A Cognitive Algorithm for Traffic Steering in LTE-LSA/Wi-Fi Resource Sharing Scenarios

Jean Cerrillo Fernandez, Rafael Kunst, Juergen Rochol
Federal University of Rio Grande do Sul, Brazil
{jecfernandez, rkunst, juergen}@inf.ufrgs.br

***Abstract*—The wireless network traffic is expected to overload the existing licensed spectrum by 2020. One method to deal with this traffic overload is to access unlicensed and shared spectrum bands using an opportunistic approach. Licensed Shared Access (LSA) allows incumbent users to provide temporary access to its spectrum resources. However, licensees must perform traffic steering to vacate the band without causing interference, whenever the incumbent requires. In this paper, a cognitive algorithm is proposed to take in advance decisions to promptly create a list of traffic steering routes whenever an unscheduled evacuation is demanded. This solution aims at guaranteeing the QoS and seamless connectivity during traffic steering. A performance evaluation conducted in a scenario composed of one LTE-LSA and three Wi-Fi network operators demonstrates that the proposed solution fulfills the time required by the unscheduled evacuation as well as guarantees the QoS and seamless connectivity of evacuees.**

I. INTRODUCTION

The traffic generated by mobile network operators is constantly growing and by 2020 it is expected to overload the existing licensed spectrum [1], leading to a resource scarcity problem. Licensed Shared Access (LSA) is an emerging solution to deal with this kind of problem, since it authorizes spectrum sharing by allowing the spectrum rights holder (*i.e.,* the incumbent user) to temporarily provide access to the LSA licensees [2]. However, the incumbent user is eligible to dynamically request the resources back at any time. Such request compels the LSA licensees to promptly evacuate the spectrum to avoid interfering with the incumbent services. In order to vacate the resources in a timely manner, the LSA licensees must implement fast handover strategies and consequently manage to steer the traffic of evacuees to available portions of the spectrum.

The main goal of this paper is to provide a cognitive mechanism to perform in advance decisions to allow traffic steering in unscheduled evacuation of LSA bands. Various solutions have been proposed to address this kind of evacuation ([3] [4] [5] [6] [7]). The main contribution of the proposed approach in comparison with these related works is to take decisions beforehand. In other words, the proposed approach enables the LSA licensee to create a list of potential traffic steering routes before an evacuation request is received, which considerably shortens the evacuation duration. An additional important contribution of the proposed solution is the in advance association of the Quality of Service (QoS) metrics considering different classes of service during the decision process. Thus, the traffic steering decision aims at maintaining the QoS of the evacuated users.

A novel traffic steering solution is proposed by extending an existing cognitive QoS-aware resources sharing architecture originally proposed by Kunst *et al.* ([8] [9]). The original architecture is used to gather updated information regarding resources usage of various operators in heterogeneous network scenarios. Since this architecture allows the implementation of different decision algorithms, in this paper, the original algorithm is replaced by one which is capable of taking in advance decisions. This kind of decision allows the selection of alternative routes for traffic steering in unscheduled spectrum evacuation scenarios. Specifically, a scenario composed of LTE-LSA and Wi-Fi network operators is considered to evaluate the performance of the proposed solution. Such evaluation is conducted via Matlab simulations based on an analytical system model. Results show that the proposed solution is able to allow fast spectrum evacuation and traffic steering, taking into account the QoS requirements of the evacuating users.

The main contributions of this paper are summarized as follows:

1) Proposal of a cognitive in advance decision algorithm to allow fast evacuation of LSA spectrum bands;
2) Fast traffic steering in unscheduled evacuation of LSA bands;
3) Performance and viability analysis (in terms of evacuation duration) of the proposed solution in heterogeneous network scenarios composed of LTE-LSA and Wi-Fi network operators.

The remainder of this paper is organized as follows. Current solutions for LSA spectrum evacuation are analyzed in Section II. The proposed solution is described in Section III. The performance evaluation is presented in Section IV. Finally, conclusions and directions for future work are presented in Section V.

II. RELATED WORK

Traffic steering is a current topic of research in LTE and LSA network scenarios. The goal of traffic steering is to find the most suitable evacuation route when vacating a frequency is necessary [10]. According to Mustonen *et al.* [11], the traffic steering is carried out on the basis of the capacity and load of heterogeneous networks. Nowadays, LTE features such as handover and traffic steering are oriented to be performed considering algorithms which provide cognitive decisions. This kind of decision brings intelligence to the allocation of radio and network resources, aiming at increasing the overall network QoS [7].

The cognitive engine designed by Martinmikko *et al.* [7] is the essential part of the cognitive radio trial environment to control different radio systems with the aim of guaranteeing QoS while carrying out handover and traffic offloading procedures. In fact, the cognitive engine analyzes alternative networks when high priority clients experience QoS degradation and when possible, carry out forced handover to deal with the problem. The cognitive decision making is an essential functionality to perform the forced handover of users and thus guarantee the QoS in accordance with their priority, regardless an evacuation of the LSA band takes place.

A Multilevel resource architecture was designed by Kunst *et al.* for the allocation of QoS-aware resources in heterogeneous wireless networks [8] [9]. This architecture relies on a broker which gathers together the updated information regarding the available network resources and them to be shared between the network operators.

Despite very relevant, related works are not concerned with time-sensitive traffic steering and handover procedures. Considering this limitation, in this paper is proposed a cognitive algorithm to carry out a fast traffic steering procedure. Our proposed solution takes into account both the QoS requirement of the evacuees and the time limit set by an LTE base station to release the LSA band ([6]) and thus avoid interference with the incumbent services. Details on the proposed approach are presented in next section.

III. Cognitive Traffic Steering Algorithm

An adaptation of Kunst *et al.* architecture ([9]) is presented in Fig. 1. The architecture allows communication among diverse network operators through a polling based mechanism. The left side of the figure illustrates the coexistence of LTE-LSA and Wi-Fi operators within the same geographical area. In the right side of the figure, the structure of the resources broker is represented. This Broker is responsible for coordinating resources sharing in heterogeneous networks scenarios and it is also adapted from Kunst *et al.* proposal.

The Broker plays the role of a centralized entity which keeps track of the network resources availability. Three levels are defined to provide independent and simultaneous control of different tasks of resources sharing management. These levels communicate with each other via Service Access Points (SAP) and are named accordingly to the function executed by each one: (I) Traffic Analysis Level, (II) Resources Knowledge Level, and (III) Cognition Level.

The first level of the Broker is responsible for controlling the polling mechanism used to gather updated information on the resources conditions of the Wi-Fi access cloud. The information received from each Wi-Fi operator contains a tuple composed of its identification, current average Delay, Jitter, and Throughput. This tuple is received and pre-processed by a Traffic Status analyzer and then relayed to the Traffic Profile Analysis block, which is responsible for keeping track of both current and historical values of the QoS parameters, which will feed the Resources Knowledge Level.

Databases are organized in the Resources Knowledge, which is the second level of the Broker. In the approach proposed in this paper, the Resources Knowledge level implements two databases to store information regarding the resources availability of LTE-LSA and Wi-Fi networks, respectively. This level plays a crucial role both on the traffic

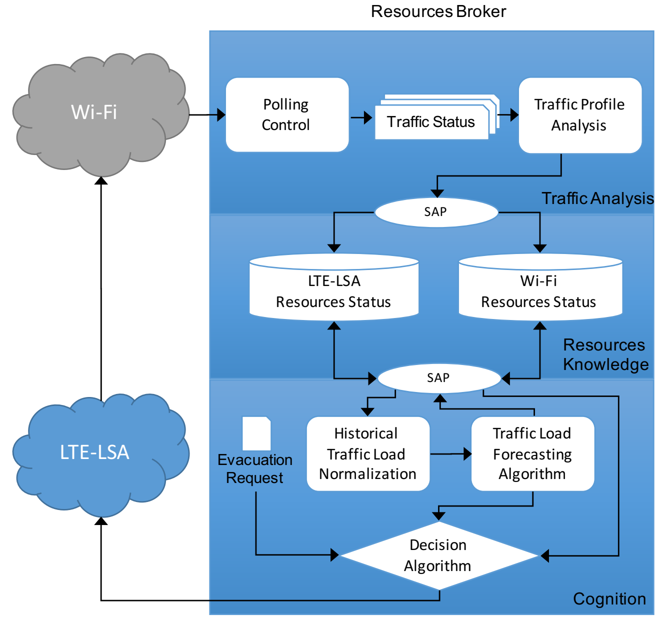

Fig. 1. Architecture Design

forecast and on the cognitive decision process which allows the unscheduled evacuation of the LSA band whenever necessary.

The Cognition Level accesses information on the second level of the Broker to take decisions when an evacuation is required. The evacuation request is composed of a struct which informs the CoS and the QoS requirements of the client. This level is constantly running, with the goal of taking in advance decisions regarding the traffic steering, which is used to promptly vacate the LSA band when required. This in advance decision demands the Cognition Level to forecast the traffic of the LTE-LSA and Wi-Fi operators in order to identify the best evacuation route. Such forecast requires knowledge about the historical traffic load, which is stored in the Resources Status Database of the LTE-LSA and Wi-Fi networks, respectively. Later, the historical traffic load is processed and normalized in the Cognition Layer. The resulting values serve as inputs to the Traffic Load Forecasting Algorithm.

In order to forecast the traffic behavior, a Multiple Linear Regression (MLR) model is implemented using Matlab. This model is based on a traffic measurement Y, which is related to a single predictor X for each observation. Therefore, the conditional mean function can be described as in (1), where α is the intercept and β is the coefficient.

$$\mathrm{E}[Y \mid X] = \alpha + \beta X \tag{1}$$

Considering that multiple predictors (n) are available from the traffic traces, in this paper, the MLR modeled according to (2).

$$\mathrm{E}[Y \mid X] = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \tag{2}$$

The variability of the ith measurement Y around its mean value is specified in (3).

$$E[Y \mid X_i] = \alpha + \beta_1 X_{i,1} + \beta_2 X_2 + \cdots + \beta_n X_{n,i} + \epsilon_i \quad (3)$$

In this case, the error assumptions for ϵ_i are: $E[\epsilon_i] = 0$ and $\mathrm{var}(\epsilon_i) = \sigma^2$. The accuracy of the forecast can be measured by the mean absolute percent error (η), which is given by (4). In this equation, e_t represents the actual network occupation based on network traffic traces and y_t is the forecast occupation of the same network in a given instant of time.

$$\eta = \frac{1}{n}\left(\sum_{t=1}^{n}\left|\frac{e_{(t)}}{y_{(t)}}\right|\right) \quad (4)$$

The resulting forecast points compose a continuous traffic function, $f(x)$, which describes the occupied area of each analyzed network. In this context, let $f : D \rightarrow R$ be a function defined on a subset D of R and let $I = [a, b]$ be a close interval contained in D. In this paper, this closed interval represents the start and the end time of the forecast. Finally, let $P = \{[x_0, x_1], [x_1, x_2], \cdots, [x_{n-1}, x_n]\}$ be a partition of I such as $P = \{a = x_0, x_1, \cdots, x_n = b\}$. Thus, a Riemann sum (S) of f over I with partition P is defined in (5).

$$S = \sum_{i=1}^{n} f(x_i^*)(x_i - x_{i-1}) \quad (5)$$

When the number of points in P increase indefinitely, the equation (6) calculates the occupied area of each network, which can be related to the occupied network capacity.

$$A_{occupied} = \int_a^b f(x)dx = \lim_{x\rightarrow\infty}[s^*(P, f)] \quad (6)$$

This value is normalized considering the total capacity area (A_{total}) of each network operator. Its complement therefore represents the percentage of available resources of a given network. Let $\Theta = \{o_0, o_1, \cdots, o_{n-1}, o_n\}$ be a set of network operators. Thus, the free capacity percentage of the network operators is given by (7).

$$\forall o \in \Theta, A_{free}(o) = 1 - \left(\frac{A_{occupied}(o)}{A_{total}(o)}\right) \quad (7)$$

Three CoS are defined to accommodate different types of traffic regarding the QoS requirements. (I) Real-Time Services (RTS), to support delay and jitter sensitive real-time transmissions, (II) Multimedia Services (MS), comprehending real-time services with high throughput but no strict delay and jitter, and (III) Best Effort Services (BES), designed to support best effort transmissions without strict QoS requirements. Based on the CoS requirements and on the amount of free resource of each operator calculated beforehand by the traffic forecasting algorithm, a decision algorithm is implemented, as defined in Algorithm 1.

In the proposed algorithm, the decision is based on information gathered from the Traffic Load Forecasting Algorithm. The outcomes of this algorithm are stored in the databases of the Resources Knowledge Level of the Resources Broker.

Algorithm 1 Decision Algorithm

Require: r ▷ A struct containing a cognitive evacuation request
Require: $A_{total}(o)$ ▷ The total amount of resources of each operator
Require: $A_{occupied}(o) = \int_a^b f(x)dx = \lim_{x\rightarrow\infty}[s^*(P, f)]$ ▷ The amount of occupied resources of each operator

```
selected_operator = 0
c ← r.CoS; d ← r.Delay; t ← r.Throughput
switch c do
    case RTS:
        for all o ∈ Θ do
            A_free(o) = 1 − (A_occupied(o) / A_total(o))
            delay(o) = get_knowledge_level(Wi − Fi, delay)
            if A_free(o) ≥ t & delay(o) ≤ d then
                return o
            end if
        end for
    case MS:
        for all o ∈ Θ do
            A_free(o) = 1 − (A_occupied(o) / A_total(o))
            if A_free(o) ≥ t then
                return o
            end if
        end for
    case else:
        for all o ∈ Θ do
            max_operator = 0
            A_free(o) = 1 − (A_occupied(o) / A_total(o))
            if A_free(o) ≥ max_operator then
                max_operator = A_free(o)
                return selected_operator = o
            end if
        end for
        return selected_operator
```

Whenever an evacuation request is received, the decision algorithm queries the referred databases to obtain the updated forecast. This forecast is then considered along with the class of service of the request to search for a traffic steering route which is able to guarantee QoS of the evacuees.

IV. Performance Evaluation

In this section, an evaluation of the traffic steering is conducted that involves cognitive in advance decisions. This includes conducting an analysis of accurate decisions, processing time, and QoS requirements. The simulation scenario is discussed in Subsection IV-A, and the performance of the proposed solution is analyzed in Subsection IV-B with regard to three key factors: (I) traffic load forecasting, (II) cognitive decisions accuracy, and (III) cognitive traffic steering efficiency.

A. Simulation Scenario

Modeling the traffic demand of the LTE network operator is important to simulate the behavior of the proposed solution. The traffic models consider the arrival distribution and the traffic demanded per connection. This model is based on the WiMAX forum specification [12] and simulates three kinds of traffic: HTTP, Video, and VoIP. The remaining simulation parameters are summarized in Table I.

HTTP are used to model BES traffic. The transmissions comprise the main page, which has a given number of embedded objects, such as images, scripts, and other sorts of attached files. After requesting and receiving the files, the browser

TABLE I. TRAFFIC SIMULATION PARAMETERS

Parameter	Values for LTE-LSA Network
Channel Bandwidth	10 MHz
LTE Frame Length	10ms
Simulation Duration	1800s
% of HTTP Traffic	40%
% of VoIP Traffic	30%
% of Video Traffic	30%

parses the page to make it readable to the user. The user then reads the page before making a new request. The values of each phase of the HTTP statistical model are described in Table II.

TABLE II. HTTP TRAFFIC PARAMETERS

Component	Distribution	Parameters	PDF
Main Page Size	Truncated Lognormal	Mean = 10710 bytes SD = 25032 bytes Min = 100 bytes Max = 2 Mbytes	$\sigma = 1.37$ $\mu = 8.37$
Embedded Object Size	Truncated Lognormal	Mean = 7758 bytes SD = 126168 bytes Min = 50 bytes Max = 2 Mbytes	$\sigma = 2.36$ $\mu = 6.17$
Number of Embedded Objects	Truncated Pareto	Mean = 5.64 Max = 53	$\sigma = 1.1$ $\mu = 55$
Reading Time	Exponential	Mean = 30 s	$\mu = 0.033$
Parsing Time	Exponential	Mean = 0.13 s	$\mu = 7.69$

RTS are modeled to include VoIP transmissions, and Adaptive Multi-Rate (AMR) audio codec, which has ON/OFF behavior. This behavior is modeled to cover the activity of speech in conversations using this codec system. The duration of each period was modeled on the basis of an exponential distribution with an average of 1026 ms for ON period of (conversation) and 1171 ms for OFF period (silence). Finally, MS are modeled by video transmissions encoded using the MPEG-4 format.

The simulations are performed in Matlab considering the architectural model presented in Section III, the above traffic models, as well as the realistic traces obtained from CRAWDAD database to model Wi-Fi networks traffic [13]. The scenario consists of three Wi-Fi networks operating in no interfering channels and one LTE network operator using the LSA spectrum band.

B. Performance Evaluation

With regard to the performance of the proposed solution, the first factor to analyze is the accuracy of the traffic load forecasting model. The forecasting follows three key phases. The first is the time series extraction of traffic data from LTE-LSA and Wi-Fi networks. The second consists of fitting the polynomial curve of traffic data of both LTE-LSA and Wi-Fi networks. In the third phase, the forecasting is carried out by means of the MLR model as detailed in equation 2.

Considering that the time series is a sequence of data points, that generally consists of successive measurements made in a time interval [14]. These data points are divided into three data sets: training, validation, and testing. The training data set contains the traffic load measurement that corresponds to the first 15 minutes of the time series. The validation data set consists of 10 percent of the testing data set which is used to analyze the outcomes of the prediction, by taking account of metrics such as accuracy and processing time.

The MLR model processes the trained data set of simulated traffic demands for the LTE-LSA network, as well as the aggregate traffic of the Wi-Fi networks. The simulated traffic in the LTE-LSA network and the traffic traces of Wi-Fi are computed in units of seconds to improve the accuracy of the model. The first step of the analytical methodology involves calculating the polynomial curve fitting for smoothing out the peaks and noise of the network traffic. The polynomial was fixed at 10 degrees for curve fitting analysis of traffic of each network. The classification is then performed again and includes the new data points obtained from the ten degrees polynomial for the training, validation, and testing datasets. After this, the MLR model carries out the traffic load forecasting and the validation data set is used to evaluate its accuracy for each network.

The MLR accuracy is evaluated by the cross-validation method which involves the comparing the forecasted values with the current values. At this point, the MLR model can be adjusted to improve the accuracy of the upcoming predictions. The MAPE equation (4) is also used to calculate the accuracy of the MRL model. Fig. 2 shows the analysis of the accuracy of traffic load forecasting, which examines three Wi-Fi networks as possible traffic steering routes. As can be seen in the graph, the traffic load forecasting was very accurate and reached levels of 96.18%, 93.61%, and 94,20% degree of accuracy, for Wi-Fi networks 1, 2, and 3, respectively.

The traffic load forecasting is also correlated to the classes of service to analyze the QoS support feature of decision algorithm in terms of selecting the traffic steering route which presents the higher probability of preventing future network congestion. The outcomes of the simulation related to this scenario are depicted in Fig. 3 which shows the traffic load forecasting of VoIP, Video, and HTTP in the LTE-LSA network. In this case, the levels of accuracy are up to 95,72%, 98,47%, and 94,76%, respectively.

Every time the traffic load forecasting is performed, the values of the time series data points prediction are updated and input into the cognitive decision algorithm, which is responsible for selecting the traffic steering routes. The first step taken by the decision algorithm is to estimate the availability and occupation of bandwidth for each target network on the basis of the previous forecasting. The second step involves selecting the Wi-Fi networks which can guarantee the same level of QoS as that offered in LTE-LSA network. This kind of decision is made on the basis of the predicted availability of network resources. However, the same QoS level can only be ensured if the proposed solution is also able to include the delay metric. The third step performed by the decision algorithm is also related to the QoS and entails association of the CoS to the decision process.

The traffic load forecasting starts from the 15 minutes in Figs. 2 and 3 because it requires the historical traffic load measurements of the last 15 minutes to train the MLR model and predict the next 15 minutes traffic load trend with an accuracy close to 95% and to guarantee a fast response.

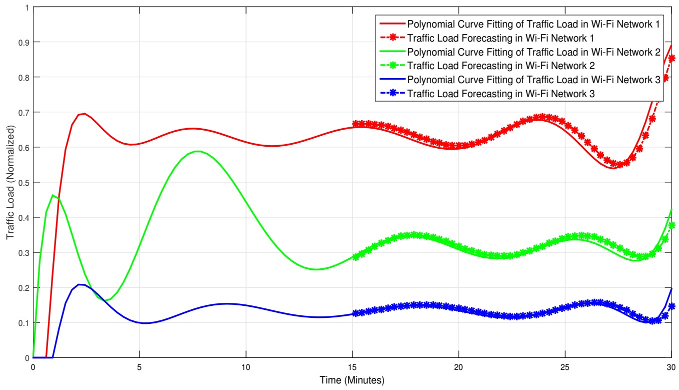

Fig. 2. Actual vs. Predicted Traffic Load for each Wi-Fi Network

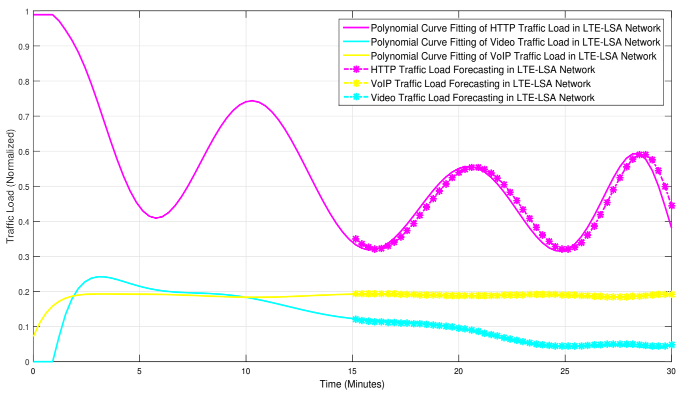

Fig. 3. Actual vs. Predicted Traffic Load for CoS in the LTE-LSA Network

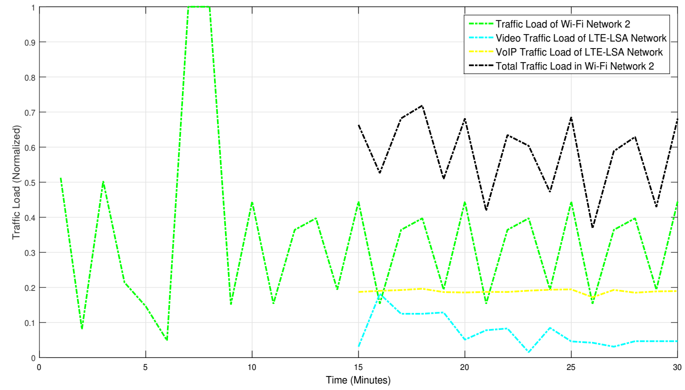

Fig. 4. Video and VoIP Traffic Steering from LTE-LSA to Wi-Fi 2

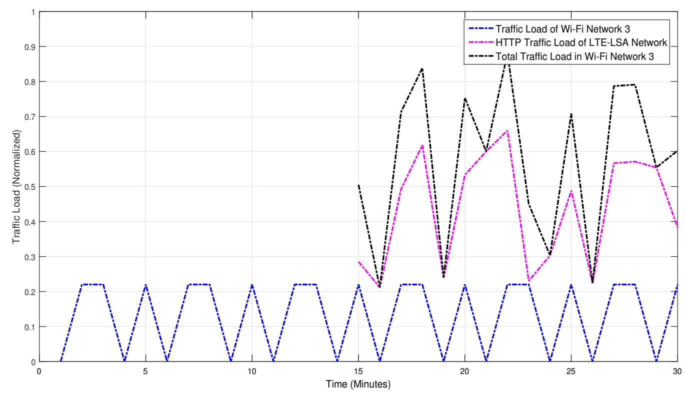

Fig. 5. HTTP Traffic Steering from LTE-LSA to Wi-Fi 3

The cognitive decision algorithm conducts the analysis of future bandwidth capacity of each overlapping Wi-Fi network by relying on the trapezoidal numerical integration to calculate the area under the curve of the MLR forecast. The area under the curve is equivalent to the percentage of occupied bandwidth resources for each Wi-Fi. As stated of the evaluated network scenario and an analysis of Fig. 2, the percentage of forecasted occupied bandwidth for Wi-Fi 1 is 65.8%, for Wi-Fi 2 is 31.6% and for Wi-Fi 3 is 15.4%. Based on these values, the in advance decision algorithm determines Wi-Fi 1 as a low priority route for traffic steering because of its very high traffic load. On the other hand, the cognitive decision defines Wi-Fi 2 and 3, as high-priority traffic steering routes. After this initial analysis, when an evacuation is required, the decision algorithm associates the class of services with the previous information to perform the traffic offloading while taking account of the QoS requirements of the evacuees.

The bandwidth occupation in Wi-Fi 1 oscillates close to 95% with its original users, making this network unavailable. Figs. 4 and 5 show the occupation of Wi-Fi 2 and 3 after the traffic steering. The bandwidth occupation in Wi-Fi 2 fluctuates between 40% and 70% after the offloading of Video and VoIP traffic demands from the LTE-LSA network, while Wi-Fi 3 network bandwidth occupation is around 80%. These results show that all the traffic was accommodated in the destination networks without overloading them. Thus, the QoS of the evacuees can be guaranteed without interfering with the original Wi-Fi users in terms of network capacity.

Another important QoS metric is the delay. Fig. 6 shows the behavior of this metric considering a variable amount of connections accommodated by each Wi-Fi network. As can be seen in the graph, Wi-Fi 1 has the smallest delay value because it is a low-priority traffic steering route and thus the cognitive decision algorithm does not make it eligible to receive traffic from delay-sensitive applications. Wi-Fi networks 2 and 3, on the other hand, receive QoS sensitive traffic and are capable of keeping the average delay below 30ms. This value is sufficient to guarantee the QoS of multimedia traffic, which generally requires the delay to be between 100 and 200 ms.

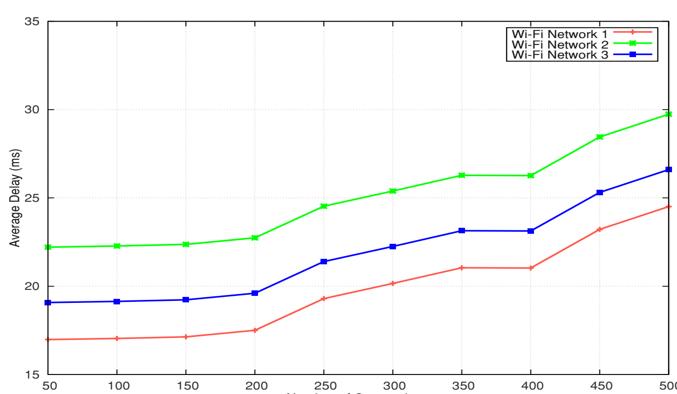

Fig. 6. Average Delay in Wi-Fi Networks

Another crucial factor that must be covered by the decision algorithm is to avoid interfering with the incumbent services in the event of an unscheduled evacuation. For this reason, the traffic steering must occur as fast as possible. The outcomes of this approach are similar to those of related work in the literature. Matinmikko *et al.* [7] was able to perform the decision in approximately 0.9 seconds on average, while Palola *et al.* [3] designed an algorithm which was able to carry out the decision in 0.624 seconds. Owing to the cognitive in advance decision mechanism, which is based on accurate forecasts, the proposed solution reduces the average decision time to values as low as 0.0371 of a second.

The processes related to the overall time required by the proposed solution to evacuate the LSA band and hence to offload the traffic to the selected Wi-Fi network, are outlined in Table III. Since the proposed approach involves making decisions in advance, the duration of both the decision process and the overall evacuation can be reduced. The CEPT Report 56 [6] stated that the duration for turning off an LTE base station with one sector delays 20.620 seconds on average. This limit of time constraints the ability of the traditional procedures to evacuate the UEs at a lower time to avoid interfering with the incumbent services in the LSA frequency and ensure the QoS of the evacuees. The results of the simulation show that the proposed solution allows the overall evacuation to be conducted in about 11.3 seconds, which represents a value that is around 46% below the specified time limit.

TABLE III. DURATION OF EVACUATION

Process	**Average Duration [s]**	**Standard Deviation [s]**
Traffic Load Forecasting	3.8267	0.2161
Cognitive Decision	0.0371	0.0051
Traffic Steering	7.3962	0.9477
Total Duration	11.2698	3.0163

V. CONCLUSIONS

This paper proposed a QoS-aware cognitive algorithm designed to take in advance decisions in the context of the unscheduled evacuation of LSA bands. This algorithm creates a list of candidate traffic steering routes taking into account the CoS and consequently the QoS requirements of the evacuating users. This kind of in advance decision allows a very fast evacuation to take place. The results show that the decision algorithm is faster than those in two related works and that the overall time consumed during the evacuation process is 46% faster than the maximum time allowed to avoid interfering with the incumbent user. Moreover, the outcomes of the simulations show that the proposed solution is able to guarantee QoS by including metrics such as throughput and delay.

Directions for future investigation include a deeper analysis of the performance of the proposed solution. This analysis can include the execution of the cognitive algorithm and the resources broker in realistic testbeds. Moreover, other QoS metrics, such as jitter and packet loss can be taken into account during the decision process. Finally, the proposed algorithm can be extended so that it can be executed in scenarios with a larger number of network operators which are able to implement different technologies, leading the application of the proposed solution to more heterogeneous scenarios.

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