A Distributed Brokerage Framework to Balance the Load in Wireless Networks

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Abstract: In this paper, we describe a novel solution to automatically balance the load in wireless access networks. The proposed approach exploits the enhanced capabilities of a brokerage framework distributed among the mobile terminals and the network. We present a procedure able to retrieve the access network context, which is the input of a selection process that aims to drive mobile users towards the most appropriate point of access to the network, among those available. The numerical results obtained with a NS-2 based simulator show the effectiveness of the proposed load balancing mechanism in an 802.11b access network.

Keywords: access network context, access point selection, load balancing, 802.11b

1. INTRODUCTION

Network users today typically exploit a variety of different terminals to ubiquitously access a wide set of services. Users who attempt to access and handle services on offer have to deal with multiple procedures for configuring devices, multiple authentication mechanisms, multiple access technologies and protocols. This creates an enormous burden of complexity, which is likely to limit the use of the services themselves. Heterogeneous services, terminals, and networks create a complexity barrier not only to end-users but also to operators, who have to devise and deploy tools and procedures to engineer their network efficiently.

An important feature of 2G wireless systems is the portability of user identities among different mobile phones. The Simplicity project [1][2] proposes a generalization of this concept, allowing users to move seamlessly between different distributed applications and services, using heterogeneous networking technologies and devices. The goal is to provide a user-friendly solution to the challenges posed by a diverse service and technology environment. The personalization concept is based on a user profile. In our view, each user will be characterized by a personalized profile, providing access to different services and networks, and using different classes of terminals. Users will enjoy the automatic selection of services appropriate to specific locations, the automatic adaptation of information to specific terminal devices and user preferences, and the easy exploitation of different telecommunications paradigms and services. The user profile will be stored in a so-called Simplicity Device (SD). Users could personalize terminals and services by the simple act of plugging the SD (e.g., a

Java card or a USB stick) into the chosen terminal.

A novelty of the SD is that it is not tied to a single networking environment, or to a single class of user terminals. Another key attribute of Simplicity is re-configurability, at various levels. To integrate different paradigms from the user point of view, it is necessary to break logical wires that still tie mobile users to networks and services, also at upper layers. This way, heterogeneous and mobile access networks can be really integrated, as IP has glued heterogeneous networks. To enable this full-spectrum re-configurability, our system encompasses three components: the Simplicity Device, the Terminal Broker (TB) and the Network Broker (NB). The TB is the entity that manages the interactions between the information stored in the SD and the terminal in which the SD is plugged in. The TB enables the SD to perform actions like terminal capability discovery, adaptation to networking capabilities and to the ambient, resource and service discovery and usage, adaptation of services to terminal features and capabilities. The NB has the goal of providing support for service description, advertisement and discovery. Moreover, it orchestrates service operation among distributed networked objects, taking into account the issues related to the simultaneous access of several users to the same resources, services, and locations. It also shares/allocates available resources, and manages value-added networking functionality, such as service level differentiation and quality of service, location-context awareness, and mobility support.

The enhanced capabilities of the Simplicity brokerage framework could play a twofold role: i) allow users to use ICT systems spontaneously and simply; ii) provide operators with new possibilities and options to define new automatic management tools for network control and self-configuration in a heterogeneous framework. This should strengthen the operator interest in deploying a Simplicity system, since it would help to make the network resources easier to manage. In this paper, we focus on load balancing in wireless networks, which is an emerging research field (e.g., see [4][5][6][7][8][9]). The reference scenario is that of a single administrative domain that offers a heterogeneous wireless access. In principle, mobile terminals may be provided with a number of wireless interfaces (multi-mode terminals).

The novelty of our solution is the exploitation of the Simplicity brokerage framework distributed among terminals and network. We propose a monitoring procedure able to track the access network context, i.e., the current state of resources, the amount of service demand, and the wireless access points available to terminals. As regards the last point, we assume that the TB is able to perform frequency scanning and to listen to the L2 beacons transmitted by surrounding wireless access points periodically, and to learn their L2 IDs (in accordance with [5]). These Access Points (APs) are candidate wireless accesses to hand over to. Then, an appropriate selection procedure running in the NB uses this set of information to drive MNs towards the most appropriate point of access to the network. Moreover, user information retrievable from SDs can be useful to predict users' behavior and to differentiate the network service according, for instance, to users' role and tariff profile.

We present a numerical analysis showing the effectiveness (in terms of load balancing capabilities) of the proposed Simplicity mechanism with respect to a legacy one in an 802.11b access network. To this end, we exploit the NS-2 simulator [12].

The paper is organized as follows. In the next section, we illustrate the basic lines of the access network control procedure from both functional and architectural viewpoint. Section III illustrates numerical results. Finally, in section IV, some final remarks conclude the paper.

2. LOAD BALANCING IN THE WIRELESS ACCESS NETWORK

The typical goal of a network manager is to optimize network performance in terms of QoS (users' side), throughput and load balancing (operator's side), pre-empting critical situations and minimizing the load on human operators. In general, network control actions will depend on users' side information, on the spatial distribution of users over the area covered by the network, and on the characteristics of the network, such as network topology, network resources, and available tuning capabilities. If this data is largely unknown, network management will be essentially reactive. Our goal is to have the highest possible amount of data available as input to the decision engine. In this regard, we argue that the goals mentioned above could be achieved more easily by exploiting specific features of Simplicity.

In this paper, we consider the operator's perspective and focus on load balancing techniques in the wireless access network. Obviously, balancing the traffic load is convenient also for the users, which, in this way, can experience an improved QoS.

Some papers in literature present architectures and protocols to manage layer 2 handovers in a homogeneous 802.11 access section. In [4], the Authors propose a distributed architecture based on agents running on 802.11 APs. The APs exchange traffic load information to cooperatively balance the traffic among them, by forcing the handover of a subset of MNs associated to an overloaded AP. The drawback of this approach is that the procedure is not aware of which APs are available to an MN, and this implies that an MN forced to leave the current AP could be denied a subsequent association. In our opinion, if load balancing decisions are taken on the network side, information about the access network context from the terminal side are necessary to make the approach effective. Otherwise, as proposed in [6], users could be explicitly requested to cooperate by physically moving towards specific locations within the network for load balancing purposes. If decisions are taken by MNs, in [8][9] Authors propose to embed load balancing information in 802.11 beacons, which are periodically transmitted by APs and can be received by MNs. This approach would require some modifications to the structure of an IEEE 802.11 beacon. Following this approach, some vendors have introduced proprietary solutions for load balancing purposes in 802.11 wireless networks (e.g., see [11]). They add information about the traffic load to the beacon frames. MNs should use this information, in addition to the signal strength, to select the AP. This solution also leads to a lack of interoperability between different vendors. In addition, information broadcasted by beacons, can be listened to by everyone, thus easing threats to privacy and security.

Our approach is intrinsically different. Its scope is an IP network with a number of Access Routers (ARs) that control a set of heterogeneous APs. Handovers can be both inter and intra-technology, intra and inter AR, at both layer 2 and layer 3. For what concerns mobility among ARs, it can be managed with the Mobile IP protocol or by means of higher layer solutions (e.g., SIP) [16]. Here, without loss of generality, we assume to use Mobile IP.

We exploit the capabilities of SD-enabled terminals. MNs are assumed to perform frequency scanning and listen to L2 beacons transmitted by surrounding APs periodically, and to learn their L2 IDs (identifier of an AP that uniquely identifies that AP, [5]); these APs are candidates to hand over to. Note that the capacity of performing frequency scanning is actually a minimum requirement for all wireless technologies.

In the following, we first give details about the load balancing procedure. Then, we present some considerations about the overall architecture of the system. The reference scenario is that of a single administrative domain (e.g., a campus network) which offers a heterogeneous wireless access (e.g., 802.11, GPRS/UMTS, Bluetooth). We assume that the wireless coverage offers many options for selecting a wireless access (dense wireless coverage), so that a load balancing mechanism makes sense. A mobile terminal may be provided with a number of wireless interfaces (multi-mode terminals).

2.1. The Simplicity load balancing mechanism

The main peculiarities of the Simplicity brokerage framework are:

- the capabilities of SD-enabled terminals, which can be exploited to assist the network in monitoring the availability and performance of wireless coverage;
- user information retrievable from SDs (profiles and preferences), which can be useful to predict users' behavior and to differentiate the network service according, for instance, to users' role and tariff profile.

We assume that the network operator is in charge of taking network configuration and traffic engineering decisions. Users may only provide inputs (through the SDs) to influence the management actions of the operator. Thus, the NB is the entity in charge of acting as Policy Decision Point (PDP), i.e., it is the functional entity in charge of taking decisions.

In turn, the TB is in charge to assist the NB, by providing inputs regarding the access network context (i.e., the radio access technologies currently perceived by the terminal through a frequency scanning), and by acting as Policy Enforcement Point (PEP), e.g., to change AP.

In addition, a proper monitoring process has to provide the NB with information about the current status of wireless resources available at the APs.

To sum up, the inputs to the NB are:

- users' related information (e.g., (i) the user role; (ii) the set of subscribed service; (iii) the willingness to pay). This set of information is sent once (e.g., when the user registers to Simplicity) and updated if needed;
- terminal capabilities (e.g., the radio access technologies supported);
- access network context (e.g., the available wireless accesses, the perceived power level, and the status of network resources). This set of data is dynamic and has to be refreshed (either periodically or upon request);
- specific management policies, defined by the network operator, with the aim of improving network performance while maintaining user satisfaction.

The output of the NB consists of network control decisions. By applying properly designed algorithms, the NB can automatically optimize the distribution of mobile users within the wireless section, but also activate/deactivate APs, tune APs transmission power, and so on. In this paper, we focus on load balancing actions; mobile terminals are driven towards the most appropriate AP, according to specific policies of the operator. The selection process may be invoked: (i) when the terminal is turned on; (ii) periodically, due to specific operator's policies; (iii) when a handover is needed. The overall process is sketched in Fig. 1. It is worth noting that when a terminal turns on, the TB is allowed to exchange information with the NB through a default network connection. Then, the NB drives the terminal towards the most appropriate wireless access.

As a final note, we stress that the proposed approach is not tied to the scenario considered in this paper and can be used in a heterogeneous wireless access network environment. In section 3, we will provide numerical results for a homogeneous 802.11b scenario.

2.2. The NB architecture

In principle, the NB may be either centralized over a specific network entity or distributed among a number of network entities. In this latter case, we assume that the NB instances are co-located with ARs. This means that each AR is in charge of directly managing only those mobile users under its control.

If the network size is small the deployment of a single centralized NB is a reasonable choice. On the other side, if the network is quite large, the distributed solution could be mandatory, for scalability reasons. In this case, each AR has to be able to retrieve the network status of both its APs and the APs belonging to neighboring ARs, the coverage area of which overlaps with its own. In this way, MNs can be driven by its current AR to perform handovers at both layer 2 and 3. The configuration of the surrounding wireless coverage map at each AR (discovery phase) may be either manual or automatic. In this latter case, the network has to be able to self-discover its wireless coverage. In operation, neighboring ARs have to exchange the service capabilities of their APs (steady phase). The analysis of both the self-learning discovery phase and the steady phase, along with a quantitative evaluation of discovery time and signaling burden, can be found in [10]. In this regard, we remark that the signaling burden associated with both discovery and steady phase in the whole network is definitely low (few Kbps). Thus, in our opinion, the benefits that can be obtained by implementing a Simplicity-enabled load balancing mechanism justify the relevant cost in terms of network resource consumption and complexity of implementation.

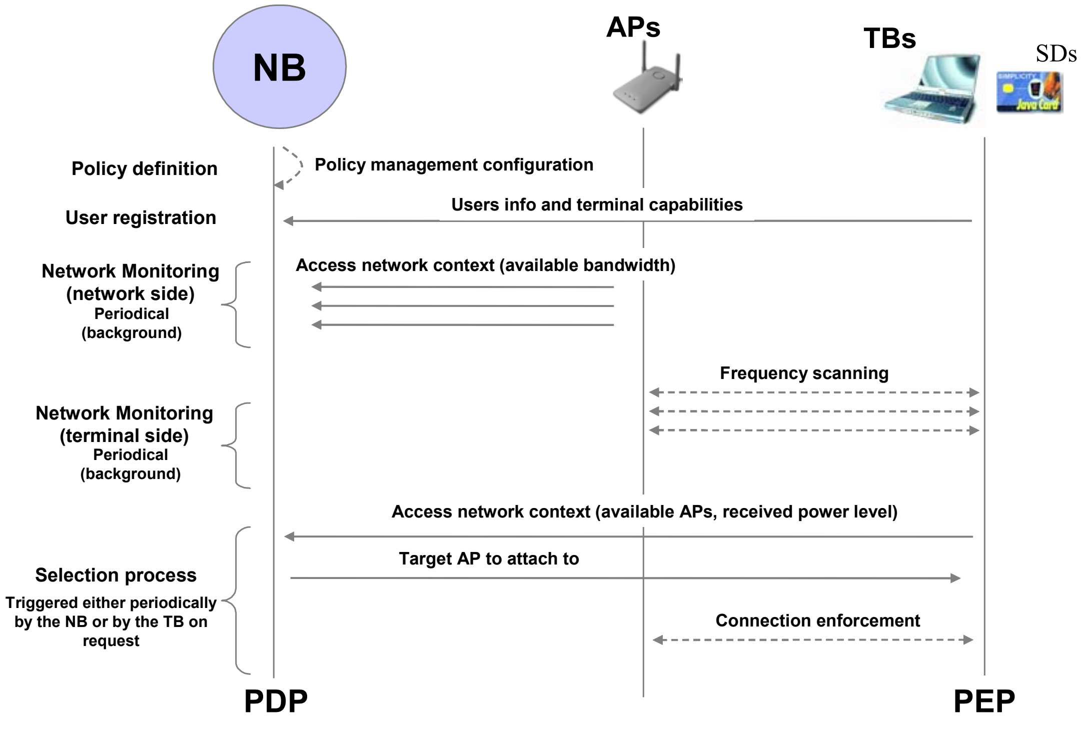


Fig. 1 - SD-assisted network control: an overall picture.

3. NUMERICAL ANALYSIS

In this section, we show the numerical results from a simulation campaign. The aim is to highlight the effectiveness of the Simplicity load balancing system. We carried out a large number of simulations with NS-2 [12], in a homogeneous 802.11b access network.

3.1. Simulation scenario

We simulated a network scenario with 25 APs (802.11b). Each AP is controlled by an AR. This is due to a limitation of NS-2, which allows to connect only one AP to each AR (thus in the following, we will refer to AR and AP indifferently, since they are co-located).

We have distributed the ARs with a hexagonal cellular pattern over a rectangular area of 100 m x 130 m, representing a section of a campus area. This implies that the ARs in the center of the simulated area always have six neighbors. The distance between any two neighboring ARs is set at 28.8 m. The coverage radius is equal to 22.4 m (corresponding to a coverage area equal to 1576 m^2), and the overlapping area between two adjacent APs is equal to 381 m^2. We assume that the coverage area of an AP is divided into two zones: the *optimal* zone and the *border* zone. The former is relevant to a received power level in the range [PW_{opt}, P_T], where P_T=100 mW is the transmission power, and PW_{opt}=9.889 nW (corresponding to a radius equal to 19.4 m according to a free space propagation model) defines the threshold for an optimal reception. The latter zone is relevant to a received power level in the range [PW_{min}, PW_{opt}], where PW_{min}=6.677nW is the receiver sensitivity. The overlapping between the optimal zones of two neighboring APs is equal to 125 m^2.

In order to simulate a real setting, we adopted a frequency reuse strategy based on a triangular structure, and selected channels numbers 1, 6, and 11 of the IEEE 802.11b standard [13]. This implies that at any point in the simulation area, there is only one AP active for a given frequency channel. The version of the Mobile IP adopted in the simulator is MIPv6.

MIP advertisements are sent each second, whereas the L2 beacons are sent each 100 ms. Since three 802.11b channels are used, the duration of the beacon listening phase is bounded by 200ms (i.e., the time needed to scan the two channels different from the current one).

To test the load balancing capability of the Simplicity-enabled system, we considered the network loaded with UDP CBR traffic, with an overall transmission rate equal to B=64 Kbps (modeling VoIP calls). The call duration is exponentially distributed with an average duration of 5 minutes. Call arrivals are modeled as a Poisson point process. The value of the average arrival frequency is set so as to have a traffic load within the network equal to ($0.6 \cdot N_{MN}$) Erlang, where N_{MN} is the number of MNs in the network area. Such a number is variable in the different simulation settings and ranges from 50 to 200. MNs move according to the Gauss-Markov mobility model [3], with average speed equal to 1m/s, and a step fixed to 1s (i.e., the MN position is updated every one and a half meters, on average). When a MN is near to the edge of the simulated area, its average direction is inverted. We adopted the Gauss-Markov model since it avoids sharp direction changes thus allowing previous speed and direction to influence future mobility.

It is worth noting that we do not implement any call admission control scheme to limit the number of VoIP calls in the network.

As regards the process of selecting the AP to attach to, we implemented in the simulator two models: the legacy 802.11b system and the Simplicity-enabled 802.11b system.

The legacy one is designed according to the typical implementation of real 802.11b systems, in which a terminal remains attached to the current AP until the received power level goes below PW_{min}. When the terminal detects that it is going to be disconnected, it performs a beacon scanning and selects the AP with the highest signal strength among the set of the discovered APs.

In the Simplicity mechanism, when the power level of the current AP goes under PW_{opt}, the TB performs a L2 beacon scanning, communicates the relevant outcome to the NB, and requests a driven handover. We assume that when the terminal turns on, it initially selects the AP with the strongest signal strength, to enable the message exchange between TB and NB. We have implemented the distributed version of the NB. In other words, each AR is in charge to control the MNs under its coverage. The NB, based on context information from the TB (available APs and relevant power level) and on the measurements collected each T_{BW}=6 s at the neighboring APs (i.e., the amount of available bandwidth, which is measured on a time window equal to 6s), identifies the best AP to attach to among the set of candidates. An AP is considered a candidate if the power level of its L2 IDs is above PW_{min}. As mentioned above, the selection process is also triggered periodically. The period, T_{SEL}, is set to T_{SEL}=60s.

Finally, the terminal associates itself to such AP.

The Simplicity enhanced system selects the best AP by using a cost function, M_{AP}, that takes into account the bandwidth currently used by the AP (BW) and the power level (PW) perceived by MNs during beacon listening. The choice of the cost function has been driven by the following considerations (refer to Fig. 2). Whenever possible, the MN has to be driven towards the APs the power level of which is higher than PW_{opt}, since a MN in the border zone of an AP is in a precarious situation (the network connection can be lost even with a small movement). Let us define this set of APs as belonging to class I candidates. Among the APs of class I, the selection is made by taking into account the load balancing criterion. Obviously, the load balancing influences the AP selection also if the MN is in the border coverage of all candidate APs; let us define these APs as class II candidates.

Thus, the AP selection is really a 2 stage decision. In the first stage, APs are selected on a power-basis. In the second stage, the less loaded AP is chosen among the ones selected in the first stage.

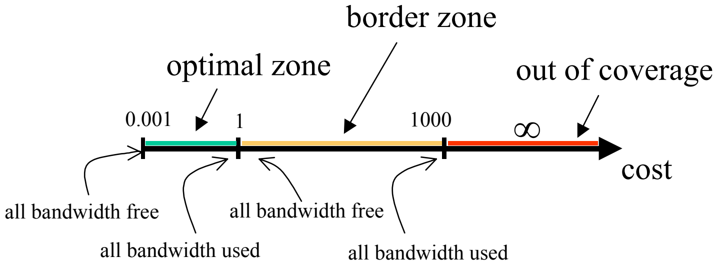


Fig. 2 - A sketch of the cost function.

Finally, the selected AP is the one with the lowest cost, defined as

$$M_{AP}(i) = f_1(BW_i) \cdot f_2(PW_i). \tag{1}$$

The function $f_1(BW_i)$ represents the cost related to the amount of occupied bandwidth on AP_i, and is given by

$$f_1(BW_i) = \max\left(1/a, \frac{BW_i + H \cdot B \cdot j}{C}\right), \tag{2}$$

where j=0 for the AP to which the MN is currently attached and j=1 for the candidate APs.

The parameter C is a normalization value and is set equal to 11Mbps (i.e., the bandwidth of an 802.11b AP); B=64 Kbps is the amount of bandwidth associated with a call. The parameter H (hysteresis) is introduced to avoid annoying ping-pong effects (i.e., continuous switches among overlapping APs). A first comment is that the higher the value of H, the lower the load balancing effect of the procedure, and the higher the stability of the process. Thus, the choice of the value of H has to be made considering a trade-off between performance and stability. The value $a>1$ is a design parameter introduced to make the cost function $f_1(BW)\neq 0$.

The function $f_2(PW_i)$ is the factor related to the power level of AP_i, and it is equal to

$$f_2(PW_i)=\begin{cases}1 & \text{if } PW_i \geq PW_{opt}\\ a & \text{if } PW_{\min} \leq PW_i \leq PW_{opt}\end{cases}. \quad (3)$$

In this way, we separate the cost associated with class I APs and the cost associated with class II APs, for any BW value and for each choice of a. We choose $a=1000$ to make the bandwidth cost relevant to no traffic load lower than B/C (bandwidth cost relevant to a single call). In this way, $f_1(BW)$ ranges from 0.001 (all the bandwidth is free) to a value which is lower than 1, since the maximum net bandwidth of an 802.11b AP is quite lower than 11 Mbps and is around 5 Mbps. The overall cost function is depicted in Fig. 2.

3.2. Numerical Results

The simulation time is set to 3000s and divided in two phases. In the first phase, lasting till the time instant 2000s, MNs move accordingly to the Gauss-Markov mobility model; then they stop till the end of the simulation (phase 2). This allows testing the load balancing mechanism when both MNs move and are motionless.

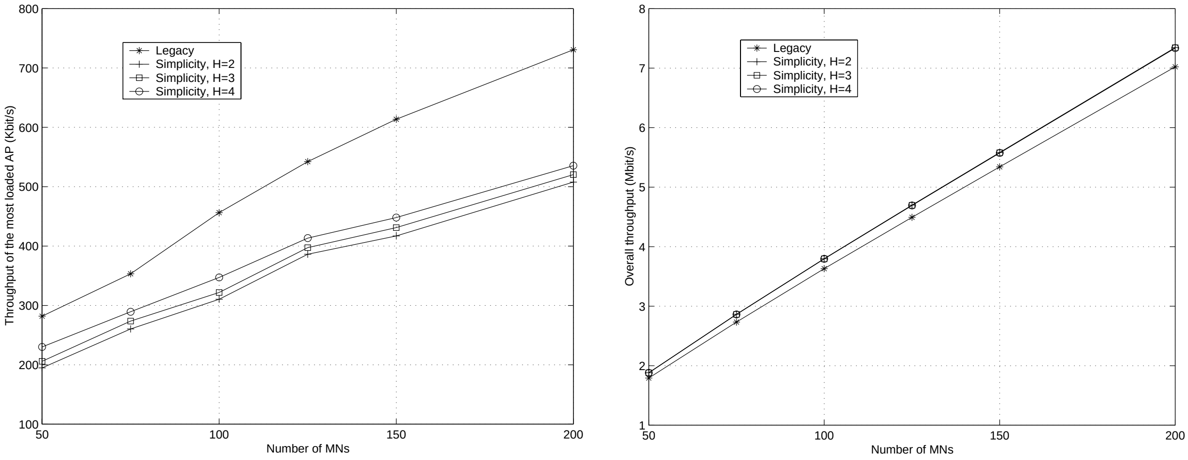
Our goal is to minimize the traffic load of the most loaded AP in the network area. In other words, the Simplicity load balancing procedure has to be able to minimize the maximum utilization coefficient among the APs. A preliminary comment is that, due to the mobility model adopted, MNs tend to concentrate in the center of the simulated area. Consequently, the APs in the central region of the network are the most loaded ones.

Fig. 3(a) shows the average throughput of the AP which is, on average, the most loaded one during phase 2 (i.e., when MNs do not move). Such a value is reported for both the legacy and the Simplicity system as a function of the number of MNs, N_{MN}, and with H as a parameter. Clearly, the throughput is increasing with N_{MN} since the traffic load increases with N_{MN} as well, as mentioned above. The improvement of the Simplicity load balancing mechanism is evident. As expected, the lower the value of H the higher the gain with respect to the legacy system. We have verified that a value of $H=2$ yields the best performance and the stability of the system.

In Fig. 4(a), we report the average throughput of the APs for both the legacy system and the Simplicity system, when $H=2$ and $N_{MN}=125$. Histograms show that the traffic load is well distributed among the APs when the load balancing is performed. The APs in the central area of the network (e.g., AP_7, AP_{12}, and AP_{18}) are definitely the most loaded ones. A part of their load is distributed among neighboring APs when the Simplicity mechanism is turned on. In any case, note that some APs deliver a low amount of traffic since they are at the border of the network area and are clearly useless for load balancing purposes.

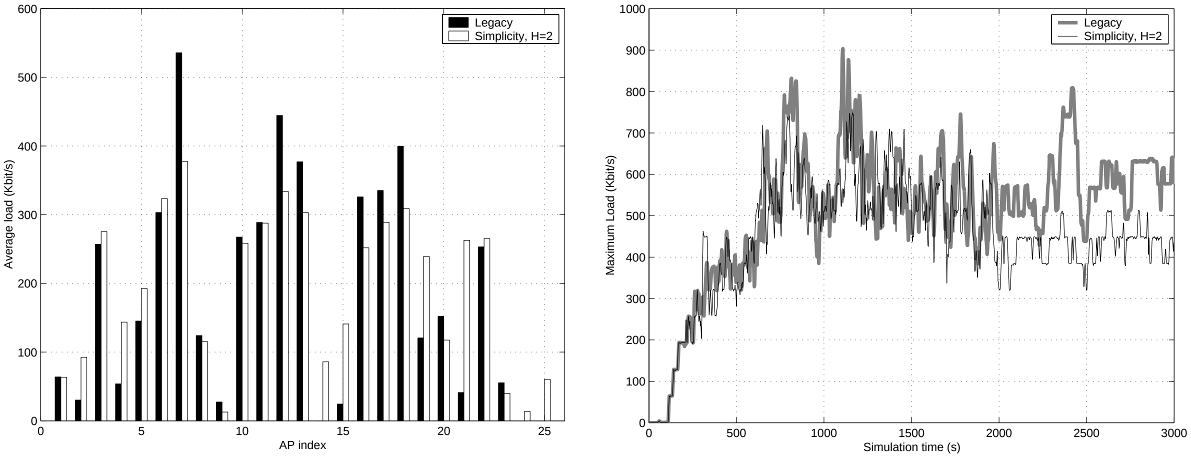
Fig. 4(b) shows the throughput of the most loaded AP as a function of the simulation time. The improvement in phase 2 is quite noticeable, whereas during phase 1 the performance of the legacy system and of the Simplicity system is quite similar. This result was expected since, in phase 1, the network scenario is highly dynamic due to both MNs movement and call arrivals/departures, and the load balancing procedure is not able to follow the network changes.

However, it is worth noting that when MNs move, the Simplicity approach is able to drive handovers before MNs get disconnected from their previous link. This allows limiting the time in which MNs are disconnected, thus reducing packet losses. Fig. 3(b) illustrates the overall throughput of the network as a function of the number of MNs in both the legacy and the Simplicity system. The Simplicity mechanism yields a throughput higher than the legacy one, independently of the value of the hysteresis. This behavior becomes more evident when the number of MNs increases, since the traffic increases as well. In more detail, the improvement in terms of aggregated throughput is around 4%.



(a) (b)

Fig. 3: (a) average throughput of the most loaded AP versus N_{MN} when MNs do not move; (b) comparison between the overall throughput of the Simplicity system and of the legacy system when MNs move. Curves are averaged over 20 simulation runs.



(a) (b)

Fig. 4: (a) average throughput of the APs when MNs do not move (N_{MN}=125); (b) throughput of the most loaded AP versus simulation time (N_{MN}=125). Curves are relevant to a single simulation run.

Finally, it is worth noting that the current AR knows the surrounding wireless coverage and is able to communicate to the MN the IP address of the AR to hand over to. This allows speeding up the overall handover process and executing fast handover procedures ([14][15]). Note that these procedures are not implemented in our simulator.

4. CONCLUSION

We presented an automatic procedure which allows a network operator to drive MNs towards the most appropriate wireless access, for load balancing purposes. To this end, network operators can use the enhanced capabilities of the Simplicity brokerage framework distributed among terminals and network.

The simulative analysis performed with a NS-2 based simulator has shown the effectiveness of the mechanism in an 802.11b access network.

Future work includes considering also inputs from the SD to differentiate the network service according to user profiles.

To show the feasibility of the system, the development of a demonstrator is in progress.

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