

A Resources Sharing Architecture for Heterogeneous Wireless Cellular Networks

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Abstract—The current static model used for allocating the spectrum of frequencies and the increasing demand for network resources imposed by modern applications and services may lead to a resources scarcity problem. Dealing with this problem demands optimized resources allocation. An alternative to provide this optimization is by allowing resources sharing among network operators. In this paper, an architecture is presented to encourage network operators to share their underutilized resources. A multilevel broker is proposed to control the resources sharing. This broker dynamically establishes a service level agreement that takes into account the quality of service requirements of resources renters and the cost of the resources. A performance evaluation shows that the implementation of the proposed architecture leads to better allocation of underutilized network resources.

I. INTRODUCTION

The current spectrum allocation model prioritizes main network operators who purchase exclusive rights over portions of the spectrum of frequencies. This model makes it challenging to unlicensed network operators to provide high quality of service (QoS) to their users. Such challenge increases in the current traffic demand scenario, where network devices demand significant amounts of both spectrum and capacity resources to manage the traffic generated by both wireless applications and services. The described scenario may lead to a network resources scarcity problem in the near future.

The main goal of this paper is to present a solution to deal with this network resources scarcity problem. The proposed solution is based on the premise that both commercial and non-commercial network operators have underutilized resources during periods, especially in off-peak hours. The main idea is to allow these network operators to improve their profits by leasing the underutilized resources to opportunistic network operators that will be able to improve the QoS offered to their users.

Network resources can be shared according to two main approaches. The first one is called Collective Use of Spectrum (CUS) because specific licenses are not demanded to allow devices access to network resources. On the other hand, there are scenarios in which licenses are necessary to provide the devices with network resources access. In these scenarios, devices are submitted to a licensed access regime before accessing the resources, which is called Licensed Shared Access (LSA) [1].

Different approaches have been considered to implement resources sharing both in CUS and LSA regimes ([2], [3], [4], [5], [6], [7]). Most of these proposals involve the implementation of complex algorithms aiming to mitigate interference

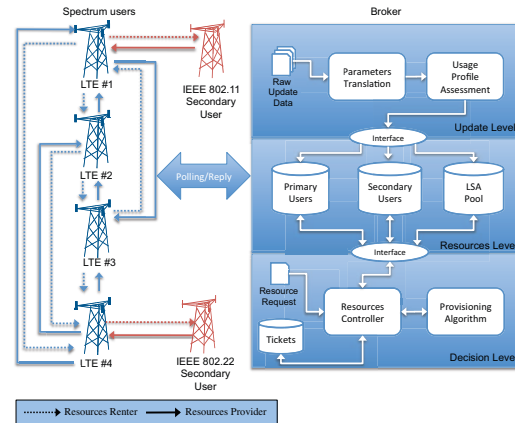


Fig. 1. Architecture Design

or to find spectrum access opportunities using artificial intelligence techniques. Although very relevant, these solutions generally identify the need for additional resources and search for available resources without taking into account the QoS requirements of the resources renter and the cost of these resources. This common approach of related works may lead to the allocation of network resources that are not suitable for the users. Considering the aspects not fully covered by the related work, in this paper, an architecture is presented to allow resources sharing among different network operators. The most important component of the proposed approach is a multilevel resources broker, which is designed to dynamically establish a service level agreement that takes into account the QoS requirements of resources renters.

II. RESOURCES SHARING ARCHITECTURE

The design of the proposed architecture is presented in Fig. 1. The architecture is divided in two parts which communicate through a polling/reply mechanism. In the left side of the illustration, the spectrum users coexist in a geographical area considering a scenario that allows one operator to communicate with all neighboring network operators. In the right side of the figure, the structure of a broker is represented. This broker is responsible for coordinating resources sharing among the spectrum users.

A novel multilevel broker is proposed to play the role of the centralized entity in the resources sharing architecture. Three levels were defined to provide independent and simultaneous

control of different tasks of spectrum sharing management. These levels were named accordingly to the function executed by each one: (I) Update Level, (II) Resources Level, and (III) Decision Level. These levels are interconnected by interfaces which implement the flow of information.

The **Update Level** is responsible for collecting operation parameters from the network operators which participate in the spectrum sharing initiative. The updating mechanism is based on the implementation of a polling-based technique, which is controlled by the Parameters Translation block of the broker. This block allows the configuration of the interval between polls and translation of the raw update data (operator ID, delay, jitter, and throughput data) into useful information to allow the architecture to take proper decisions regarding to resources sharing.

The pre-processed raw data is sent to the Usage Profile Assessment block, which applies the concepts of cognition to keep track of the historical information provided by the network operators. This historical information is taken into account to define the current usage profile of the network to minimize the effect of abnormal behaviors of the traffic that may occur in realistic operation scenarios. The weight given to the historical information (α) and the weight considered to the most recent update ($1 - \alpha$) are parameters of this block. Equation 1 is applied to calculate the weighted load (ℓ) of each considered QoS parameter of the network operators.

$$\ell = \alpha \cdot \sum_{i=1}^n \ell_{(t-i)} + (1 - \alpha) \cdot \ell_{(t)} \quad (1)$$

This equation considers a pre-defined number (n) of historical evaluations of ℓ and performs an exponential smoothing to obtain the weighted load of a given QoS parameter. The same equation is applied to the remaining QoS parameter in order to obtain the complete assessment of the usage profile of each network operator.

The processed usage profile information is then sent to the **Resources Level** using the proper interface. For the sake of simplicity in dealing with resources allocation, two classes of users are considered to coexist in the same geographical area in the proposed approach. The first class, called primary users, is composed of users who hold a license issued by a regulatory agency concession to occupy a pre-determined range of the spectrum of frequencies. The second class is called secondary users and comprehends all those network users who aim to opportunistically access the available network resources. To help accommodating these two classes of users in the same geographical area, the broker must have knowledge about exclusive use, shared use, and exclusive shared use frequencies [8].

The Resources level of the broker is responsible for providing information regarding the users currently operating in the geographical area as well as about the available ranges of frequencies of each type. Therefore, this level implements three databases which are often fed by the Update Level and provide the Decision Level with information about the resource allocation status, called Primary Users, Secondary Users, and LSA Pool.

Request for resources renting are received and processed

by the **Decision Level** of the multilevel broker. The Resource Request contains all information demanded by the broker to decide which resources will be designated for sharing, taking into account the QoS requirements (*i.e.* class of service, delay, jitter, and throughput requirements), the cost, the estimated duration of the lease, and the priority of the request. Three levels of priority and three classes of service are defined: Real Time Services (RTS), Multimedia Services (MS), and Best Effort Services (BES).

Every time a resource request is received, it is processed by a Resources Controller. This entity of the broker has direct access to the Tickets database, which is responsible for controlling the cost of the resources sharing transactions. Through the proper interface it is also able to retrieve information from the databases in the Resources Level of the broker. The aim of the resources level is to obtain updated knowledge about the network resources status and feed the Provisioning algorithm with possible resources servers for a given request. Towards this aim, the execution of the Resources Controller follows the specification of algorithm 1.

Algorithm 1 Resources Controller

Require: r ▷ A struct containing a resource request
Require: $get_mno([databases], [QoS\ Requirements])$
1: $p \leftarrow r.Priority; d \leftarrow r.Delay; j \leftarrow r.Jitter; t \leftarrow r.Throughput$
2: **switch** p **do**
3: **case** High
4: $mno \leftarrow get_mno([Primary, Secondary, LSA], [d, j, t])$
5: **case** Medium
6: $mno \leftarrow get_mno([Secondary, LSA], [d, j, t])$
7: **case** Low $mno \leftarrow get_mno([Secondary], [d, j, t])$
8: **for all** mno **do**
9: $cost(i) \leftarrow [mno.Id, mno.Tickets]$
10: **if** $cost = \emptyset$ & $p = \text{High}$ **then**
11: **return** 0
12: **else if** $cost = \emptyset$ & $p = \text{Medium}$ **then**
13: $mno \leftarrow get_mno([Primary], [d, j, t])$
14: **for all** mno **do**
15: $cost(i) \leftarrow [mno.Id, mno.Tickets]$
16: **if** $cost = \emptyset$ **then return** 0
17: **else if** $cost = \emptyset$ & $p = \text{Low}$ **then**
18: $mno \leftarrow get_mno([Primary, Secondary], [d, j, t])$
19: **for all** mno **do**
20: $cost(i) \leftarrow [mno.Id, mno.Tickets]$
21: **if** $cost = \emptyset$ **then return** 0
22: **return** provisioning($cost$)

The input of the Resources Controller algorithm is a resource request. In the first stage, the algorithm classifies the resource request according to the priority and the class of service informed by the requesting operator. The function called $get_mno(< Type\ of\ Resource >, < QoS\ Parameters >)$ is responsible for searching the databases of Resources Level to retrieve candidate resource providers which have enough resources to guarantee QoS. After accessing the Resources Level databases, the algorithm calculates the cost of each resource available. The cost (ζ) follows the model of favors exchanged among resources providers. The cost of each favor is influenced by three main factors: (I) the type of service provider (ρ), (II) the amount of resources currently compromised by the selected resources provider (ℓ) at a given instant of time, and (III) the priority of the request (κ). ζ is calculated

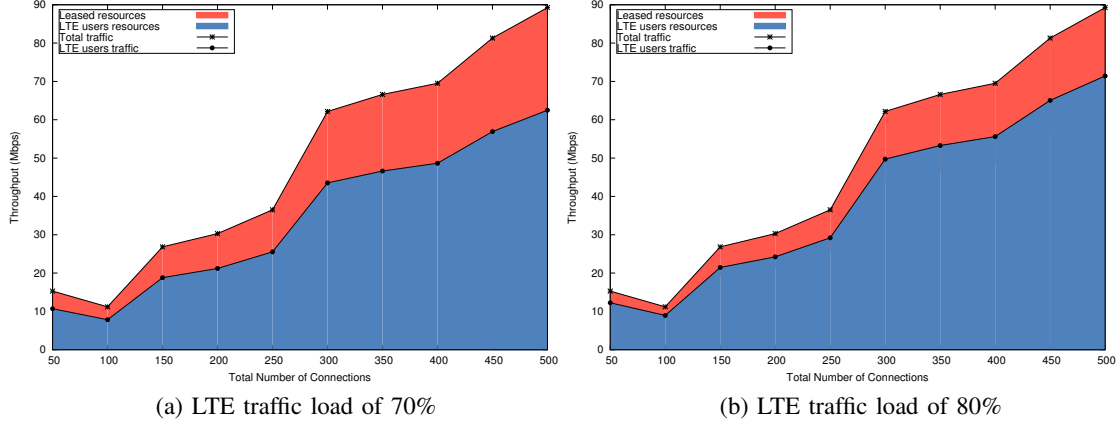


Fig. 2. Underutilized resources considering a total frame capacity of 113Mbps

using (2).

$$\zeta = \rho \cdot \kappa \cdot \left(\frac{\ell_{RTS} + \ell_{MS} + \ell_{BES}}{L} \right) \quad (2)$$

In this equation, L represents the total amount of currently unused resources in a given resources provider. The values related to the priorities and types of service providers are summarized in Table I.

TABLE I
PARAMETERS USED TO CALCULATE THE COST

ρ		κ	
Type of Provider	Value	Priority	Value
Shared Use	1	Low	1
Exclusive Shared Use	2	Medium	2
Exclusive Use	3	High	3

The Resources Controller algorithm generates an array of candidate resources providers. Each entry of the array is composed of the unique identification of the service provider and the cost of this transaction. The resulting array is used as the input to a Resources Provisioning algorithm, which takes an optimized decision on which resource provider is the best to serve a specific request.

In order to deal with the resource request, it is fundamental to accurately assess the amount of resources (*i.e.* network capacity) controlled by each operator. The capacity is modeled according to Shannon's model. The channel bandwidth (B) is considered to calculate the theoretical channel capacity (C). In the proposed equation, P represents the transmission power, g is the gain provided by the transmitting antenna, and σ^2 is the noise power. The link efficiency (η) is considered to model a more realistic scenario. The resources demand in a given instant of time ($d(t)$) takes into account the individual demand ($d_i(t)$) of the i th active connection of each network operator. The total number of active connections is represented by n . Moreover, the overhead, caused by both cyclic prefix insertion (ϑ_{CP}) and pilot subcarriers used for synchronization (ϑ_{PS}) is considered.

To simplify the decision process implemented by the Decision Level of the broker, a resources occupation factor $\delta(t) = (d(t)/C)$ is defined. It is important to consider that this equation correlates the current demand ($d(t)$) with the capacity of a network operator (C). The demand is originally

calculated in unit of Mb, while the capacity is obtained in terms of Mbps. Therefore, to guarantee the consistency of $\delta(t)$ factor, the demand must be observed during the period of one second, to transform its unit into Mbps before applying the equation. $\delta(t)$ follows equation 3.

$$\delta(t) = \frac{(\sum_{i=1}^n d_i(t)) + \vartheta_{CP} + \vartheta_{PS}}{B \log_2 \left(1 + \frac{P \cdot g}{\sigma^2} \right) * \eta} \quad (3)$$

III. PERFORMANCE EVALUATION

In this section, the performance of the proposed solution is evaluated considering a case study where four LTE-Advanced network operators coexist in the same geographical area. To simulate the behavior of the proposed architecture it is mandatory to properly model the traffic demands of the users. The traffic model must consider the connection arrival and the amount of traffic demanded per connection. The *System Evaluation Methodology* document, published by the WiMAX Forum [9] was selected to model the traffic because it is based on realistic measurements and provides a solid base to estimate the actual traffic demanded by the different users. In the simulations three different kinds of traffic are considered: HTTP (60%), VoIP (20%), and Video (20%).

The first kind of results show the amount of resources used by LTE-Advanced primary users and consequently, the amount of underutilized resources, which may be shared. This analysis takes into account two scenarios to represent different loads in the network managed by a LTE-Advanced operator. The results presented in Fig. 2 show the amount of resources that may be shared in an inter-networking scenario that considers a theoretical capacity of 113Mbps. The traffic load of LTE-Advanced network was also varied to consider a total load of 70% in Fig. 2 (a) and a total load of 80% in Fig. 2 (b).

As can be seen in Fig. 2, the amount of resources allocated to LTE-Advanced primary users varies from 9% to about 54% of the network throughput when the proposed resources sharing architecture is not implemented. Results obtained after the proposed architecture is implemented show that up to 25% of the resources can be shared with opportunistic users when the LTE-Advanced traffic load is 70%. When this load is

increased to 80%, the gain is still observed, reaching values of up to 18% of the resources which may be shared with opportunistic users. This leads to advantages to both network operators, since underutilized resources of a given network operator can be used by another operator.

In Fig. 3, the amount of underutilized resources of a traditional, non cooperative LTE-Advanced network is analyzed. The occupation of the LTE-Advanced frame is normalized to the maximum capacity, already taking into account the overhead. The total number of connections is also considered. In a situation with no resources sharing, portions of more than 50% of the frame are underutilized. In situations in which resources sharing is implemented, the underutilization can be reduced as low as 15% in the considered traffic demand scenarios. These results demonstrate that the concept of resources sharing is feasible for the scenario analyzed in this paper.

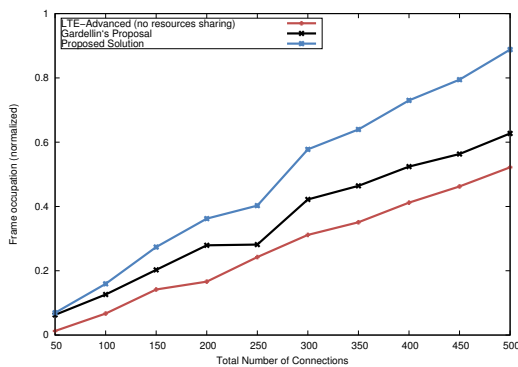


Fig. 3. Normalized Frame Occupation. Maximum capacity of 113Mbps

The performance of the proposed architecture was also compared with two different resource allocation algorithms found in the Literature. Both algorithms were originally analyzed by Gardellin *et al.* [2] and are called Random Channel Allocation and Non-cooperative Channel Allocation. Both approaches consider that the shared resource is the channel capacity and are applied to IEEE 802.22 networks but are general enough to be adapted to other network scenarios, such as the one analyzed in this paper. The evaluation scenario presented in Fig. 4, is related to the throughput supported by the LTE-Advanced network under conditions in which the number of connections is varied.

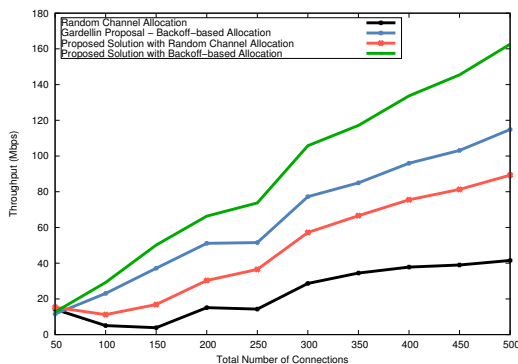


Fig. 4. Throughput behavior with variable number of connections

As can be observed in Fig. 4, the random channel allo-

cation is the worst case scenario. This behavior is explained due to the nature of a random algorithm. Since no channel access control is implemented in this case, an uncontrolled number of collisions may occur, leading to a decrease in the overall throughput, which will impact negatively on the QoS. Results showed that up to 30% of the total number of transmissions typically result in collisions when this kind of allocation is applied. The throughput significantly improves when LTE-Advanced resources sharing is implemented. In this case, it is important to highlight that although the channel allocation is random, when LTE-Advanced resources are demanded, a SLA is established, what leads to more efficient resources allocation. A similar behavior is observed when the backoff-based non-cooperative channel allocation algorithm is analyzed. However, in this case, the nature of the algorithm reduces the number of collisions and consequently improves the network throughput. In the non-cooperative algorithm, collisions are significantly reduced, reaching values as low as 2.5% of the total number of transmissions.

IV. CONCLUSIONS AND FUTURE WORK

This paper dealt with the spectrum scarcity problem by proposing a resources sharing architecture for wireless cellular networks. The results show that the implementation of the architecture is feasible, and the LTE-Advanced is able to serve up to 500 connections (60% http, 20% video, 20% VoIP) and yet share up to 25 % of its network capacity opportunistic users. The results were also compared with two solutions found in the literature. The gains surpass the related work by allowing the resources server to improve its resources utilization by as much as 28%. Directions for future work include the analysis of the overhead generated by the proposed architecture. Designing a novel provisioning algorithms at the Decision Level of the broker is also planned. Enhancements in such algorithm could improve the QoS delivered to the resources renters.

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