A BROKERAGE SYSTEM FOR ENHANCING WIRELESS ACCESS

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ABSTRACT

This paper contributes to the management of a network infrastructure formed by distinct wireless access technologies, which are administered by several cooperating mobile operators. These wireless technologies may cover a public area, which at specific times of the day are overwhelmed by a large number of users. A new management solution is proposed that controls the heterogeneous network infrastructure in a distributed way, using policies and metrics, and ensuring a Quality of Service (QoS) level associated with each terminal connection. The QoS level is supported through a novel, vertical and dynamic aggregation of performance information about the wireless access, originated at distinct technologies. A closed innovative control loop among a flexible brokerage service in the network, and agents at the mobile terminals, counteracts any abnormal data load. This allows the terminals to make well-informed decisions about their connections to improve on the QoS offered to the application layer. In this way, depending on the management policies of the brokerage service and the quality metrics, wireless access technologies that by default only offer a best-effort connection service can be enhanced in a very straightforward way. The obtained results highlight the advantages for using this new distributed solution to manage the heterogeneous network infrastructure in several distinct usage scenarios[1].

Heterogeneous Access; Distributed Management; Brokerage Service; Network Resources; Policy-based Handover; Quality Metric.

I. INTRODUCTION

According to the Cisco Global Forecast, mobile data traffic will grow at a compound annual growth rate of 108 percent between 2009 and 2014 [1]. To illustrate this situation, the network infrastructure of a very significant mobile operator experienced recently a significant loading in London[2]. This problem originated with customers using smartphones and repeatedly pulling multimedia off the web at short intervals. Due to the lack of capacity in the mobile network infrastructure, originally dimensioned to support only voice calls and text messages, a considerable number of clients could not make a voice call during the time of congestion. This particular operator has attenuated the negative consequences of congestion by deploying additional Base Stations (BSs) and performing changes in terms of network management software. Nevertheless, either business or technical aspects can impair the operator's strategy for upgrading their network infrastructure to deal with congestion. At public places, like busy train stations, airports or malls, it could be very expensive to upgrade the network infrastructure, or there may be a lack of radio spectrum available to operate new BSs. Consequently, the authors of this paper argue that an alternative and more realistic strategy to avoid congestion in mobile networking is establishing roaming contracts among national mobile operators, enabling customers from a specific operator to move from the home network to other operators' networks, when the former lacks resources. The sharing of available capacity among mobile providers is already a reality. For example, in the UK, there is a business agreement between Vodafone and O2 to share network infrastructure. There are also some business agreements between mobile operators and Wifi providers; as an example, O2 offers their customers as part of the monthly fee, additional free Wifi connectivity with The Cloud and BT Openzone. However, there is scope to improve the cooperation in this new type of roaming contracts.

A strong reason for performing the current work was a result of previous analysis based on Game Theory that pointed out a number of flaws in the most relevant management proposals to satisfy Next Generation Network (NGN) requirements, such that the available network resources could be efficiently used to satisfy both the aims of network operators and users [2]. In addition, some exploratory work in the specification and design of a NGN management solution has been made to satisfy emergent requirements, including the management of congestion, namely in the wireless media, at public places, with a variable user demand depending on the time-of-day [3] [4].

Despite the large progress occurred in the network interoperability, up to now most attention has been placed on Authentication, Authorization and Accounting, with less emphasis on Quality of Service (QoS) [5]. The current paper addresses this problem, focusing how a heterogeneous network environment can be managed to guarantee a QoS level for each connected terminal through a specific wireless access technology. In this paper, the QoS represents the wireless status in terms of the available network capacity at the network edge for each individual connection. Further, the QoS is completely controlled by policies and a set of convenient metrics, across the entire network infrastructure.

The current paper proposes an innovative brokerage service that supervises the entire network infrastructure and applies distinct management policies. These policies can be used by each terminal to rank the discovered Network Attachment Points (NAPs) from diverse access technologies and to choose the most suitable NAP. These features can distinctively balance the network load among all the available NAPs from diverse technologies, which is a relevant, relatively new and interesting research issue [6]. In addition, the solution proposed in the current paper can enhance the connection service of any wireless access technology that by default only supports a best-effort service. This work holds the potential for further

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[2] http://www.msnbc.msn.com/id/34634571/ns/technology_and_science-tech_and_gadgets/ (verified in 26/01/2012).

investigation in a relevant area that, at the time of writing, is weakly covered in literature. In this way, the current solution can offer additional ways to rank and select the best NAP. For example, the final decisions can be made by the network (operator) side and assisted by terminals. Alternatively, the current paper assumes that management decisions are issued by terminals and helped with status information from the network.

Section II contextualizes the current work in the literature and highlights the novel aspects of our research. Section III discusses the usage scenario and the functional requirements of the work. Section IV describes the design of the management solution. Section V evaluates the new proposal. Finally, section VI summarizes the main contributions of the work and addresses possible future work.

II. RELATED WORK

The current work discusses how a brokerage system can manage congestion in a network access environment, balancing high data demand among distinct wireless access technologies and so guaranteeing a satisfactory connection quality to the attached mobile terminals. The connection quality is measured in terms of the bitrate provided by each wireless link. Finally, in this work the terminal mobility is mainly related with the need to implement an effective load balancing mechanism among access technologies. For distinct scenarios of mobility support, one can consult a comprehensive survey [7].

There are some open issues in the integration of distinct wireless access technologies [8], namely the following ones that are covered in the current work: load balancing, traffic management among networks, QoS support, connection admission control and resource sharing. In addition, the work here supports at the network side the dynamic calculation of NAP quality in terms of the wireless status. Furthermore, the terminal side supports a dynamic cost function to rank target NAPs based on the connection quality offered by each one of these. In this way, the final decision is issued at terminals with the help of the network side.

From the literature review in network brokers, a very diverse set of applications has been found for both fixed networks [9] and emergent network environments: dynamic allocation of RF spectrum [10] [11], service provisioning [12] and very large-scale network computing systems (i.e. grids) [13] [14] [15]. In addition, in a distinct area, brokers can help a smooth transition from IPv4 to IPv6, acting as network proxies to manage the encapsulation of IPv6 packets inside IPv4 packets as specified in [16]. Further areas where tunnel brokers can be useful are the gradual deployment of multicast [17] or security in the core network (e.g. IPsec [18] [19]). The current work proposes a distributed bandwidth broker that uses policies for managing a high amount of unicast data load crossing a heterogeneous NGN environment and, enhancing some traditional network services, like user admission and network selection. In fact, Figure 1 illustrates that the complete heterogeneous wireless access infrastructure is controlled at the network edge by broker units BU2 and BU4 through a peering communication. While the broker unit BU4 controls in a centralized way Wimax and Cellular technologies. This broker architecture has a novel hybrid design, aggregating both centralized and distributed functional features in comparison with [20]. In addition, the current proposal is more flexible than [20] because it can operate in both inter-domain and intra-domain networking scenarios. Finally, the current proposal also extends previous work [21], which only manages an 802.11b access network. In fact, the current proposal is able to control a network infrastructure, composed by any access technologies.

III. SCENARIO AND REQUIREMENTS

This section discusses the scenario, the addressed problems and the functional requirements for solving congestion situations on a heterogeneous network infrastructure. Figure 1 illustrates this scenario. There is a public area covered by several wireless access networks. Each one of these is administered by a distinct network provider. The number of mobile terminals (or nodes) located inside the coverage area, that requires a network connection, changes during the day. The resources of each access network may not be sufficient to always guarantee a good connection quality to all customers, due to either poor wireless coverage or insufficient network capacity. The current paper proposes a cooperative model among network providers, coordinated by a brokerage service on the edge of the network. For this reason, the work described here attempts to balance the data load across the available capacity of the entire network infrastructure, offering a better connection service quality level to end-users, and applying convenient management policies.

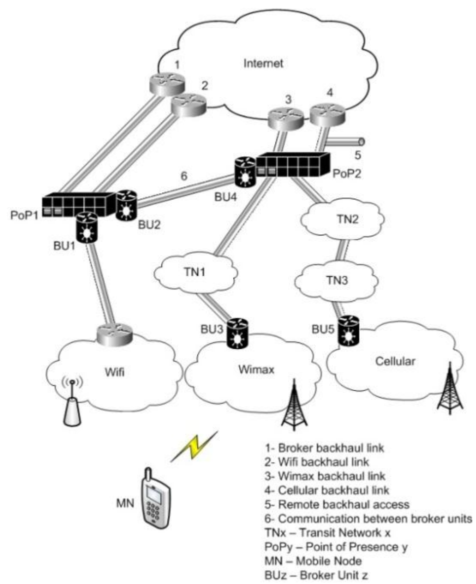

Figure 1 - Scenario of the heterogeneous network

As shown in Figure 1, the brokerage functionality is completely distributed amongst Points of Presence (PoPs) and access networks. There are several broker units located in convenient locations in the wired infrastructure. A PoP is a location where several wireless access technologies exchange their traffic with the Internet through backhaul links. In this scenario, it is assumed that each access technology has a well-provisioned backhaul and the broker can optionally offer an additional backhaul to expand the connection capacity of any access technology. The broker enables a flexible service to efficiently manage the edge of the network infrastructure on behalf of the network providers. In addition, this local brokerage service can coordinate its management decisions with remote brokers located at neighbor PoPs in a peer-to-peer communication (link 6 of Figure 1). This coordination is very useful to anticipate congestion in a certain area using relevant information disseminated by neighbors. Finally, Figure 1 also illustrates that a backhaul link can become congested due to the multiplexing of local traffic with remote traffic associated with other PoP through the link 5.

To guarantee that the network infrastructure operates correctly, a number of requirements should be verified by a management proposal based on a brokerage service. First, each customer obtains a connection to the network infrastructure, paying a fee that depends on the subscription contract with his network provider. There is no additional cost for roaming users. Second, the brokerage service evaluates the quality associated to each NAP. Third, the brokerage service detects any wireless congested links. Fourth, the broker remediates the congestion situations applying adequate management policies to the network infrastructure. Finally, the brokerage service evaluates the success/failure of each applied management policy, ranks the policies according to their success, learns when and how a network problem has been solved and predicts when the next problem could happen. This functionality can be incorporated in the current proposal as future work.

In the scenario presented in Figure 1, as an example, the passengers of a train can choose a network connection between a Wifi AP located inside the train or LTE macrocells covering the train route. Depending on several aspects, like, the user requirements, the load of each technology, the train location and the train speed, the most suitable NAP that each user should connect to can change very often, during the journey of that user by train. Consequently, the distributed management algorithm based on a brokerage service can balance the high load among the available connection capacity offered by the complete set of available NAPs, from the distinct access technologies. Further, the broker can keep the quality of each connection over a pre-configured quality value.

The broker units can be deployed as a software routine at already existing network units like either the Access Router of Wifi or the ASNGateWay of Wimax. In addition, Multimedia Independent Handover Services (i.e. IEEE 802.21) can be used to enable the brokerage service to supervise and control several access technologies, either locally at a single network node or remotely between distinct network nodes.

IV. SOLUTION DESIGN

This section presents the design of a model that illustrates how a distributed brokerage service can efficiently manage the entire available network resources of a heterogeneous access infrastructure. In this way, congestion in wireless links can be detected and attenuated. The generic flowchart of model is visualized in Figure 2. This models a distributed algorithm that runs continuously in consecutive iterations. Due to simulating rush-hour traffic, with an excess amount of users logging in at the same time, an iterative simulation mode was chosen, where a single iteration of the current model deals with a specific number of new users, blocks, drops and call ends. This way, the time was digitized to small amounts, and simulations were performed very efficiently without loss of precision.

The brokerage service can be decomposed in several steps inside a specific iteration. In the first step, the brokerage service detects new users and enables these users to select the most suitable network to obtain a wireless connection. More information about this function is discussed in section IV.A of the current paper. Secondly, the brokerage service could detect if some of the connected users are required to move to an alternative wireless access technology with a better connection quality. This last functionality is out of the scope of the current paper and it will be addressed in future work. The next and last relevant functionality that the broker supports is the one related with dropping some connected users. Further explanation about this function is available in section IV.B of the current paper.

A. Network Selection

This section discusses the network selection feature of the brokerage system. The flowchart of this feature is visualized in Figure 3. It is assumed that the load of each technology information is available through the entire network, with no delay. The algorithm can also block some users to avoid data load could overlap the Max_Rate value of each technology.

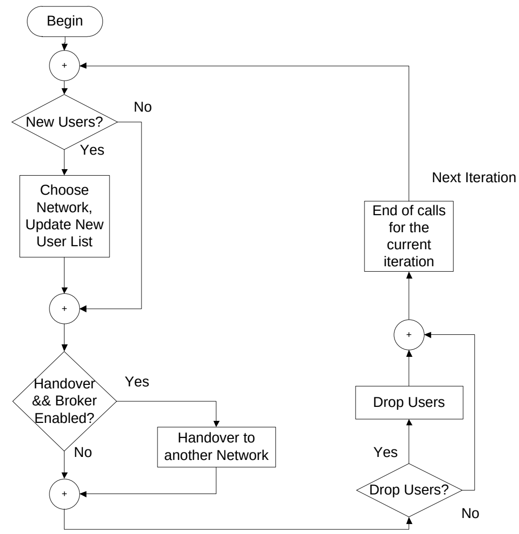

Figure 2 – Generic flowchart of the brokerage service

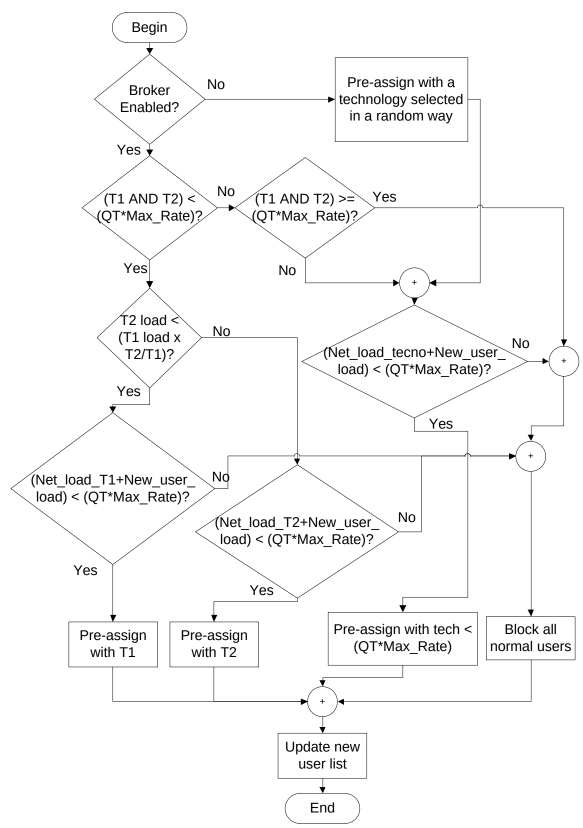

Figure 3 – Network selection flowchart

If the broker is disabled, the terminal randomly selects an access network. This assumption was made because depending on the terminal location any of the available access technologies can be selected, potentially the one with the best Signal to Noise Ratio (SNR). In addition, each network has an admission control that allow new users up to the maximum rate of that network weighted by the parameter Quality Threshold (QT), which assumes a value within the range [0, 1]. This parameter value specifies the amount of new load each access technology is allowed to accommodate, guaranteeing that the accepted terminals have a satisfactory connection quality.

When the broker is enabled, both network selection and admission control features, presented in the last paragraph, are enhanced with a rich set of management policies based on a choice preference of a specific access technology in detriment of others (i.e. "T2/T1 factor" in Figure 3). For example, in the case T2/T1=2, this means that access technology T2 is more preferrable than T1 because T2 has a better quality coverage than T1 (e.g. train usage scenario).

B. Drop Users

This section discusses in what situations the users are dropped by the network. In fact, some terminals are dropped in a random way, as shown in Figure 4. This models the situations that due to problems occurred in the communications channel (e.g. interference) the user connections are stopped. In this way, there is a probability for the channel dropping a terminal. It is assumed a distinct probability for each technology.

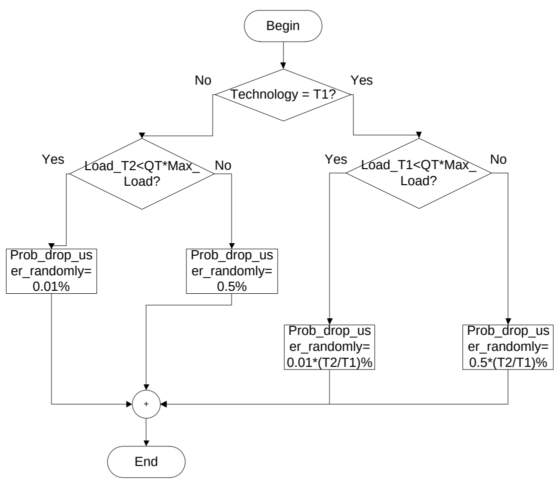

Figure 4 – User random drop flowchart

The drop probabiliy depends on the access technology and the load of each technology. In this way, the channel drops users per technology with a probability of 0.01% if the load of that technology is below the Quality Threshold (QT) associated to that access technology. Otherwise, the channel drops more users with a probability of 0.5% because the wireless access technology is more overloaded. The chosen values for the channel drops were estimated from BER (Bit Error Rate) performances for OFDM schemes, with special focus on the LTE [22] [23]. Finally, a large number of drops can potentially create a significant number of unsatisfied users with the connection service provided by the network infrastructure.

In a realistic network implementation, there is a delay for the dissemination of the network status along the control loop embracing the network and the terminals. This delay and its consequences are out of the scope of the current paper. The study about the aspect of delay is planned for future work.

V. EVALUATION

This section evaluates the new management proposal based on a brokerage service when it manages the available connection capacity of the heterogeneous network infrastructure, for ensuring that the connection quality perceived by each terminal is the best possible one. To perform this evaluation, the scenario in Figure 1 was used, but with two access technologies: T1 and T2, respectively LTE and Wifi. Both of these technologies offer individually a best-effort wireless access service to multimode terminals. Each access technology can accept a maximum load of 70% of the maximum connection capacity supported by that technology. The average rate of terminals requiring a network connection is 10 new terminals during a time instance of our simulation (i.e. 1 second). The distribution of new users follows a Poisson probabilistic distribution with a variance of five.

A terminal is associated to a single connection (i.e. flow), which could be one of the four possible flow types. The characteristics of each one of these are shown in Table 1. For example, flows of type Audio-L (i.e. Audio – Low rate) are 50% of the total number of flows used during a single evaluation scenario. The Audio-L flows have a rate of 12.2 Kbps and average time duration of 80 instances of time. The time duration of each flow follows a Log-normal distribution with a variance of five.

Table 1-Flow types

Scenario	Audio-L	Audio-H	Video-L	Video-H
Rate (Kbps)	12.2	64.0	128.0	1000.0
Average duration (time)	80	80	300	300
Average user ratio (%)	50	30	10	10

A MATLAB model of a brokerage service to manage a heterogeneous wireless access network environment with two access technologies was built to evaluate the 4 usage scenarios listed in Table 2. The brokerage service is disabled or not with different management policies to control the load distribution amongst access technologies. All the discussion here is driven by average values from one hundred simulation results per scenario. The Confidence Interval of average results is 85%.

Table 2-Evaluation scenarios

Scenario	Broker	T2/T1	Visualized results
1	Enabled	1	Both technologies
2	Enabled	2	Both technologies
3	Disabled	1	T1 or T2 (both have similar results)
4	Disabled	2	T1 or T2 (both have similar results)

Further, the results discussed in the current section address the next relevant functional aspects: load history, channel drops, successful termination of connections and blocked users. Finally, the results of the current section are discussed using diverse trends (i.e. Figures 5-9) associated to each technology during a total simulation of 1500 time instances (i.e. from now on also designated by seconds). Each value result visualized in any figure of the current evaluation is obtained through the average of twenty five sampling results, each one obtained during a simulation time instance.

The simulation time is decomposed in two distinct phases. During the first phase (as an example, the reader can observe Figure 5), between time instances 0 and 1000, the number of new users trying to obtain a network connection through a technology increases with an average rate of 10 users per second. This user growth is perfectly visible during roughly the initial 200s of the simulation in Figure 5 because the entire new load is totally accepted by both access technologies still lightly overloaded. Nevertheless, after 200s, both technologies become significantly overloaded and, in this way, an increased number of new users is blocked or suffer a channel drop. These two negative actions seems to counterbalance the growth rate of new users, which justifies the flat trend of Figure 5, between 200s and 1000s, with an almost perfect equilibrium between users entering into and leaving from each technology. After 1000s, as shown in Figure 5, it initiates the second and last phase with no new users arriving to the network until the end of the simulation time. During this time, the users leaving both access technologies are anymore replaced by new users and the network load decreases, as also shown in Figure 5. In addition, the scenarios labeled with T2/T1=1 mean that the user chooses randomly the technology to connect to and both technologies have the same QT value of 0.8, giving no preference to any technology. Otherwise, twice more new users attach to T2 than to T1 if both technologies have loads below the associated QT. In this last case, the access technologies have also distinct QTs; T1 has a QT of 0.6 and T2 has a QT of 0.8. In this way, it is used the policy T2/T1=2, which gives a higher priority to T2 than T1 in terms of the technology selected by each user. This means that T2 offers better quality connectivity than T1 when both technologies have a similar load.

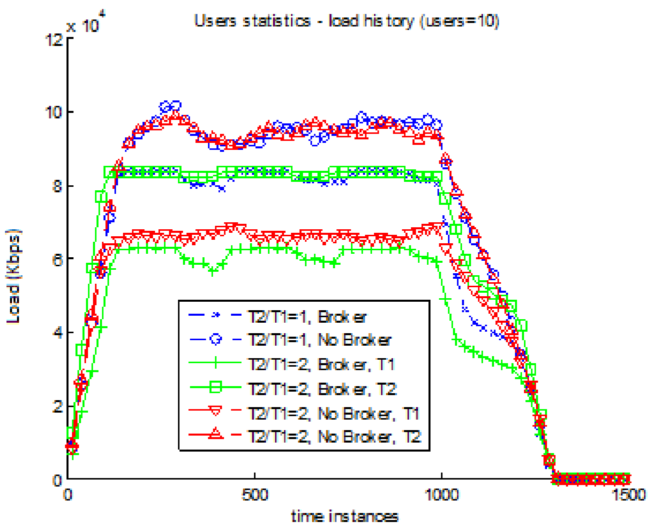

Figure 5 – Load vs. time

Figure 5 shows the load of each access technology during simulation time. From this, it is possible to compare the network performance of distinct scenarios. In fact, the scenarios with no broker show higher network loads than the corresponding scenarios with the broker enabled. However, the scenarios with no broker have a strong drawback shown in Figure 6: a high number of channel drops that would potentially create a relevant number of unsatisfied users with the connection service provided by the network infrastructure.

Figure 7 illustrates again the advantage of using a brokerage service to manage the heterogeneous access network because the total number of users in both technologies that terminates with success their connection is higher in the scenarios with the broker active than the others with the broker switched off. The low number of successful users connected via technology T1, with the broker enabled, is justified by the policy T2/T1=2 that gives a higher priority to T2 than to T1 if both technologies are not overloaded.

Figure 8 illustrates the user blocking mechanism used by the broker when some users require a connection and there is a scarcity of available network resources to guarantee a connection with a satisfactory quality, as it is suggested by the results of Figure 7. Otherwise, each connected terminal, in the scenarios with no broker, it has a poor connection quality, as also shown in Figure 7. In this way, the broker by blocking new users, it implements a user admission mechanism, in a distributed way, through all the heterogeneous access technologies.

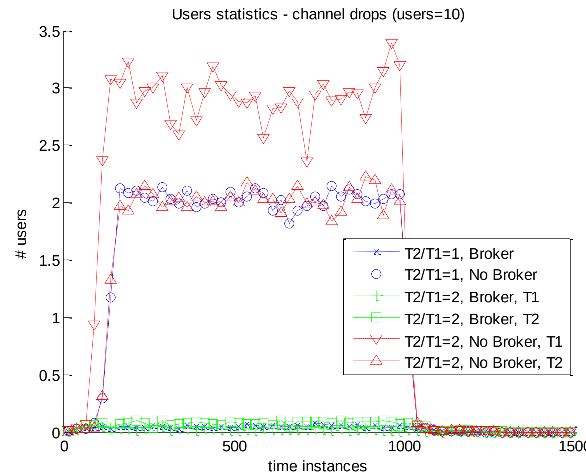

Figure 6 – Number of channel drops vs. time

The Figure 8 of blocked users portrays some peaks for when using the broker. In order to understand this system behavior, we have simulated a similar scenario but with a large simulation time. The obtained results are shown in Figure 9. The block peaks in our opinion are due to the transient characteristic between an empty system load and a fully loaded system – this transient is explained by the initial loading of 10 users per time instance responsible for the transition between zero blocks (network not overloaded) and the first peak of blocks (network overloaded). After, there is an instance of time with almost no blocks because new users allocate the network resources released by some users ending their calls. Then, the second peak of blocks is lower than the first one because during the former some connected users are still ending calls and this fact attenuates the need to block so many users as during the latter with no users terminating their calls; and so on for the next peaks. In this way, the exponential decreasing trend on the consecutive peaks of blocks is caused by the interaction between bursts of new users arriving to and users leaving from the network, which creates an oscillatory effect on the number of blocked users that decays exponentially with time, converging to a specific average value, as shown in Figure 9.

VI. CONCLUSIONS

This paper provides a model for specifying, designing, and evaluating a management solution based on a novel brokerage service that supports user admission and network selection among distinct wireless access technologies. This proposal has enough flexibility to support a few of architectures, including the hybrid one. Our evaluation results with a simplified version of the brokerage service illustrate that it is possible to control two access technologies, which offer connectivity to diverse user types. In addition, the performance of a heterogeneous network access environment can be significantly using a set of convenient management policies and quality metrics.

In a more realistic and complex topology, eventually with a hybrid design, it must be considered the delay associated to the dissemination of the network status along the control loop embracing the network and the terminals. This delay and its consequences will be addressed in future work.

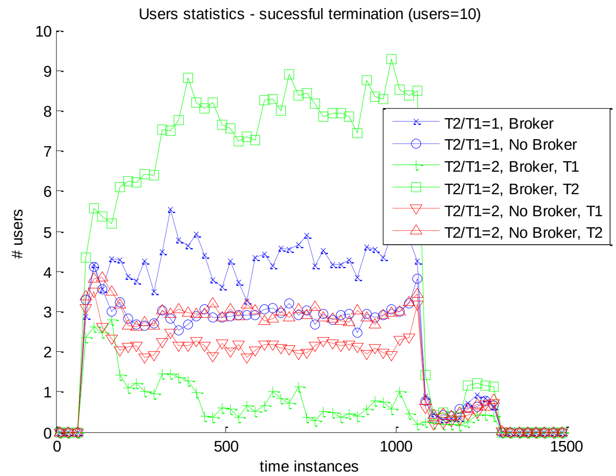

Figure 7 – Number of successful users vs. time

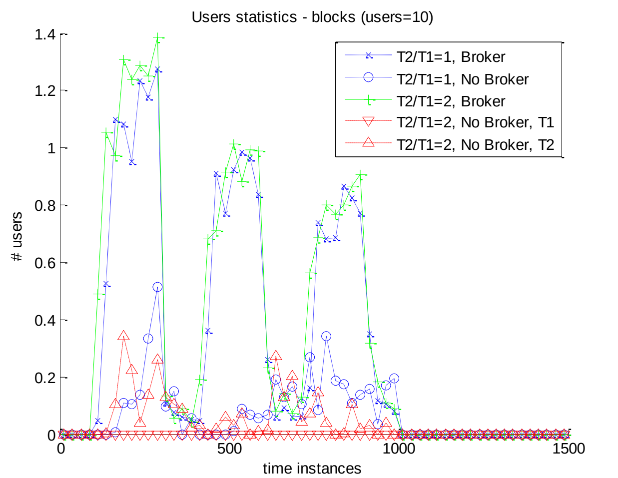

Figure 8 – Number of blocked users vs. time

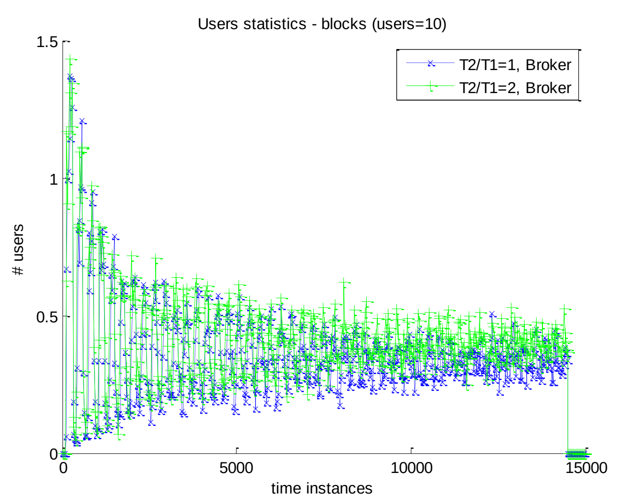

Figure 9 – The combined effect of both new accepted users and leaving users on the average number of blocked users vs. time

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