Quality of Service Management Mechanism for Wireless Systems with Dynamic Spectrum Access

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Abstract*— Wireless communication systems are limited by the radio resources available, e.g. spectrum, transmit power, etc. Therefore, it turns important to define mechanisms that allows to use those resources efficiently to maintain the quality of service of the system. For this reason, this paper presents a quality of service management mechanism for wireless systems with dynamic spectrum access. A load balancing management mechanism is used together with the Simulated Annealing algorithm to demonstrate that an access method or group of them operating with a certain level of load balancing can maintain the channel capacity above the proposed threshold while minimizing the total operating cost of the system.

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I. INTRODUCTION

The demand of mobile devices, which requires transmission with a certain level of quality of service, has been increased in the last years by the increase number of PDAs, mobile phones, drones, wireless monitoring systems, wireless information systems, car navigation systems, long-distance educational equipment, and intelligent devices connected to the Internet. However, lots of these equipments use one access method at time which expose them to several issues in their radio link, i.e.: high co-channel and adjacent channel interference level due to the simultaneous access in shared frequency bands, such as the ISM band where the radio spectrum is limited [1, 2]. This leads to a reduction of the transmission capacity of the radio channels and a shorter-range coverage. The situation could get even worse with the advent of IoT, resulting in a serious issue where devices will have a very limited connectivity and unable to communicate at all. However, the use of dynamic spectrum access is a technology that could alleviate this situation. By using exclusive channel devices (e.g. 3G), it could be possible to raise the wireless coverage [3] of ISM band devices and address this issue. Although, this could produce new drawbacks such as higher consumption of energy [4, 5] or a higher cost by using the proprietary infrastructure network [6]. Still, it is a valuable option that could solve this issue.

One option to solve this problem is to provide multiple access methods for each mobile device. Nevertheless, the use of different accesses creates a new challenge in the scientific community. In the context of multiple access methods, it has been proposed several solutions that improve some aspects like: operating costs, energy consumption, runtime reductions and quality of service. For example in [6], it is proposed a power control mechanism for wireless systems who have the IEEE 802.11e standard, allowing to obtain better energy saving capacities and quality of service based on game theory. In [7], a tool is described that can be used to solve problems like the inefficient use of transmit power of mobile devices that use this methodology.

For achieving an efficient management of the load balancing requirements (i.e data flux capacity), in [8] the parameter *load balancing* is defined. Load balancing distributes the duties in a more precise and equitable way, which are data assignments that are transmitted in a communications channel. Similarly, in [9], a dynamic algorithm for data balancing is proposed with the goal of increasing the global system efficiency and reducing the runtime using a probability vector and adaptive matrixes.

Currently, load balancing management in multiple access methods systems is one the main study topics in the scientific community because tasks could be split among several processes instead of allocating all of them to one. The load balancing solution allows to maximize the data processing capacities, as well as the task execution. According to [9], it is possible to increase considerably the system global yield by using the load balancing algorithms, which redistribute the tasks of the overloaded access to another with a lighter load.

Therefore, this article proposes a load balancing management mechanism for a wireless multiple access method system, which minimizes the total operating cost of the system while maintaining the channel capacity threshold, with the intention of obtaining an operating access method or a group of them with a certain level of balanced load. For this reason, a metric is defined for each access method. These metrics consider several parameters like receive power, signal to noise ratio, channel capacity and economic cost of the technology. These access utilities establish a utility function for the whole system, which will be optimized using the optimization probabilistic technique called SA [10-13] because is a well-known optimization technique for resource assignment [14].

This article is organized as follows. In Section II it is described the main aspects of the study scenario to model. In Section III, the load balancing statement is formulated mathematically. Then, in Section IV, it is shown the proposed algorithm and the utility functions. In Section V, the algorithm test is done. And finally, Section VI shows the conclusions of the article.

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II. SYSTEM MODEL

A. Scenario Description

In this work, an urban scenario with a high building density has been considered. In a scenario, such as this, there could exist a high concentration of multiple and different wireless communication systems. In addition to that, we will consider a mobile device (*DM*) that follows a path along a street, having several wireless access methods available such as: Wi-Fi, 3G, 4G and others. Along this path, the multiple access scheme of the mobile device will experience multiple interferences coming from other devices located inside the buildings (e.g. APs).

To illustrate the scenario proposed, Fig. 1 is used, where n_b buildings are placed and distributed on each side of the street, the street has a length a_1 and width a_2. A scenario such as this, with a high density of buildings is based on a Manhattan model [14]. The buildings have a height b_1, width b_2 and depth b_3. There is a separation of a_3 between them and they are a_4 far from the street border. Each building has a_5 floors with b_7 rooms each one, and a b_4 of width, b_5 length and b_6 height.

The mobile device DM is provided with a i and j wireless access methods and moves a total distance q in steps of p, with initial position o_1 and final position o_2. For each step q an interference analysis is performed for every access method of the *DM* related to the other devices deployed in the scenario. Another equally significant aspect of this analysis is the use of a remote control (*CR*) that controls the *DM*'s path and the multiple access scheme used. Thus, depending on the interference level between the *DM* and *CR*, the access method with the best performance will be used.

B. Signal Models

This specific study considers a *DM* with i number of Wi-Fi accesses and j accesses that maintain communication with their respective base stations BS_{WF} and BS_{3G}, as shown in Fig. 1. The signals levels perceived by *DM* and originated from any other device in the scenario, could be described in the following way:

- The *DM* received signal level of each one of its i Wi-Fi access methods that has been transmitted by BS_{WF} can be calculated with the following expression:

$$P_{BS_{WF_i}\rightarrow DM_i} = P_{BS_{WFi}} - L_{BS_{WF_i},DM_i} - \Delta_{WF} \qquad (1)$$

$P_{BS_{WF_i}}$ is the transmitted power of BS_{WF_i} in access i, $L_{BS_{WF_i},DM_i}$ is the signal loss among BS_{WF_i} and DM_i, and Δ_{WF} is a loss factor from the i access due to overlapping channels.

-The *DM* received signal level of each one of its j 3G access methods that has been transmitted by BS_{3G} can be calculated with the following expression:

$$P_{BS_{3G_j}\rightarrow DM_j} = P_{BS_{3G_j}} - L_{BS_{3G_j},DM_j} \qquad (2)$$

being $P_{BS_{3G_j}}$ the transmitted power of BS_{3G_j} to access j and $L_{BS_{3G_j},DM_j}$ is the signal loss between BS_{3G_j} and DM_j. The received signal level by *DM* is shown in Fig. 2.

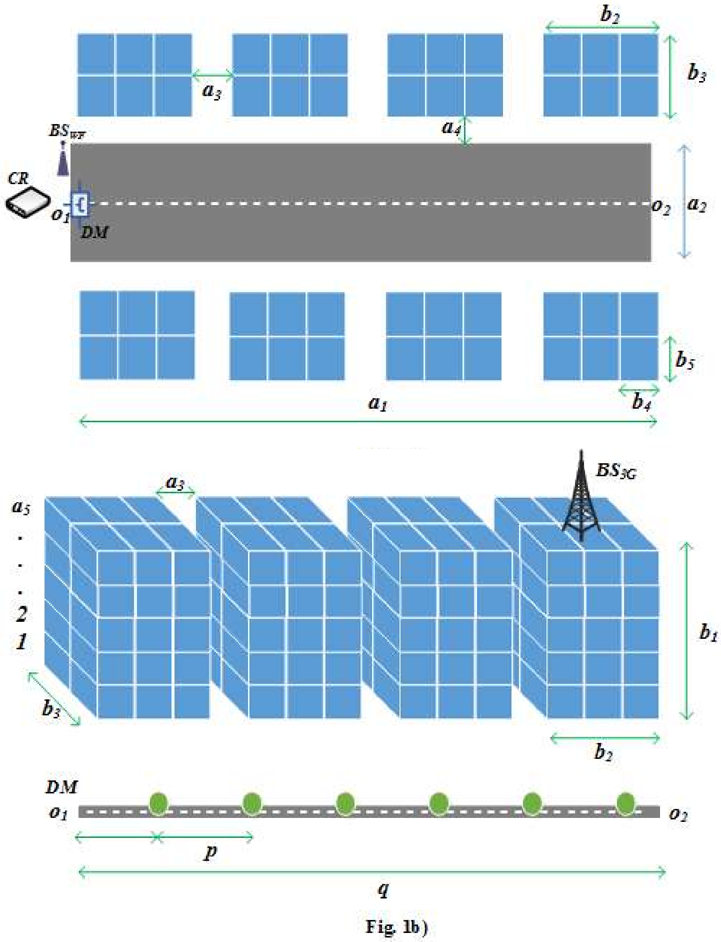

Fig. 1 Study Scenario. a) Top View, b) Tridimensional View

Moreover, the band of the Wi-Fi access is shared with other users, and due to that fact, it could experience interference coming from different APs in the vicinity that are distributed inside the buildings of the scenario proposed. In that case, is relevant to perform an interference analysis of *DM:*

- The interference level on each one of the i access of *DM* in the channel k from any of the ap_m devices deployed in the urban zone whose signal is transmitted in a r channel, is defined by:

$$I_{ap_m^r \rightarrow DM_i^k} = P_{ap_m} - L_{ap_m,DM_i} - \Delta_{r,k} \qquad (3)$$

Each ap_m transmits a power P_{ap_m}, L_{ap_m,DM_i} is the signal loss between ap_m and DM_i, and $\Delta_{r,k}$ is a loss factor due to overlapping channels. This factor can be calculated with the following expression [17]:

$$\Delta_{r,k} = -10\log\left(\rho_{r,k}\right), \forall \rho_{r,k} > 0 \qquad (4)$$

where $\rho_{r,k}$ represents the interference factor due to overlapping channels, whose expression is described as follows:

$$\rho_{r,k} = \max\left(1 - 0.2|r-k|, 0\right) \quad (5)$$

Is important to note that, regarding de 3G access, the interference that could be produced from other devices is not considered, as shown in Fig. 2, since the received signal levels are limited by the operator and the bandwidth of this technology is intended for the exclusive use of one user at time. In fact, each access *i* will have assigned a non-overlapping channel in the Wi-Fi shared bandwidth, for that reason Δ_{WF} is equal to zero.

Finally, it has been considered that the signal loss between *CR* and BS_{WF} is insignificant and the communication among *CR* and BS_{3G} is optimal.

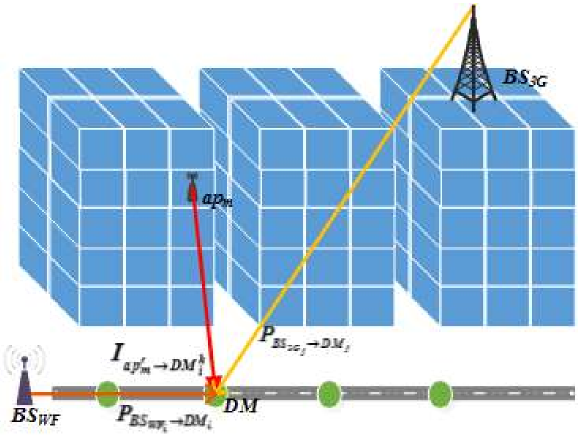

Fig. 2 Signal and Interference received by the DM

C. Propagation Models

To describe precisely the propagation losses in internal and external urban scenarios, this article uses several propagation models which allow to model this phenomenon with great accuracy. Hence, the propagation models used in this work, sorted per the transmission type, are shown in the following section.

Propagation Losses between BS_{3G} and *DM*

In this case, since the base stations are in external locations, the propagation model should only consider this type of scenario. That being the case, the chosen model is the Log-Normal model, which is an empirical propagation model that considers the shadowing fading effect (Shadowing Path Loss Model) [16-17]. Therefore, the signal loss between BS_{3G} and *DM* is described as follows:

$$L_{BS_{3G_j},DM_j} = L_o + 10\alpha \log d_{BS_{3G_j},DM_j} + Shadow \quad (6)$$

L_o being the propagation loss in 1 meter of distance from the transmitter, expressed in dB (this is calculated using the Free Space Model) [17]. The L_o expression is defined as follows:

$$L_o = 10\alpha \log\left(41.9f\right) \quad (7)$$

where f is the system operating frequency, α is the propagation slope which is related with the environment conditions, $d_{BS_{3G_j},DM_j}$ is the distance between BS_{3G} and *DM*, and *Shadow* is the standard deviation of the loss because of the fading obtained from a Gaussian random variable [17].

Propagation Losses between *DM* and BS_{WF}

The communication among BS_{WF} and *DM* is in an external scenario, in this case the propagation model is the same as the propagation model between BS_{3G} and *DM* [16-17]. And for that reason, the signal loss BS_{WF} and *DM* is defined as:

$$L_{BS_{WF_i},DM_i} = L_o + 10\alpha \log d_{BS_{WF_i},DM_i} \quad (8)$$

L_o corresponds to the same value used in equation (7) and $d_{BS_{WF_i},DM_i}$ is the distance among BS_{WF} and *DM*.

Propagation Losses between any *ap* and *DM*:

Because the access points are located inside the buildings, it is necessary to consider indoor and outdoor losses. Therefore, to determine the path loss between each ap_m and DM_i, the COST 231 Kennan and Motley propagation model described in [17] is used and described as follows:

$$L_{ap_m,DM_i} = L_o + 10\alpha \log d_{ap_m,DM_i} + L_{obs_{ap_m,DM_i}} \quad (9)$$

For this equation, L_o and α are defined in equation (7), d_{ap_m,DM_i} is the distance from ap_m to DM_i, and $L_{obs_{ap_m,DM_i}}$ is a loss factor resulting from the obstacles the interference signal from ap_m must overpass. This term is described as follows:

$$L_{obs_{ap_m,DM_i}} = \sum_{floor=1}^{n_{floor}} L_{floor} + \sum_{wall=1}^{n_{wall}} L_{wall} + \sum_{window=1}^{n_{window}} L_{window} \quad (10)$$

being n_{floor} the number of floors, n_{wall} the number of walls and n_{window} the number of Windows that must overpass the signal from any ap_m to interfere with DM_i. The loss factors for walls, floors and windows are L_{floor}, L_{wall} y L_{window} respectively.

III. Mathematical Formulation

A. Problem Statement

In this work, it is considered that any operating type of access method could experience communication issues like signal degradation, whose origin can be the path loss or the channel saturation caused by other systems' interference. Thus, is imperative to find a solution that satisfies the demands of quality of service of the wireless multiple access system. Fig. 3 shows a solution scheme for these issues.

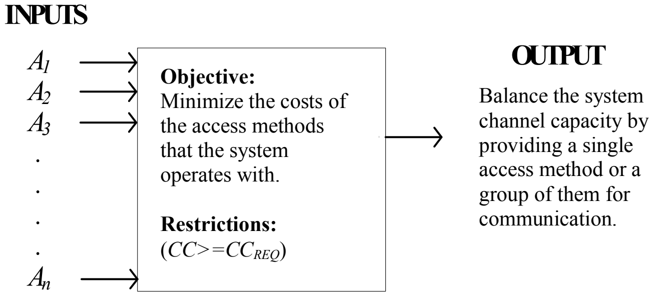

Fig. 3 System Functioning scheme.

Fig. 3 shows a block with the multiple access methods available of the system ($A_1, A_2, A_3, \ldots, A_n$) as inputs. Also, a cost is allocated either for each access method or a group of them. The system is configured to achieve the goal of using an access method or a group of them that minimizes the operating cost of the system and allows to hold up the channel capacity of the system (*CC*) above a defined threshold (CC_{REQ}). This process will return either an access or a group of them with a load balancing level.

B. Problem Formulation

To formulate this problem mathematically, it has been considered that the group $AP=\{ap_1, ap_2, \ldots, ap_n\}$ are the *n* APs deployed evenly inside the buildings, the location of an ap_m is defined as $pos(ap_m)=\{(x,y,z)/x,y,z\in\mathbb{R}\}$ and the channel *r* is the Wi-Fi channel being used (11 channels in USA). This is denoted by [18]: $ch(ap_m)=\{r \mid r=1,2,\ldots,11\}$.

In the case of *DM*, the non-overlapping channel *k* is used for each access *i* for communicating with its respectively BS_{WF_i}, this is denoted by $ch(DM_i)=\{k \mid k=1,6,11\}$ and the instant coordinates of its path are: $tra(DM_i)=\{(x,y,z)/x,y,z\in\mathbb{R}\}$

The station position of BS_{WF} and BS_{3G} are defined by: $ubi_{BS_{WF}}\{(x,y,z)/x,y,z\in\mathbb{R}\}$ and $ubi_{BS_{3G}}\{(x,y,z)/x,y,z\in\mathbb{R}\}$ respectively, while the *CR* position is expressed by: $ubi_{CR}\{(x,y,z)/x,y,z\in\mathbb{R}\}$.

From now on, it will be denoted access g as any *DM* access method, either Wi-Fi or 3G. Hence, based in the signal model analyzed in the previous section, the metrics can be calculated as follows:

Received Power

It has been defined the power received by an access *g* as the ratio between the signal level in every access of the *DM* which is represented by (1) or (2) and the total interference level IC_g that every access perceived due to the system deployment in a shared bandwidth. Also, a random parameter δ has been added with an statistical behavior represented by a normal distribution with a protection margin [14] in the access method, so that the received power in an access *g* can be expressed as follows:

$$P_g = P_{ij} + \delta - IC_g \tag{11}$$

where P_{ij} is the received signal level in access *i* or *j*, e.g. (1) or (2), and IC_g is expressed in the following way:

$$IC_g = \sum_{m=1}^{n} \rho_{r,k}\left(I_{ap_m^r \to DM_g^k} - S\right) \tag{12}$$

where $\rho_{r,k}$ has been defined in (5), *S* is the sensibility level for this type of access method, and 3G access IC_g is zero since the band is for the exclusive use of only one user.

Channel Capacity

The channel capacity for access *g* is defined as the following way:

$$CC_g = B\log_2\left(1+SNR_g\right) \tag{13}$$

B is the necessary bandwidth to satisfy the requirements of system and SNR_g is the signal to noise ratio of access *g*, and is calculated with the following expression:

$$SNR_g = 10^{\frac{P_g - N_g}{10}} \tag{14}$$

being N_g the channel noise factor [19].

IV. Proposed Algorithm

This section presents a mechanism that allows the DM to select any of its radio access methods efficiently while trying to sort out the load balancing issue. In this way, a radio monitoring will be performed, generating several metrics that will be used to determine the utility value for each access or group of them. Besides, this utility value will have a probability based on the system restrictions and the Simulated Annealing algorithm [11-13] determines which access or group of access is the optimal.

A. Algorithm Description

The proposed algorithm bases its decision in assigning an access method with a utility that reflects the operation cost related with monetary values, power levels or channel capacities. In this way, from the *DM* received signals, the utility that can offer each access is defined as follows:

$$U_g = e^{-c}\left(w_1\left(1-\left(e^{\frac{\min(S-P_g,0)}{10}}\right)\right)+w_2\max\left(\frac{\left(CC_g-CC_{REQ}\right)}{\left(CC_g\right)},0\right)\right) \tag{15}$$

Where the first term relates the received power in the access g with the power level P_{BS_g} which transmits its base station, this term is multiplied by a value w_1. The second term allows to relate the channel capacity of the access g with the threshold channel capacity CC_{REQ} required by the system and this is multiplied by a factor of w_2. These weighing factors allow to establish a predominance of a metric to other, in the way of $w_1+w_2=0.5$. The sum of both terms is multiplied by an exponential function, so the bigger operating cost c the fewer utility for the access g.

On the other hand, if *DM* can operate with one or several access methods simultaneously, a total utility is defined as the sum of the individual utilities of each access of the combination used. This can be expressed mathematically as follows:

$$U_{T_x} = \left(\sum_{g=1}^{n_c} \frac{U_g}{n_c} \right)^{n_c} \qquad (16)$$

where x is one of the n_x possible ways to combine the g access of *DM* and n_c is the number of g access combined. So, the total capacity channel of any x combination of one of the g access, and it is defined as:

$$CC_{T_x} = \sum_{g=1}^{n_c} CC_g \qquad (17)$$

With the purpose of choosing an access or a group of that, selection probability is assigned to each access or group of access by using the following expression:

$$p_x = v1_x v2_x \frac{U_{T_x}}{\sum_{x=1}^{n_x} U_{T_x}} \qquad (18)$$

Where $v1_x$ is a discriminating factor of the probability p_x. This is for one access method combinations, and it is defined as follows:

$$v1_x = \begin{cases} 0; & if \quad CC_{T_x} < CC_{REQ} \\ 1; & others \end{cases} \qquad (19)$$

$v2_x$ is another discriminating factor p_x, that minimizes the probability of using a combination composed by several access methods which generate a high economical cost, this is defined by the following expression:

$$v2_x = \begin{cases} 0; if \ ((\exists g \in x) = 3G) \mid \exists CC_{g=WiFi} > CC_{REQ} \\ 1; others \end{cases} \qquad (20)$$

From the probability values p_x assigned to each possible combination x, a cumulated probability vector pdf_x is created. One of the n_x combinations is probabilistically selected to provide a possible solution to the system, and using the criteria from the SA algorithm, the *DM* obtains a new assignment of access which fulfill the quality requirements of the system.

B. Pseudocode

Fig. 4 shows the algorithm that is executed periodically in the *DM*, allowing to obtain a group of access with a balanced load. This is done with the goal of fulfilling a required channel capacity, which is accomplished maximizing the total utility calculated for each access o group of them through the SA algorithm.

The algorithm operates in the following way: It initiates with the assignment of an access Ax whose total interference level is minimum according with (3), therefore an initial temperature T_0 is configured to the SA algorithm (line: 1). An access or group of access Ax_0 is probabilistically obtained evaluating a value between (0~1) in the cumulate probability vector pdf_x (line: 3). The decision of keeping the access Ax or changing to a new assignation Ax_0 depends on the comparison between their utilities ΔU_{T_x} (line: 4), where $U_{T_x}(Ax_o)$ is the utility of the new access or group of access and $U_{T_x}(Ax)$ represents the utility value of the present access. Hence, if the utility raises i.e. $\Delta U_{T_x} < 0$, the new combination is accepted (lines: 5-6). In case that the utility decreases, it can be accepted based on a probability that depends on ΔU_{T_x} and the actual temperature T (lines: 7-9). Otherwise, the selected access does not change. The temperature T is updated in every iteration through a cooling factor *CF* and gradually decreases, so the probability of accepting a new assignation of access which do not improve the utility has the same trend (line: 12).

1. **Set** $Ax \leftarrow Ax_0$; initial access
   Set $T \leftarrow T_0$; initial temperature
2. **while** *number of iterations is not reached*
3. A new access is obtained, Ax_0 ;
4. Compute $\Delta U_{T_x} = U_{T_x}(Ax_o) - U_{T_x}(Ax)$
5. **if** $\Delta U_{T_x} < 0$ **then**
6. $Ax = Ax_0$;
7. **elseif** $\Delta U_{T_x} > 0$ then
8. **if** *random*[0,1] < $e^{-\Delta U_{T_x}/T}$ **then**
9. $Ax = Ax_0$;
10. **end_if**
11. **end_if**
12. Update $T=CF \cdot T$ and *number of iterations*;
13. **end_while**

Fig 4. Load Balancing algorithm pseudocode for multi-access wireless systems

V. ALGORITHM PERFORMANCE EVALUATION

In this section, the proposed algorithm is evaluated and compared to two well-known algorithms used as benchmark: MCCR and the random access assignment (RDM). The former is based on the Min Max Algorithm, the second one chooses the operating access in a random way. The proposed algorithms were performed on a Manhattan scenario of 200x200 m^2

All the tests were done using periodic instantaneous techniques in 100 iterations for a Manhattan scenario of 200x200m^2 described in Section II. Inside this area, the configuration parameters shown in Table 1 were used.

Table 1. CONFIGURATION PARAMETERS

Parameter	Value
Number of buildings n_b	16
Number of floors per floor b_7	6
Total distance q covered by *DM*	300 m
DM steps of size p	3 m
i number of WiFi access methods	3
j number of 3G access methods	1
Number of total access methods g	4
Transmission power of WiFi access method $P_{BS_{WFi}}$	20 dBm
Transmission power of 3G access method $P_{BS_{3G_j}}$	-43 dBm
Transmission power of AP P_{ap_m}	20 dBm
Propagation slope α	3.5
WiFi operating frequency f	2400 MHz
3G operating frequency f	1800 MHz
Floor loss factor L_{floor}	3 dB
Wall loss factor L_{wall}	3 dB
Window loss factor L_{window}	1 dB
WiFi sensisbility, S	-85 dBm
3G sensisbility, S	-95 dBm
Fading Standard Deviation, *Shadow*	10 dB
Channel Noise Factor, N_g	-103 dBm
Received power weight factor metric w_1	0.1
Channel Capacity weight factor metric w_2	0.4
Initial Temperature T_0	85°
Cooling factor *CF*	0.85

A. Results

The initial scenario has 480 AP's, where the calculations were performed in 20 steps with 100 iterations per step. With the goal of obtaining a greater probability of accepting an access with a minimum cost, Fig. 5 shows the maximum utility for each step as an optimal solution. This result is found under the initial parameters $T_0 = 85°$, CF=0.85 of the SA algorithm. After several tests, this CF value was found that enabled good utility values with a reduced number of iterations. A comparison of three mechanisms for load balancing, i.e. the access methods used, is made. The results show that AGCSMI mechanism has the best mean utility with about 27% up compared with the MCCR mechanism with 23% and RDM with a 17%. Moreover, if the steps increase the probability of high utility decreases, so the algorithm needs less iterations to converge as it is shown in Fig. 5. Consequently, the probability of SA algorithm decreases (i.e. line: 8 Fig 4.), so it can use more iterations to find a better access method.

Fig. 6 shows the channel capacity of the access according to the mechanism which assigned it, and it should be emphasized that AGCSMI and MCCR fulfill the quality requirements that are imposed by the system: CC_{REQ}=150 Mbps.

As observed in Fig. 6, the results obtained with AGCSMI are better than any other results in the experiment. AGCSMI is more stable than the others algorithms for changes in the channel capacity; and that can be observed too in the mean utility percentage obtained by AGCSMI. Although its speed is slower in terms of the utility function than other algorithms, as shown in Fig. 5.

To evaluate the channel capacity distribution for each Wi-Fi or 3G access method that is into the coverage of the *DM* path, Fig. 7 is used. During the execution of AGCSMI, each access is identified by a color. With SA, the results obtained in Fig. 7 show that the 3G access is the most used. Mainly because the greater coverage but also because the amount of signal attenuation losses compared to Wi-Fi. While this access is only chosen in nearby zones of the *DM*. Consequently, an extremely high channel capacity is not chosen and an optimum solution is obtained that generates a capacity near to the system threshold CC_{REQ}=150 Mbps.

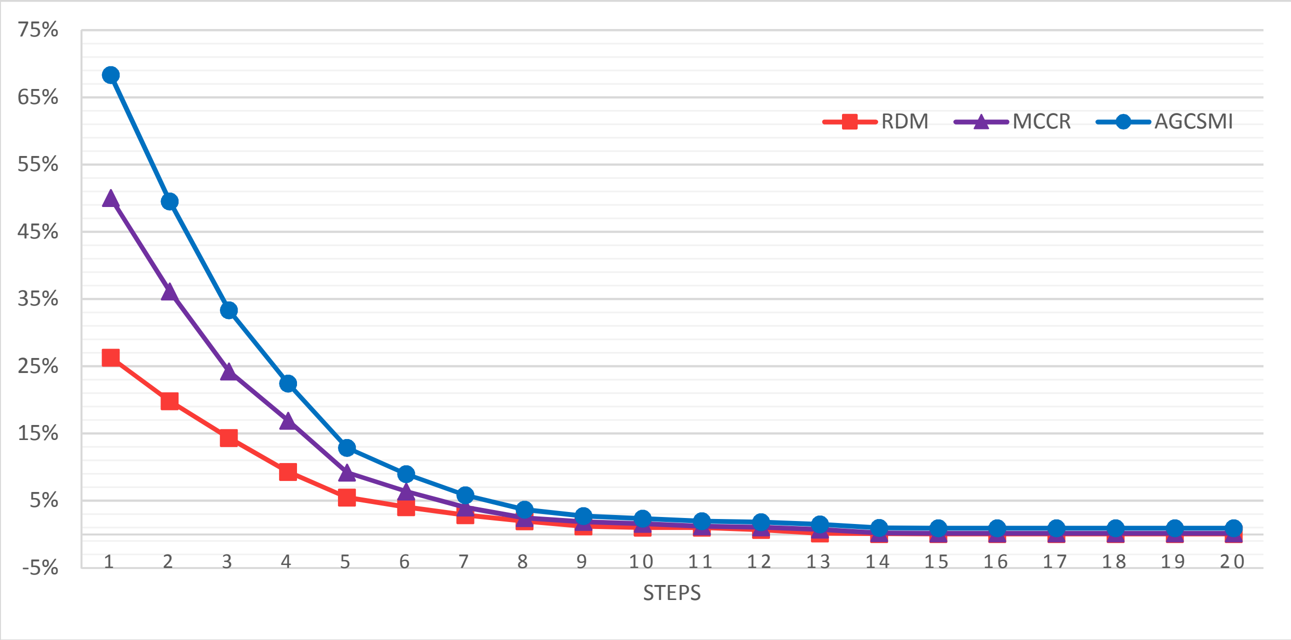

Fig. 5 Mean utility function of each cost assignment mechanism.

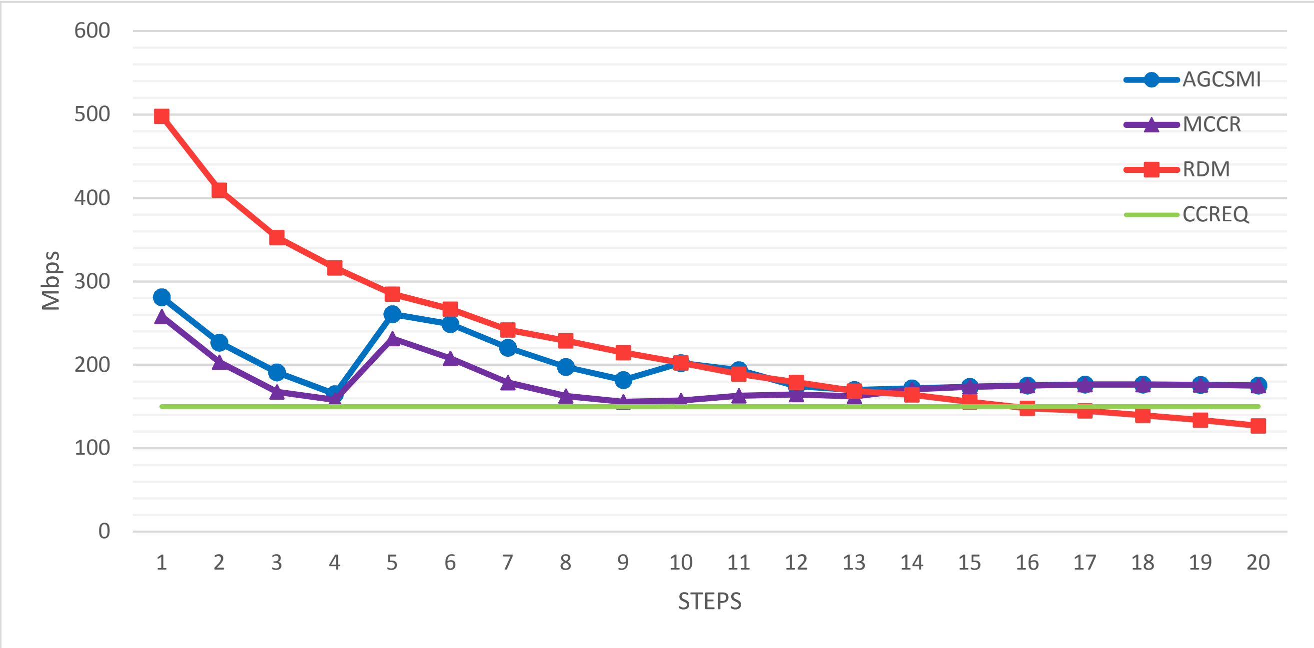

Fig. 6 Channel Capacity delivered by the access per assignment mechanism.

VI. CONCLUSIONS

In this paper, it has been proposed an evaluation of the performance of a load balancing mechanism called AGCSMI, designed for load management due to the assignment of an access or set of wireless access methods in a Manhattan style scenario with a high density of buildings. The algorithm has shown that it can increase considerably the probability of finding several access solutions through the minimization of the operating costs by balancing the loads over the different access methods.

The AGCSMI development has been tested for Wi-Fi and 3G access under different scenarios of implementation and is superior when compared to other mechanisms. The results obtained demonstrates that AGCSMI mechanism can improve the performance over wireless access methods, because it allows to optimize itself giving a priority to the access or a combination of which that satisfies the minimum requirements.

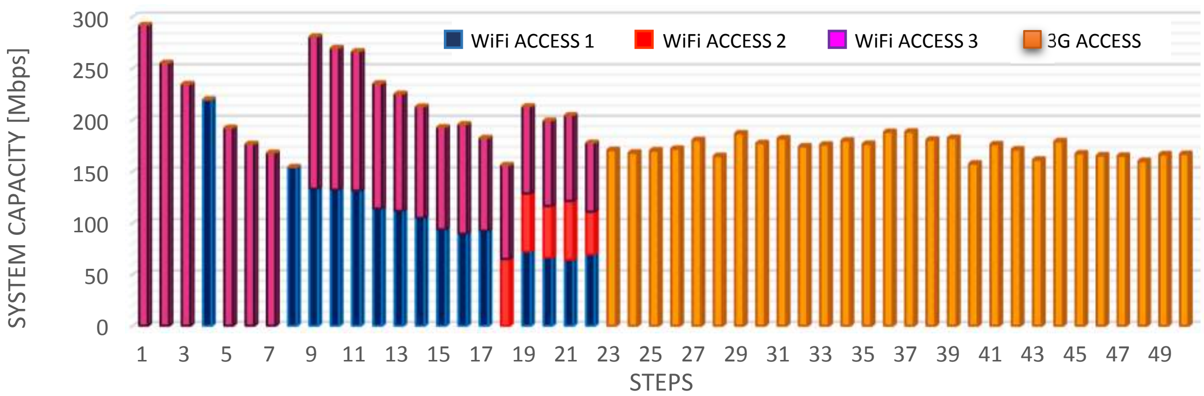

Fig. 7 Balanced Channel Capacity with Wi-Fi and 3G Access using the AGCSMI mechanism.

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