in the following figures for various combinations of data load (traffic) and MC capacity under the three different approaches; pure GA, pure LS and HPP. To observe the effect of the varying data load metric from 1 to 6, the MC capacity for all the MCs has been set to 60 for all the samples. In the following two figures, we examine the effect of the total cost instead of the total travelled distances with the same configurations used above for the three different approaches.

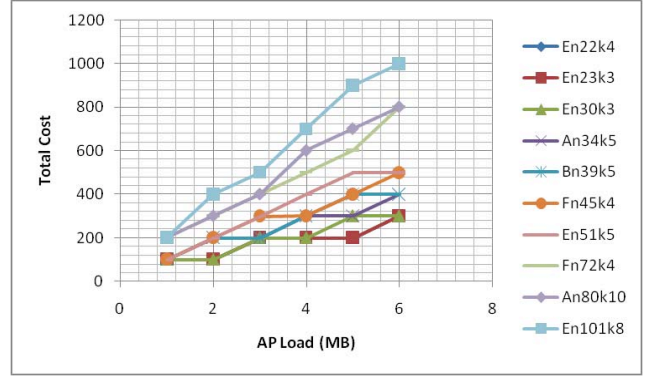


Fig. 3. Cost vs. the AP data load.

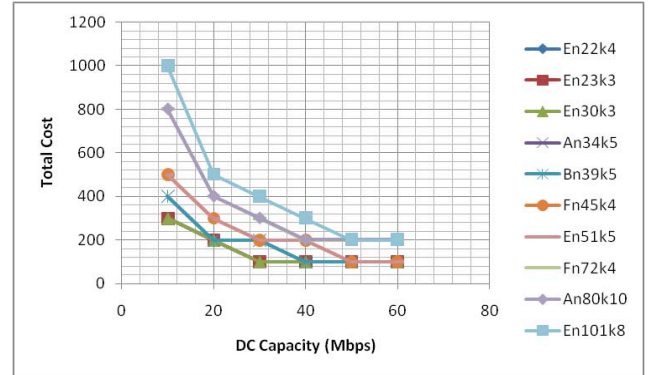


Fig. 4. Cost vs. the MC Capacity.

To observe the effect of varying data load values, the total cost values are given in Fig. 3. In this figure, we can observe the cost increase for all instances as the data load increases. To observe the capacity effect, the overall cost values are given in Fig. 4. In this figure, we observe the decrease in cost for each instance. Also, we have compared total travelled distances and overall cost for the different input samples shown in the above figures. We noticed that the proposed hybrid approach outperforms the other approaches.

VII. CONCLUSION

In this paper we introduce HPP - a hybrid IoT public sensing framework for smart cities. Our framework is based on a multi-tier architecture that caters for heterogeneous data sources (e.g. sensors) in addition to mobile Mobile Couriers in urban areas which are isolated from their corresponding data processing center (BS). According to our framework, access points at the top-tier of the proposed architecture

receive sensor readings and initiate delivery requests. Our delivery scheme implements genetic-based algorithms that realize distance-and-cost-sensitivity. At the top tier, our cost-based model employs a fitness function that maximizes the network operator gain according to the limited MCs count, storage capacity, and total travelled distances.

REFERENCES

- [1] F. Al-Turjman, H. Hassanein, and M. Ibnkahla, "Efficient deployment of wireless sensor networks targeting environment monitoring applications", *Elsevier Computer Communications Journal*, vol. 36, no. 2, pp. 135-148, January 2013.
- [2] F. Al-Turjman, H. Hassanein, and M. Ibnkahla, "Towards prolonged lifetime for deployed WSNs in outdoor environment monitoring", *Elsevier Ad Hoc Networks Journal*, vol. 24, no. A, pp. 172 – 185, Jan., 2015.
- [3] D. Said, S. Cherkaoui, L. Khoukhi, "Scheduling protocol with load management for EV charging", *GLOBECOM* 2014, pp. 362-367.
- [4] M. Biglarbegian and F. Al-Turjman, "Path Planning for Data Collectors in Precision Agriculture WSNs", *In Proc. of the International Wireless Communications and Mobile Computing Conference (IWCMC)*, Nicosia, Cyprus, 2014, pp. 483 - 487.
- [5] J. Tiu, and S. X. Yang, "Genetic Algorithm Based Path Planning for Mobile Robots", *IEEE Conference on Robotics and Automation (ICRA)*, Taipei, Taiwan, Sept. 2003.
- [6] L. Wang, S. X. Yang, and M. Biglarbegian, "A fuzzy logic based bioinspired system for mobile robot navigation", *IEEE Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, Hamburg, Germany, Sept. 2012.
- [7] J. Sahoo, S. Cherkaoui, A. Hafid, "Optimal selection of aggregation locations for urban sensing", *ICC* 2014, pp. 239-244.
- [8] F. Al-Turjman, and M. Gunay, "CAR Approach for the Internet of Things (IoT)", *IEEE Canadian Journal of Electrical and Computer Engineering*, vol. 39, no. 1, pp. 11 – 18, Winter, 2016.
- [9] F. Al-Turjman, H. Hassanein, W. Alsali, and M. Ibnkahla, "Optimized Relay Placement for Wireless Sensor Networks Federation in Environmental Applications", *Wiley: Wireless Communication & Mobile Computing Journal*, vol. 11, no. 12, pp. 1677-1688, December 2011.
- [10] J. Sahoo, S. Cherkaoui, A. Hafid, "Optimal selection of aggregation locations for participatory sensing by mobile cyber-physical systems", *Computer Communications* vol. 74, pp. 26-37, 2016.
- [11] G. Singh, and F. Al-Turjman, "A Data Delivery Framework for Cognitive Information-Centric Sensor Networks in Smart Outdoor Monitoring", *Elsevier Computer Communications Journal*, vol. 74, no. 1, pp. 38-51, 2016.
- [12] F. Al-Turjman, H. Hassanein, and S. Oteafy, "Towards Augmenting Federated Wireless Sensor Networks", *In Proc. of the IEEE International Conf. on Ambient Systems, Networks and Technologies (ANT)*, Niagara Falls, ON, Canada, 2011, pp. 224-231.
- [13] S. Al-Harbi, F. Noor, and F. Al-Turjman, "March DSS: A New Diagnostic March Test for All Memory Simple Static Faults", *IEEE Transactions on CAD of Integrated Circuits and Systems*, vol. 26, no. 9, pp. 1713-1720, Sept. 2007.
- [14] F. Al-Turjman, "Cognition in Information-Centric Sensor Networks for IoT Applications: An Overview", *Springer Annals of Telecommunications Journal*, pp. 1-16, 2016. DOI: 10.1007/s12243-016-0533-8.
- [15] G. Singh, and F. Al-Turjman, "Learning Data Delivery Paths in QoI-Aware Information-Centric Sensor Networks", *IEEE Internet of Things Journal*, vol. 3, no. 4, pp. 572 - 580, August, 2016.