Access Network Control within the Simplicity Brokerage Framework

Nicola Blefari-Melazzi, Dario Di Sorte, Mauro Femminella, Gianluca Reali

Abstract— **In this paper, we describe a novel solution to control a wireless access network. The procedure exploits the enhanced capabilities of the Simplicity brokerage framework distributed among the users' terminals and the network. We propose a monitoring procedure able to track both the current state of the access network resources and the current service demand. Then, an appropriate selection procedure uses the access network context to drive mobile users towards the most appropriate point of access to the network for load balancing purposes. We present a numerical analysis showing the effectiveness of the proposed Simplicity mechanism in an 802.11b access network environment.**

Index Terms— **access network context, access point selection, load balancing**

I. 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. On the other hand, 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 offer performance guarantees and to engineer their network efficiently through load balancing, intelligent resource exploitation, congestion avoidance, fairness, fault tolerance and so on.

The IST project Simplicity [1][2][3][4] aims to simplify the process of using and managing current and future services. The project is developing and evaluating a number of tools, techniques and architectures enabling users to customize and use devices and services with a minimal effort.

In the Simplicity framework, a key role is played by the so-called Simplicity Device (SD), which contains a properly organized user profile. Ideally, a roaming user who plugs the SD into an available terminal is enabled to access to a personalized working environment transparently, since the terminal is automatically re-configured to meet the needs of the user, as specified in his/her SD, according to the terminal capabilities and the current location/context.

To enable re-configurability actions, the Simplicity system encompasses three main components: the SD, the Terminal Broker (TB) and the Network Broker (NB). Thus, the system operation results by the interaction of the SD with a brokerage framework. The latter operates according to policy-based procedures, which coordinate and adapt applications, services, terminals and network capabilities, taking account of the user preferences, terminal characteristics, and network status.

In this view, any simplification of the network management procedures is important. A key point is the design of a self-controlled access network, where hosts and network devices require a minimum amount of manual configuration by network operators and technical effort from users. For this purpose, network operators can use both the user profiles available in the SDs, and the enhanced capabilities of Simplicity-enabled terminals.

In this paper, we focus on load balancing in wireless local area networks, which is an emerging research field (e.g., see [7]). 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., both the current state of resources and service demand. Then, an appropriate selection procedure uses this set of information to drive Mobile Nodes (MNs) towards the most appropriate point of access to the network. 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.

The paper is organized as follows. In the next section, we introduce the leading concepts of Simplicity. In section III, we illustrate the basic lines of the access network control procedure. Section IV illustrates numerical results. Finally, in section V, some concluding remarks conclude the paper.

II. The Simplicity Brokerage Framework

An important feature of 2G wireless systems is the portability of user identities among different mobile phones. The Simplicity project [1][2][3][4] 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

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profile, providing access to different services and networks, using different classes of terminals. The personalized user profile will allow: i) automatic customization and transparent configuration of terminals/devices and services; ii) uniform mechanisms for recognizing, authenticating, locating and charging the user; iii) policy-controlled selection of network interfaces and applications services. Thanks to the profile, users will also enjoy the automatic selection of services appropriate to specific locations (e.g., the home, buildings, public spaces), the automatic adaptation of information to specific terminal devices and user preferences, and the easy exploitation of different telecommunications paradigms and services. Depending on users' characteristics, preferences, and abilities, personal profiles could take the form of i) a standard profile defined by a service provider; ii) a pre-defined template whose parameters can be configured by the user; iii) an open profile designed by the user by using a high-level description language. The user profile will be stored in the SD (e.g., a Java card, a USB stick,…). Users could easily personalize terminals and services by plugging the SD into the chosen terminal.

One of the main novelties of the SD is that it is not tied to a single networking environment, or to a single class of user terminals. The SD will provide all the information necessary to adapt services to the characteristics of the terminal, the nature of the environment and the user's preferences.

Thus, a 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 this end, the Simplicity system foresees, beyond the SD, the TB and the NB (see Fig. 1).

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 TB caters also for the user interaction with the overall Simplicity system.

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.

In our opinion, the enhanced capabilities of the Simplicity broker are useful also from the network operator perspective. Thus, it 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 management tools for network control and self-configuration in a heterogeneous framework. Thus, the Simplicity broker could be of help and even instrumental in (re-)configuring the network by using also information on users' requests, preferences and profiles. This should strengthen the operator interest in deploying a Simplicity system, since it would help to make the network resources easier to manage.

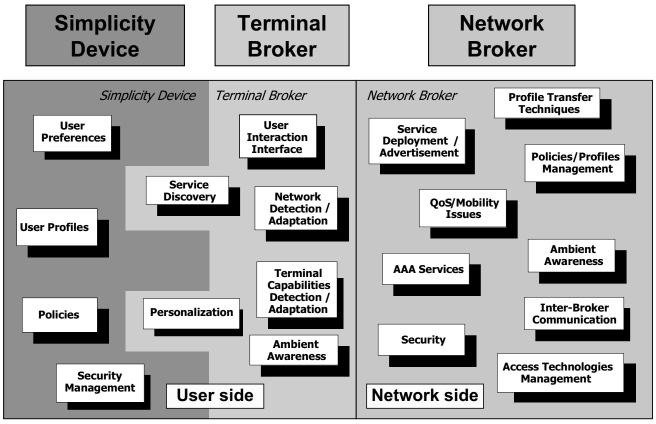

Fig. 1 - System components.

III. ACCESS NETWORK CONTROL

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, Simplicity offers enhanced terminals and users' info available from the SD. This can thus be used to improve performance with respect to the generic case in a proactive way. Dynamic network and traffic configuration should be self-constructing. Network performance should be monitored on-line so that, if proactive control running in the background does not provide satisfying results, operator policies can trigger reactive actions.

In what follows we suggest that these goals could be achieved more easily by exploiting specific features of Simplicity, namely:

- the capabilities of SD-enabled terminals, which can assist the network in monitoring availability of wireless coverage (refer also to [8]);
- user information retrievable from SDs (profiles and preferences).

The NB (Policy Decision Point, PDP), is the entity 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.

The terminal (i.e., the TB) is in charge to assist the network, by providing inputs to the NB as regards the access network context (e.g., the radio access technologies currently perceived by the terminal through a frequency scanning action), and by acting as Policy Enforcement Point (PEP) (e.g., to switch from an access point to another).

To sum up, the inputs to the NB are:

- users' side 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). This information is sent once and updated if needed;
- 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 management decisions; in this paper, we focus on load balancing. The input to the NB can be used to automatically optimize the distribution of mobile users within the wireless section. Mobile terminals can be driven towards the most appropriate Access Point (AP), according to operator's policies.

It is worth noting that when the terminal turns on, the TB is allowed to exchange information with the NB through a default network connection.

The overall process is sketched in Fig. 2.

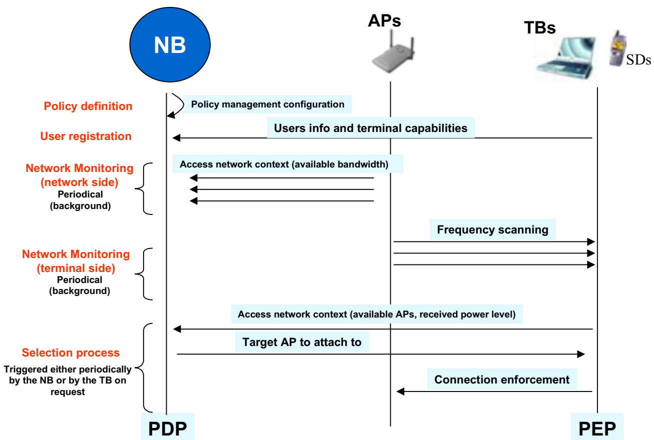

Fig. 2 - SD-assisted network control: an overall picture.

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.

We assume that the NB may be either centralized over a specific network entity or distributed over the Access Routers (ARs) controlling the wireless access section of the network. In the latter case, this means that each AR is in charge of directly managing only those mobile users under its control.

The detailed analysis of the procedure for different architectural choices and of the cost of the process in terms of signaling overhead are not reported here due to space limitations. Such an analysis can be found in [5], where we show that the signaling burden associated with the procedure is definitely low.

As a final note, we stress that the proposed approach is general and can be used in a heterogeneous wireless access network environment. In the following section, we provide numerical results for a homogeneous 802.11b scenario.

IV. PERFORMANCE EVALUATION

In this section, we show the numerical results from a simulation campaign relevant to the Simplicity load balancing mechanism. To this end, we have developed a proprietary C++ simulator exploiting the NS-2 event scheduler.

A. Simulation scenario

The simulation topology used at this stage is a square area with side 150 meters, typical, for instance, of a campus area. The number N_{mn} of simulated MNs is equal to 800. For what concerns the adopted radio technology, we emulated 802.11b. This implies that the overall gross bandwidth is 11Mbit/s for each AP. However, a common value for the maximum throughput is about 5Mbit/s, thus we used this value in the simulation for indicating the net bandwidth, BW_{net}. The number of 802.11b APs is 21. They are distributed in order to assure uniform service coverage. Most the area is covered by two different APs, and some parts by 3 APs. For what concerns the transmitted power, we used the value of 100mW, with receiver sensitivity equal to PW_{min}=11nW. This implies that, assuming a quadratic attenuation model (with transmission and reception gain equal to 1 at a frequency of 2.4GHz), the radius of a cell is equal to 30m (circular coverage). In addition, we have defined a further power level (PW_{opt}=19.5nW, corresponding to a radius of 22.5m, i.e., 75% of the radius), which defines an alarm threshold. In the Simplicity mode, when a MN realizes such a power level on the current AP, it triggers the selection process at the NB, since it is next to the cell border. We implemented the AP coverage as hard: until the received power level is higher that PW_{min}, the MN is in coverage, with a value just below that value it is disconnected.

As regards the process of selecting the AP to attach to, we implemented in the simulator two models:

- the legacy one, 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} (the receiver sensitivity). When the terminal realizes to be disconnected, it performs beacon scanning and, among the set of found APs, it selects the one with the highest signal strength;
- the Simplicity mechanism: when the power level of the current AP goes under PW_{opt}, the terminal performs L2 beacon scanning, communicates such a result to the NB, and requests a driven handover; when the terminal turns on, it initially selects the AP with the strongest signal strength to communicate with the NB. In turn, the NB, based on

context information from the TB and the measurement collected each T_{BW}=1s on the APs, decides the best AP to attach. The terminal attaches to such an AP. In our Simplicity enhanced system, the best AP is the less loaded among the set of candidates. An AP is considered a candidate if its power level is above PW_{min}. We recall that the selection process is also triggered periodically, with period T_{SEL}=1min.

The mobility model used for the simulations is the Gauss-Markov one [6]. We have used this model since it avoids sharp direction changes, by allowing previous speed and direction to influence future mobility. The value of the average MNs speed has been set equal to 1.5m/s. In addition, we have also implemented a modified version of this mobility model. This modification aims to model situations where a number of MNs move towards the same set of points (i.e., attractors). We set on the simulation area two attracting zones. The former is a large area, and comprises 5 attractors, whose co-ordinates are (45,45), (45,65), (65,45), (55,55), and (65,65). The latter is a small area, with a single attractor placed in (125,125).

The simulation time is equal to 3000s. The MNs freely move during the interval [0, 1000] s, then they stop for 500s ([0 1500] s: phase 1). At simulation time 1500s, all the MNs restart moving, and a subset of them are attracted towards the first attraction area. This setting lasts for 180s, and then all MNs stop again for 500s ([1500 2180] s: phase 2). At 2180s, all the MNs restart moving, and the same subset of MNs previously attracted by the first set of attractors move towards the point (125,125). Finally, at 2360s, all MNs stop up to the simulation end ([2180 3000] s: phase 3).

The rationale of this setting regarding both attractor placing and movement timing can be framed in a campus network. For instance, the movement towards the first set of attractors may be representative of a number of users (e.g., students and professors) gathering in laboratories or classrooms for lessons. For this reason, we placed more than a single attractor. Clearly, once arrived, it is necessary to emulate the stay in such a place. In turn, the movement of users towards a single point may be representative of movement towards refectory.

The fact that MNs stop for a given amount of time allows us testing the capability of our Simplicity-enabled load balancing procedure to reach (and maintain) a steady state condition. Clearly, phase 1 is the less critical for load balancing, whereas phase 3 represents the most crucial situations. This is due to the fact that (i) a subset of MNs move towards a single point of the simulation area, and (ii) these MNs move together starting from the same area. This implies that they follow nearly the same path contemporarily. We expect that this phase is more critical than phase 2, since, in this situation, MNs converge towards a larger area from different directions, thus they share a potential higher amount of wireless resources.

B. Numerical results

As mentioned in the previous sub-section, for the AP selection in the Simplicity system we use the criterion of the less loaded AP among the set of candidates for the considered MN. Assuming that MNs have homogeneous profile and service demand, we define the load of *i*-th AP the number, $N_{mn}(i)$, of MNs attached to it. The NB assigns to a candidate AP a cost equal to:

$$M_{AP}(i) = N_{mn}(i) + H_{MN}\left(1-(-1)^{x}\right)/2\,, \tag{1}$$

where x is equal to 1 for the current AP, and to 0 for the other candidates. The parameter H_{MN} (hysteresis) is introduced to avoid annoying ping-pong effects (i.e., continuous switches among two or more overlapping APs).

A preliminary comment is that the higher the value of H_{MN}, the lower the load balancing effect of the procedure, and the higher the stability of the process. Thus, the choice of the value of the hysteresis parameter is a trade-off between performance and stability. The need of the hysteresis mechanism is also because of the asynchronous way of functioning of the selection procedure for different MNs. We are aware that this procedure leads to a sub-optimum load balancing solution. The optimum distribution of MNs among APs can be reached if the NB has a complete and synchronous knowledge of the status of the network and of the candidates for MNs, and is able to take the decision for all the MNs in the same time. This implies the solution of a possibly complex optimization problem and the necessity to have a large amount of updated information in a very small time frame.

Please note that, in the case analyzed, the NB is able to maintain the association between each AP and the related MNs served. In other words, it is not necessary to probe APs to get such an information. Thus, no special functions within APs are required. If more sophisticated selection criteria based also on bandwidth measurements at APs are used, then the probing phase between NB and APs becomes mandatory.

The performance figure we present is the gain obtained using the Simplicity system with respect to the legacy one:

$$Gain = BW_{\min-SIMPLICITY} / BW_{\min-LEGACY}\,, \tag{2}$$

where $BW_{\min} = \min_i [BW_{net} / N_{mn}(i)]$ is the minimum bandwidth available, on average, for the users under the coverage of the most loaded AP in the network.

It is clear that the better the load balancing among APs, the higher the service level perceived by users.

Measurements are averaged over 20 simulation runs. For neatness of figures, confidence intervals are not shown.

Fig. 3 reports the performance gain obtained with Simplicity-enabled load balancing with respect to a legacy system, with H_{MN} as a parameter, when the percentage of attracted MNs is 60%. Note that the more critical the condition due to MNs behavior (from free to softly biased to strictly biased movement pattern), the higher the gain achieved by the Simplicity mechanism, up to values around 2.4. In other words, we verify a performance gain increasing with the simulation time (at least in the period when MNs are blocked and the mechanism can converge towards a steady condition). In addition, we expect that the higher the percentage of attracted MNs, the higher the gain. In order to show these effects and corroborate our thesis, consider Fig. 4. It presents the performance gain vs. simulation time for different percentage of attracted MNs, with H_{MN}=15.

In addition, let us consider the effect of the hysteresis parameter on performance and stability of the proposed procedure. In general, we can say that the higher the hysteresis, the higher the stability of the procedure and lower the performance gain. This behavior is clearly depicted in Fig. 3. It shows that a value of H_{MN}=10, even if performs better than H_{MN}=20, implies a jittering and decreasing behavior of the performance gain in the critical phase 3. We have verified that when the percentage of attracted MNs increases and reaches 80% and 100%, a value of H_{MN}=15 is the best choice for the most critical phases (2 and 3).

As mentioned above, all the curves are obtained assuming that the selection period is equal to T_{SEL}=1min and that the information about the network load on the APs is refreshed each T_{BW}=1s. As regards T_{BW}, we have verified that the higher the value of T_{BW}, the lower the stability of the Simplicity load balancing mechanism, whereas the performance remains nearly the same for values up to 10s. The former behavior is more evident for low values of the parameter H_{MN}. In particular, for H_{MN}=10, the system becomes unstable for values of the update time higher than 1s, whereas for H_{MN}=15 or 20 the system remains stable for values up to 10s. This is an interesting result, since it implies that we can lower the bandwidth consumption due to signaling exchange. As regards the selection period, the simulation analysis says that, for low values of T_{SEL} (few seconds), the system is not stable in critical situations (phases 2 and 3). For values of T_{SEL} beyond 60s, the system has a slight performance loss. This is a very good result, since it means that it is possible to reduce the signaling exchange in the network without losing the effectiveness of the procedure in terms of load balancing. In addition, the higher the value of the selection period, the lower the computational burden to be supported by the NB.

It is worth noting that the results described in this work are relevant to the specific scenario considered. Obviously, a similar analysis can be repeated in any network scenario.

V. Conclusion

We have presented a procedure able to balance the traffic load in a heterogeneous access network, by exploiting the capabilities of the Simplicity brokerage framework.

The performance analysis in an 802.11b access network has shown that the effectiveness of the mechanism is noticeable.

The next steps of the simulation analysis will comprise new inputs from the SD. For instance, in a campus network, different class of users (e.g., professors, students, and employees) may have different network service treatments. We also plan to make a full porting of the simulator to NS-2 to evaluate the performance of the Simplicity access network control approach in terms of UDP/TCP throughput.

A demonstrator of the system is currently being produced.

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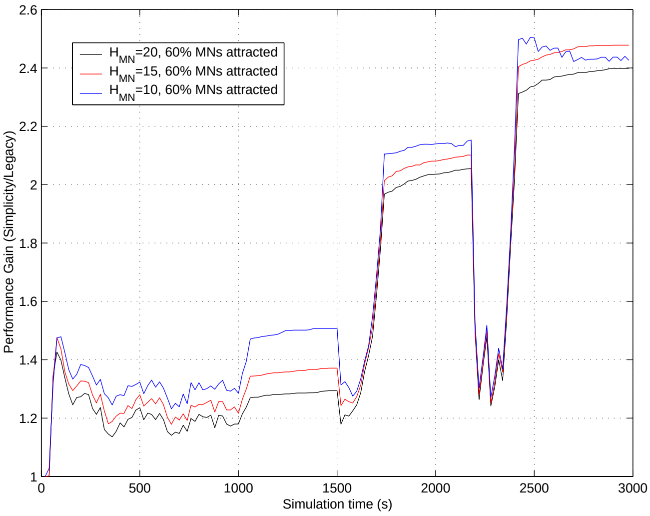

Fig. 3 - Performance gain vs. simulation time with H_{MN} as a parameter.

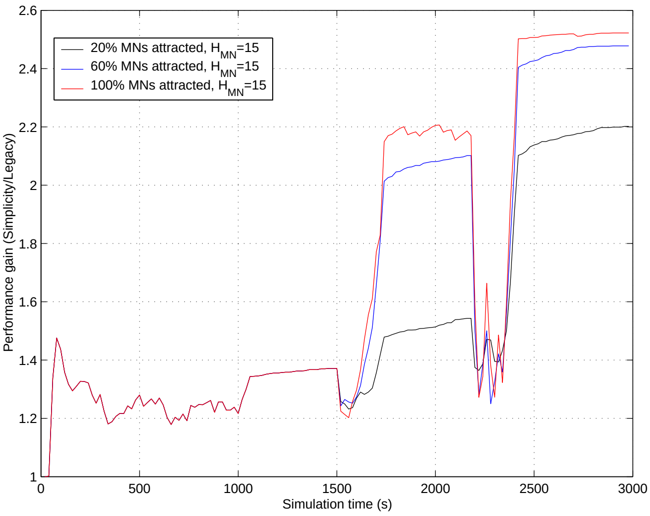

Fig. 4: Performance gain vs. simulation time with the percentage of MN attracted as a parameter (H_{MN}=15).