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# QoS Protocol Specification for IEEE 802.11 WLAN

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**Abstract:** The main aim of this study is the presentation of a new protocol for the load balancing approach in IEEE 802.11 WLAN in order to improve Quality of Service (QoS) and to provide an adaptation between application and available physical resources of network. It focuses on the presentation of QoS management solution for wireless communication system. It, mainly, presents a protocol structure between mobiles and APs to provide better resources allocation and efficiency on communication metrics. This research studies the formal validation of this communication protocol using SDL pattern. It gives the formal protocol dynamic behavior check using MSC tool. It also focuses on the implementation with Opnet tool in order to bring out the enhancement of the Quality of Service Management in hotspot environment when using this solution.

**Key words:** IEEE 802.11, Hot Spots, QoS, load balancing, SDL, OPNET simulation

## INTRODUCTION

In the last few years, the IEEE 802.11 technology becomes very interesting. One of its popular uses is its cheap hardware infrastructure price promoting to provide practical and efficient Hotspots environment (Balachandran *et al*., 2002a).

The research work (Balachandran *et al*., 2002a, b; Kotz and Essien, 2002) and (Tang and Baker, 2002) carried out in this context had proved that additional effort is still required to build up a system with a high service quality. A specification of further interaction in the IEEE 802.11 (2001) protocol between AP and the mobiles mainly in call admission will help to ensure some QoS parameters such as load distribution and packet losses (Balachandran *et al*., 2002a, b; Tang and Baker, 2000; Blinn *et al*., 2005; Guo and Chiueh, 2005. Although new standard IEEE 802.11 (2003) has been defined to ensure quality of service in Wireless LAN it seems that it is not enough to meet the application requirements.

This study presents a protocol specification managing the QoS in the context of Hotspots communication environment. It focuses on the general description of the proposed hotspots environment architecture. In this architecture, the study of new protocol primitives between the mobile and the access point managing QoS metrics will be presented and formally described with the SDL (Specification and Description Language, 1999) language (Probert *et al*., 2001; Bourhfir *et al*., 2001). The behavior of this protocol will be checked with some MSC (Message Sequence Charts) simulation results. OPNET simulations of the proposed approach are used to show a best resources allocation and efficiency on QoS metrics.

## GENERAL APPROACH PRESENTATION

The QoS management on hotspots environment becomes vital as many new emerging applications such as mobile information access, real time multimedia communications, networked games, immersion worlds and cooperative work require a minimum level of QoS (Ni *et al*., 2004; Lin et Gerla, 1989; Lindgren *et al*., 2003; Mangold *et al*., 2003).

The hotspots environment can be described as a set of access points covering overlapping cells and offering connection to a variable number of mobile stations. User's applications are not similar in terms of QoS requirements so that a fair distribution of the mobile stations among active access points can guarantee a minimum level of quality of service. The bandwidth effectively offered by an access point is given by the following formula (Shanon). BP is the bandwidth defined by the IEEE 802.11 (2001, 2003) standard.

$$Cmax = BP*\log_2(1+SNR)$$

In wireless environments, bandwidth is scare due to interferences and many obstacles. Channel conditions will be time-varying with losses.

Unfortunately, in the actual IEEE 802.11 (2001, 2003) protocol, a mobile station is associated to the access

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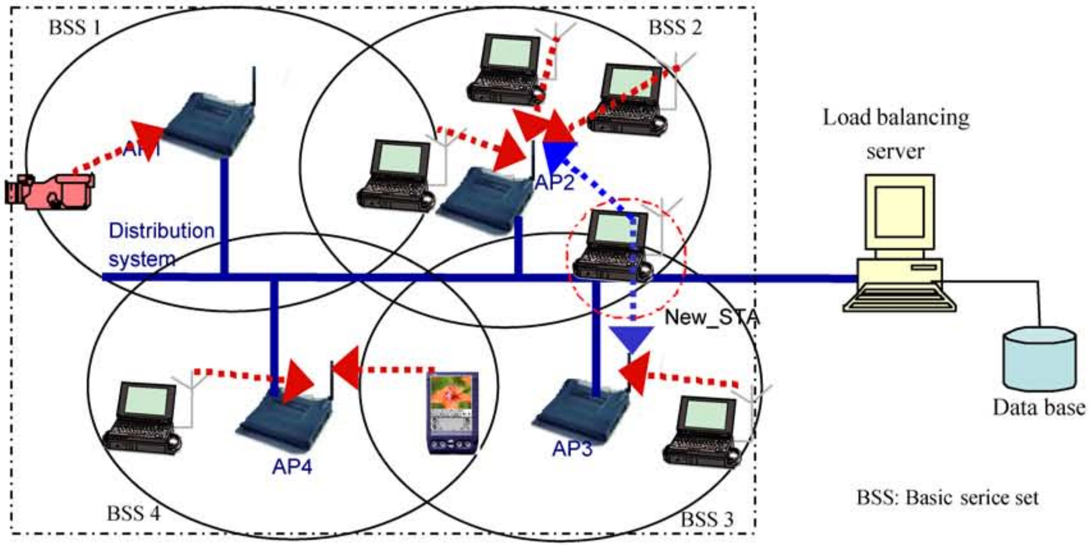


Fig. 1: IEEE 802.11 (2001, 2003) target architecture

point offering the best Signal by Noise Ratio (SNR) independently of the load being applied to the access point by other users. This can cause, in many cases, unbalanced load between access points. Some access points will be over loaded and others under loaded. For the first ones, applications requirements are not fulfilled. The keystone of our approach is to associate mobile station to access points with a minimum SNR threshold and offering the best QoS level.

Figure 1 sums up the idea we develop in this study. A new mobile station (New_STA) reaching the WLAN must be associated with an access point. The association procedure is always initiated by the station (mobile-controlled handover) and the station can be associated with one access point only. The New_STA must discover which access points are present to establish then an association with one of them. The station first initiates a scanning process that can be either active or passive (Gast, 2002). Once the scanning process has finished, the station has an updated list of access points in range (AP2 and AP3). This information is used by the station to associate with the access point that provides the higher Signal-to-Noise Ratio (SNR).

Let's suppose that AP2 is chosen by New_STA. The load distribution across access points will be highly uneven (Balachandran *et al*., 2002a). This can cause a performance degradation perceived by the other stations attached to AP2. Quality of service contracts (bandwidth, loss rate…) may be violated. It will be attractive to associate the new host to AP3 which has lower SNR and is under loaded. The lower SNR given by AP3 is also suitable to get acceptable connection quality to New_STA. In fact, according to the IEEE 802.11 (2001, 2003) standard, only access points with SNR greater than a Reception Threshold are detected by a scanning process. The available bandwidth of the WLAN link depends strongly on the number of active stations and their traffic. To achieve this balancing, in terms of quality of service offered to the stations (load, loss rate…) among access points, we have to compute a balancing algorithm each time there is a new event such as the arrival of new stations or the mobility of existing stations. This algorithm has to find the best state of associations between access points and mobile stations that offer the best quality of service level for user's applications. Thus, we have to get information about associated stations, traffic coursed by access points and users quality of service requirements (Fig. 2). This information has to be exchanged between WLAN entities and stored in an updated data base.

In this architecture, the load balancing server should periodically download a set of specific parameters from each access point. For example, when making an active or passive scan, each station gets a list of accessible access points. This information is usually transmitted to the load balancing server and stored in the data base. It runs up the balancing algorithm finding the best mobile station sharing among the available access points. The result will then be broadcasted in the system. Then, we have defined for this architecture a set of new metrics to quantify the quality of service and primitives exchanging these parameters for association and disassociation between mobile station and access point. These primitives that should be inserted into the MAC layer to improve the IEEE 802.11 (2001, 2003) define a new MAC quality of

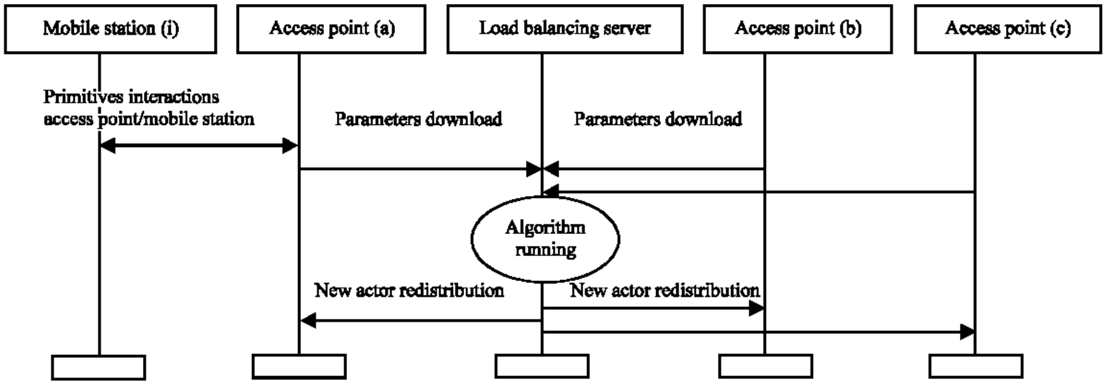


Fig. 2: System protocol interactions

service policy for wireless LANs. In our approach, we suppose that a mobile station is able to communicate its needs in terms of bandwidth. So that, an access point is usually able to determinate its total traffic. At this step of the work we do not worry about the hand-off mechanism of the mobile stations.

## LOAD BALANCING ALGORITHM DESCRIPTION

The load balancing algorithm (Velayos *et al*., 2004; Bianchi and Tinnirello, 2002) is computed by the load balancing server every time a new distribution is needed in the wireless LAN. This will occur (i) when a new mobile station reaches the wireless LAN and aims to associate with an access point, (ii) when an associated station is moving from one to another BSS (iii) and when the applications requirements in a mobile station are changing. The downloaded parameters from the access points and mobile station applications will be useful to find the best distribution of mobile stations among wireless LAN access points.

This algorithm checks if the new distribution is balanced mainly by computing the balance index ($\beta$). The balance index appeared in the first time in Chiu and Jain (1989) and it is used by Balachandran *et al*. (2002a) and Velayos *et al*. (2004) as a performance measure. The balance index reflects the used capacity in each access point.

$$\beta_j = \frac{(\sum_{i=1}^{i=n} T_i)^2}{n * \sum_{i=1}^{i=n} T_i^2}$$

n = No. of overlapping access points
$\beta_j$ = balance index of an overlapping zone j
$T_i$ = Total traffic of an $AP_i$ overlapping with other access points in the zone j

The proposed distribution of mobile stations is balanced if the balance indexes of all the overlapping cells converge to 1. At this step, the algorithm has to send the new distribution to the access points which will be authorized to dissociate, associate and reassociate mobile stations. The balance index has been used in one overlapping zone of two access points only (Balachandran, 2002b). In our approach, we have to calculate the balance index for each overlapping zone (of two or more access points) of the hot spot.

## PROTOCOL SPECIFICATION

**QoS protocol parameters:** In this approach, the QoS management is based on the idea that some added primitives must be ensured at the connection level between the mobile station and the access point. Then, each mobile in the wireless LAN may be able to propose a level of QoS and to modify it when needed.

In this architecture, the mobile station defines four variables managing its QoS state. The communication process will then base its negotiation with the access point on these parameters to build up clause for service quality. Table 1 sums up these parameters and their functions.

The following inequality describes the logical relation between these parameters:

$$QoS_{max} \geq QoS_{expected} \geq QoS_{negociated}$$

Table 1: Quality of service parameters

| Parameters | Function |
|---|---|
| $QoS_{max}$ | The maximum quality of service that the mobile station can offer to the user |
| $QoS_{negociated}$ | The quality of service used by the mobile station at time t |
| $QoS_{expected}$ | The quality of service wanted by the user or the application |
| $Old\_QoS_{negociated}$ | It is necessary to conserve the old quality of service to make comparisons in case of voluntary changes or new offers of QoS |

Table 2: Access point parameters

| Parameters | Function |
|---|---|
| $D_{max}$ | The higher throughput that can be provided by the access point according to his hardware capabilities |
| $D_{min}$ | The lower throughput agreed for each user (the Best Effort service) |
| Du | The actually used throughput, that means the offered throughput for all connected users |
| $D_r$ | The reserved throughput, that means the required throughput for a mobile station in an attachment attempt added to the current throughput |

Table 3: New wireless entities parameters

| Parameters | Access point | Mobile station | Function |
|---|---|---|---|
| $My\_Id_{AP}$ | * | | The access point identifier |
| $Id_M(X)$ | * | | The identifier of mobile station number X |
| $My\_Id_M$ | | * | Defines the mobile station identifier |
| $QoS_{negociated}(X)$ | * | * | The Quality of service negotiated with the mobile station X |
| $Old\_QoS_{negociated}(X)$ | * | * | The old level of QoS being agreed for a mobile station number X |
| St_Moving(X) | * | | Describes the state of moving state of the X mobile station |
| St_Reserved(X) | * | | Describes presence state of the mobile station X |
| Timer(X) | * | * | For actions limited in time |

From the part of the access point, some other parameters must be provided to enable QoS management (Table 2).

So, we can propose rules that enable the management of the stations access according to the requirements and the availability of QoS:

$$D_r = D_u + QoS_{expected}$$

$$D_r < D_{max} - D_{min}$$

**Device identification:** In this approach, to ensure QoS management in the WLAN some identifiers should be joined to the parameters describing present and old quality of service states in each mobile. These identifiers are maintained in a specific database both in the access point and the mobile station.

Each mobile station will then discuss the attachment attempt responses of the access point according to its own QoS parameters.

We describe in Table 3 these parameters from both the access point and the mobile station point of view (*indicates where the parameter is defined).

These parameters have to be saved in a specific data base managing the whole environment of the wireless device. This database communicates with the other layers defined in the IEEE 802.11 model to ensure coordination in call admission processes.

Table 4: Quality of service primitives

| Primitives | Access point | Mobile station | Parameters |
|---|---|---|---|
| ASK_ATTACH.conf | * | | ($Id_M$, $Id_{AP}$, $QoS_{negociated}$): |
| ATTACH.conf: | * | | ($Id_M$, $Id_{AP}$, $QoS_{negociated}$) |
| WAIT | * | | ($Id_M$, $Id_{AP}$) |
| ASK_RATTACH.req | * | | ($Id_M$, $Id_{AP}$, Set_of _available_AP) |
| ASK_ATTACH.req | | * | ($Id_M$, $Id_{AP}$, $QoS_{expected}$) |
| ATTACH.req | | * | ($Id_M$, $Id_{AP}$, $QoS_{negociated}$) |
| ATTACH.req | | * | ($Id_M$, $Id_{AP}$, $QoS_{negociated}$) |
| ASK_RATTACH.conf | | * | ($Id_M$, New_$Id_{AP}$, Old_$Id_{AP}$) |
| LEAVE | | * | ($Id_M$, $Id_{AP}$) |
| OK | * | * | ($Id_M$, $Id_{APa}$, $Id_{APb}$) |
| MOD_QoS.req | * | * | ($Id_M$, $Id_{AP}$, $QoS_{proposed}$, Time) |
| MOVE.req | * | * | ($Id_M$, $Id_{AP}$) |
| MOVE.conf | * | * | ($Id_M$, New_$Id_{AP}$, Old_$Id_{AP}$) |

## QoS PROTOCOL PRIMITIVES

The IEEE 802.11 suffers from lack of specific QoS primitives. The only parameter on which the connection negotiation between the AP and the mobile station is based, is the SNR ratio. But, this parameter does not always answer to the needs of applications. So it appears indispensable to specify new protocol primitives to enable the integration of other communication parameters in the connection decision and then in load redistribution.

We have then defined a set of new primitives expressing general requirements (*indicates from which entity the primitive could be generated) (Table 4).

## SCENARIO DESCRIPTION

The primitives are used to manage the access of the mobile stations to the wireless LAN via access points. Then we check theses primitives with many communications scenarios. Communications scenarios vary from simple to much complex situations. Here we describe one of the scenarios. This example is presented in Fig. 4. M4 enters the wireless LAN and aims to connect to AP2. The AP2 is not able to offer connection to M4 with the requested quality of service level (Fig. 3). It asks the load distribution server to find a new distribution to make possible the connection of M4 to AP2 (Fig. 5). After the computation of the load

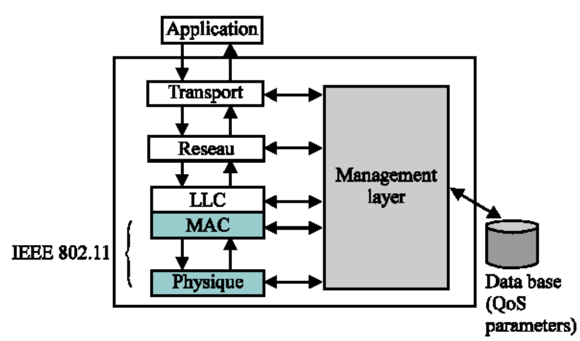


Fig. 3: System exchange design

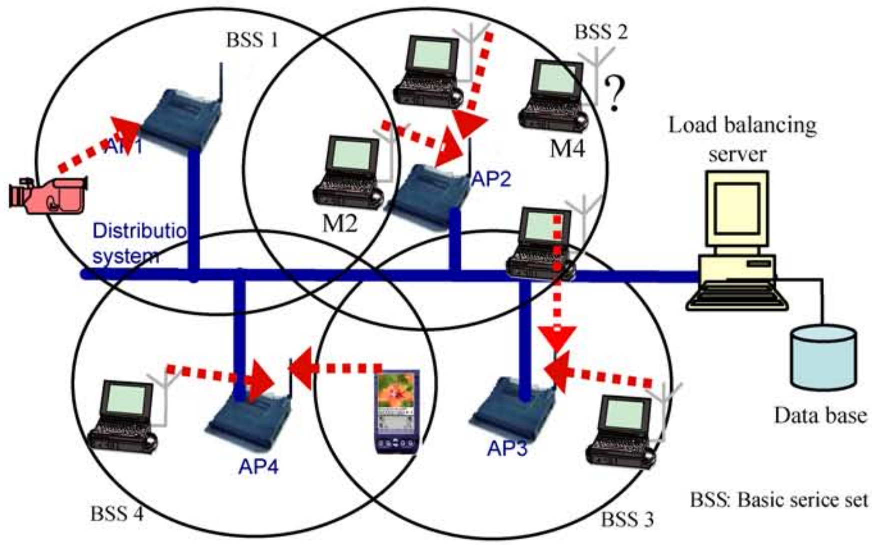


Fig. 4: M4 asking for connection

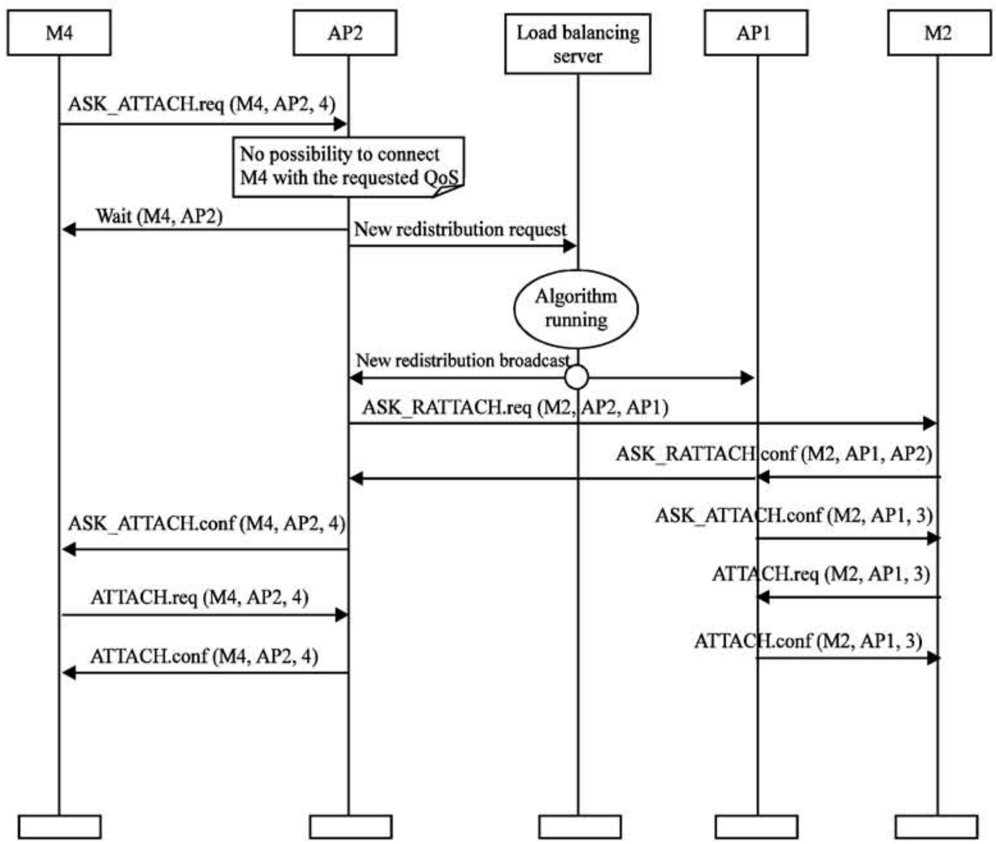


Fig. 5: Example of communication scenario

balancing algorithm, the load balancing server broadcasts the new distribution of mobile stations onto the access points. AP2 has to dissociate a mobile station M2. This one will be associated to AP2 which is able to give it the required quality of service level. Finally M4 and AP2 complete the connection procedure (Fig. 5).

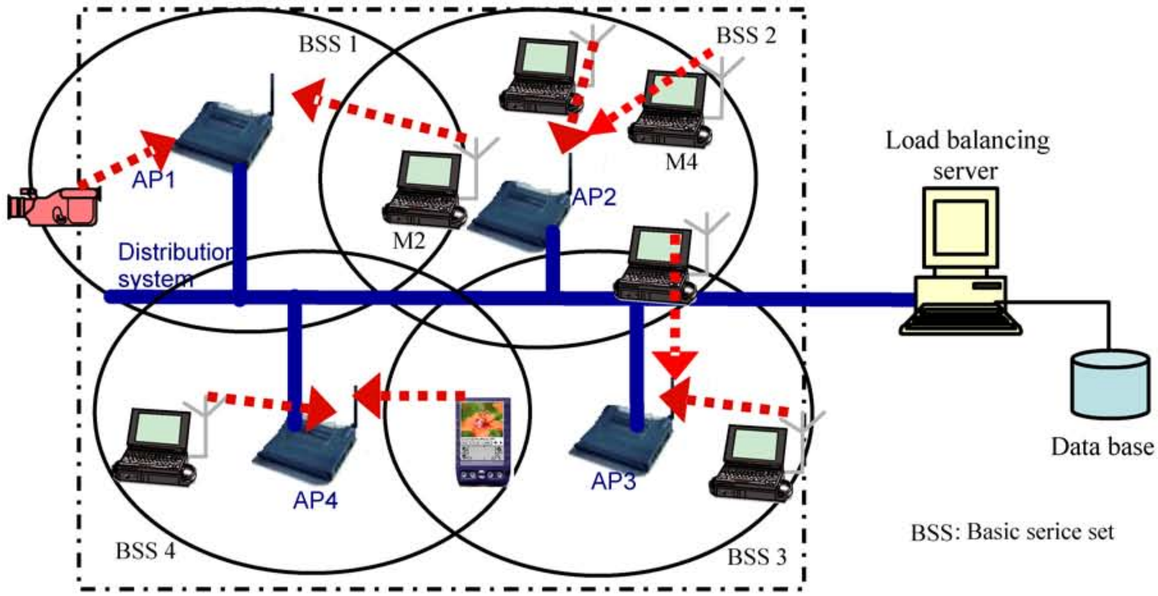


Fig. 6: M4 connected to AP2

## SDL PROTOCOL DESCRIPTION

It is widely accepted that critical and complex systems have to be analyzed formally before their implementations in order to verify their dynamic behaviour and to check component reaction when running under specific consideration. SDL (Specification and Description Language, 1999), standardized by the ITU (International Telecommunication Union) in the Z.100 Recommendation (ITU-T, 1999), is becoming one of the most used approach for the few formal description and validation of communication protocols for distributed systems.

The SDL pattern is an efficient design approach. It is a reusable software artefact that represents a generic solution for recurring design problem with SDL as a design language. One reason of its success is certainly the graphical notation that supports the intuitive understanding of specifications. It enables a formal description system by defining a static modular architecture and interactions between different blocks (Gotzhein et Schaible, 1999). Systems in SDL language are structured into interconnected entities (system, block, process and channel) where process system description provides dynamic behaviour for internal task execution. It is based on the model of Extended Finite State Machines (EFSMs) (Probert *et al*., 2001). In its dynamic behaviour, each state is reached after asynchronous signal exchange between blocks. Figure 7 resumes the development environment using the SDL pattern. It shows different stages in the description and the formal validation of system using both SDL pattern and MSC simulator.

This schema has been adopted for the study of load balancing approach. We have used the ObjectGeode tool based on SDL and MSC. We have described with SDL the hotspots architecture as being represented in Fig. 8.

The model is composed of Three AP connected to Load_balancing_server. The mobile block represents a Mobile Mi asking for communication process after the reception of an application protocol data unit (APP_PDU). The request connexion can be sent to any available APi providing the best SNR. The APi_Manager process will then check that the connection can be accepted or the load balancing server should be involved to find a new mobile redistribution among available APs. The behaviour of each component in the system has been described as a set of EFSM. We have described all new exchange primitives and services required to manage different interactions between system components (AP, Mobile and Load Balancing Server). The new defined primitives are a set of added communication packets to the standard IEEE 802.11 to provide new interaction mechanisms for QoS enhancement with a suitable mobile distribution.

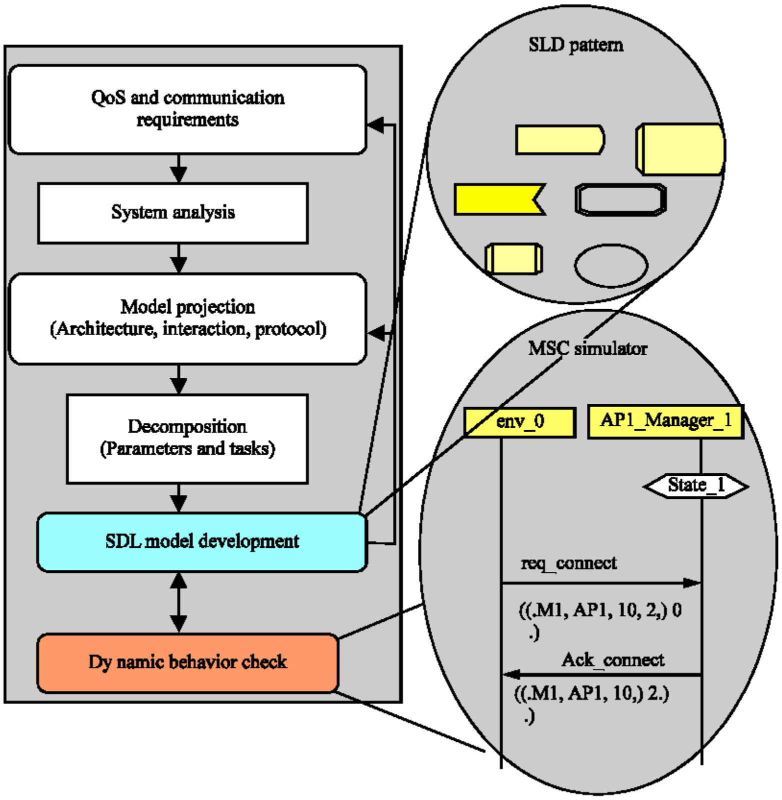


Fig. 7: SDL pattern design process

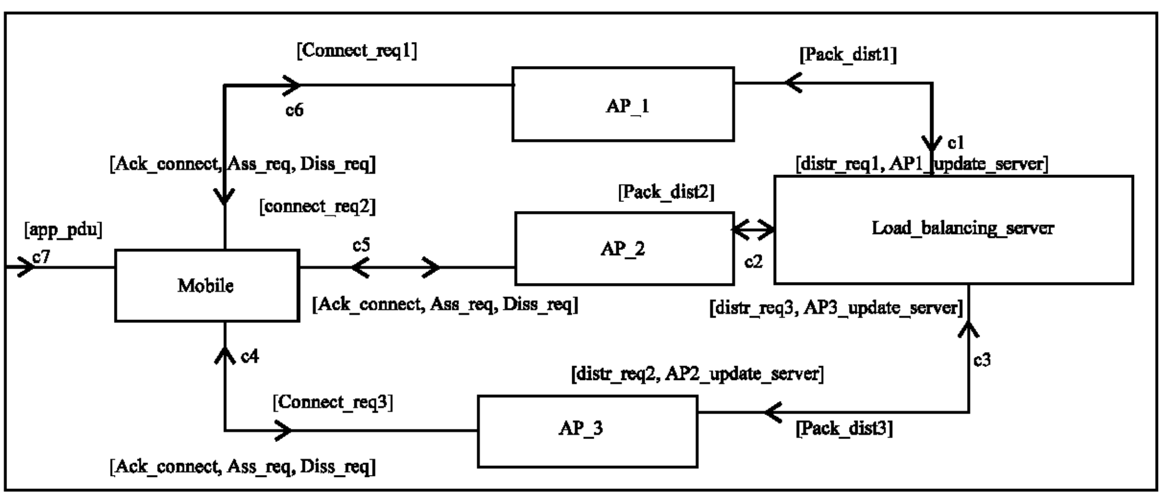


Fig. 8: System hotspot

## MSC VERIFICATION AND SIMULATION

The simulation of this model with the MSC (Message Sequence Chart) has been carried out to check under different scenarios the interaction responses between different blocks of the system. This step is a formal validation of the proposed protocol that has been done for different possibilities of system configuration. The ObjectGeode tool offers different kind of system verification. It allows through a provided graphical interface the possibility to generate adequate inputs to the system in order to check its reaction. We present in this study only two simulation- scenarios to sum up the main protocol actions. Figure 9 shows a scenario when a

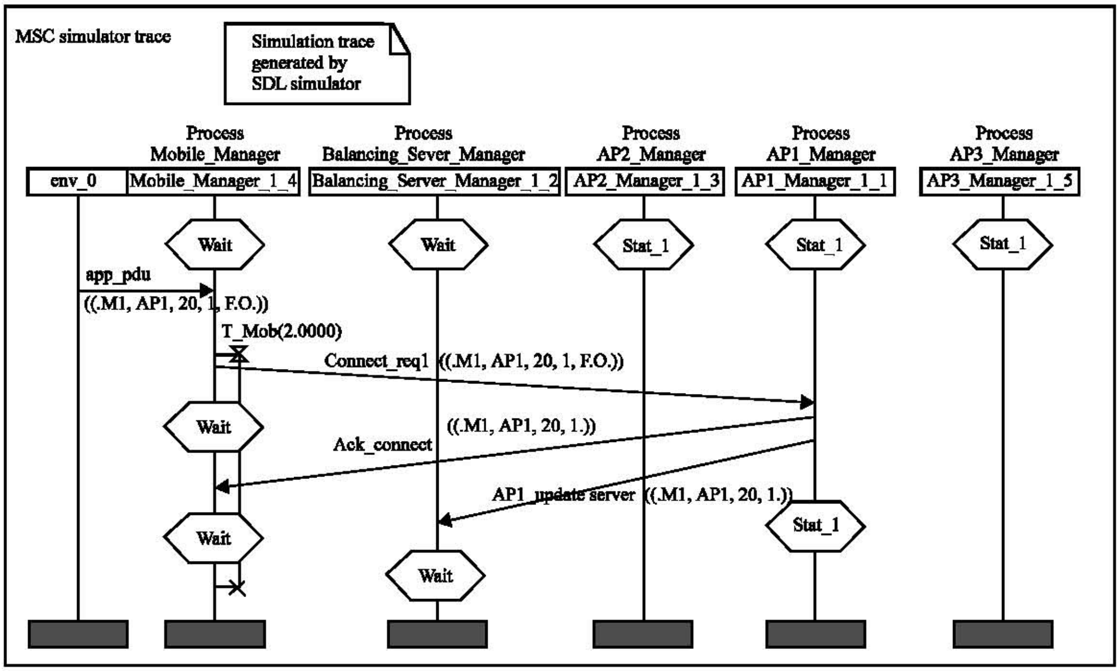


Fig. 9: MSC simulation of a first example of exchange between wireless entities

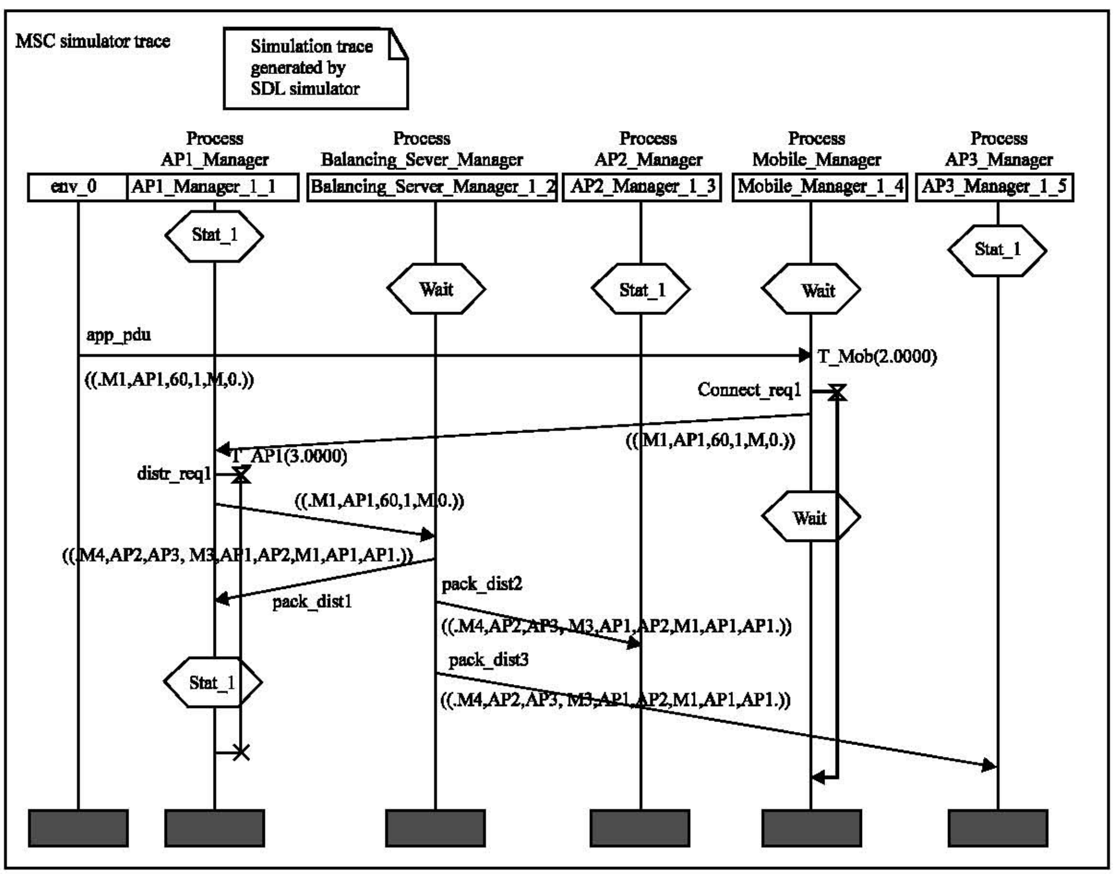


Fig. 10: MSC simulation of a second example of exchange between wireless entities

mobile requests a connection establishment to AP1 with the connect_req1(Conn_PDU_Parameters). In this case the AP1_Manager is able to provide the communication process requirements (bandwidth, loss, mobility_state) initiated at the mobile. Then, a positive connection acknowledgment will be returned to the mobile with a confirmation of the Conn_PDU_Parameters. The Access Point accepting the connection informs the load_balancing_server to update its data base concerning mobile distribution among different APs.

In a second simulation scenario, showed in Fig. 10, the Access point is not capable to provide directly mobile application requirements because of unavailable bandwidth as required at the application process level. In this case, AP1 sends a distr_req1 to the load_balancing_server with some information related to the new mobile request. The server runs up the load balancing algorithm being previously presented to find the fair mobile distribution among different APs. The provided solution will be then broadcast to Access Points in order to run up IEEE 802.11 associations and dissociations according to the received pack_dist() message. In this simulation scenario the symbols (state_1, wait) represent the name of the state of the EFSM describing the component function at this level of simulation.

The SDL model described in our approach has been tested with MSC Simulator under different scenario considerations, mainly for border-line configurations to bring out the behaviour of this system. Then, we have verified that it is error free working model and that it can be tested with either a simulator such as OPNET or in a real IEEE 802.11 network.

## OPNET SIMULATION

In order to study the performance of the load distribution approach we propose to simulate a wireless LAN architecture described using OPNET Modeler 11.5. The simulation topology contains 3 fixed AP, an Ethernet Switch, an application server and 14 mobile stations. The standard OPNET WLAN model is based on the IEEE 802.11 WLAN MAC and Physical Layer (PHY) specifications (IEEE 802.11, 2001) and the extension to higher-speed PHY to 11 Mbps in the 2.4 GHz band (IEEE 802.11, 2003).

We use an OPNET standard node model for IEEE 802.11 wireless station called wlan_station_adv. This model includes the MAC, PHY (comprised of transmitter and receiver), WLAN MAC interface, source and sink. The higher layers (such as TCP/IP protocols and applications) are replaced by a source and a sink process. The MAC interface wlan_mac_intf is an equivalent of Address Resolution Protocol (ARP). In this way, the load balancing approach can be evaluated by considering only the attributes of the WLAN MAC layer.

The wireless topology has been simulated with and without using the load balancing approach (Fig. 11). Simulations last 180 sec of simulated time. In the first simulation, M6_Video is still associated to AP2. The wireless LAN is then unbalanced. We run the load balancing algorithm to get a balanced load between access points. M6_Video is now associated to AP1. In the second simulation, we simulate the wireless LAN with balanced access points loads.

In first time, we try to monitor the global performances of the wireless LAN. Figure 12 plots the total size of higher layer data packets (in kbits/sec) dropped by all the WLAN MACs in the network due to full higher layer data buffer. The global data dropped when the wireless LAN is not balanced is 6 times higher than when the wireless LAN is balanced.

Figure 13 tells us that the global media access delay is better when the wireless LAN is balanced. Global media access delay represents the global statistic for the total of queue and contention delays of data packets received by all WLAN MACs in the network from higher layer. For each packet, the delay is recorded when the packet is sent to the physical layer for the first time.

Figure 14 represents the total number of bits (in kbits/sec) forwarded from wireless LAN layers to higher layers in all WLAN nodes of the network. We can observe that the load that has been routed by AP1, AP2 and AP3 to the destination server is greater when the wireless LAN is balanced.

We can conclude that using load balancing approach conduct to better global performances in the wireless LAN. With a load balanced wireless LAN, it is possible to associate a higher number of wireless stations and enhance the global QoS parameters at the same time.

In Figure 15 we present the media access delay of the New_station with and without load balancing. We can observe that, load balancing has reduced almost 7 times the media access delay for the new associated station. It's almost equal to 90 ms which seems acceptable for a video traffic.

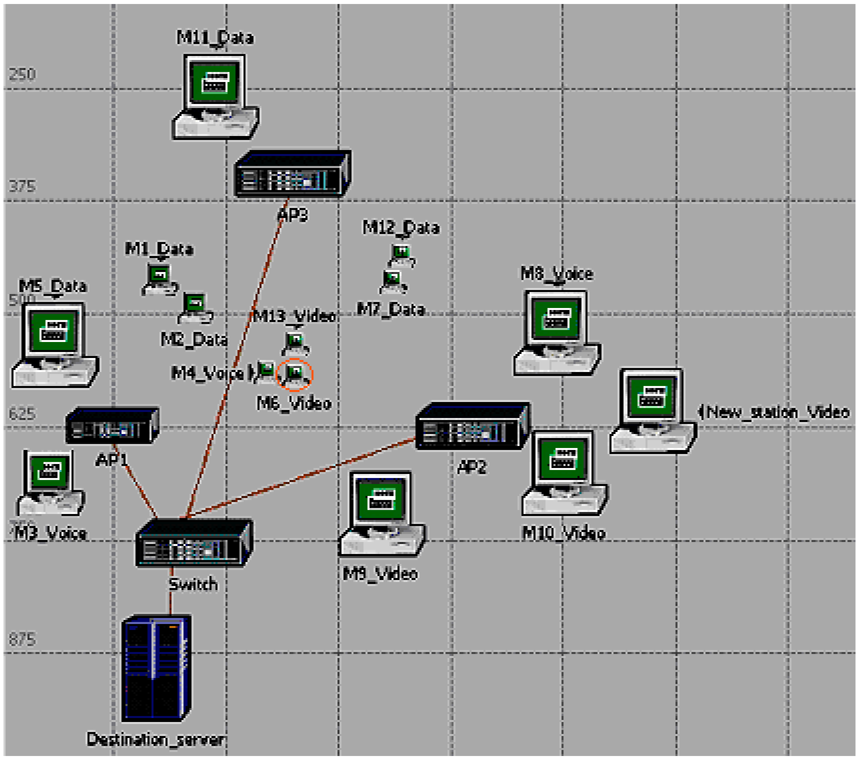


Fig. 11: The wireless LAN simulated topology

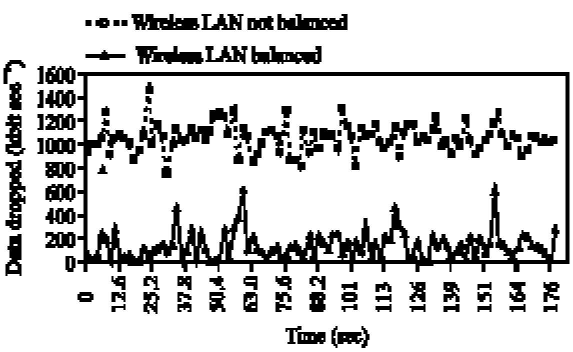


Fig. 12 : Global data dropped in the wireless LAN

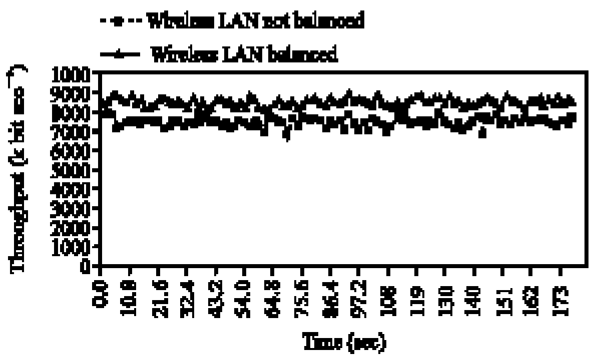


Fig. 14 : Global throughput in the wireless LAN

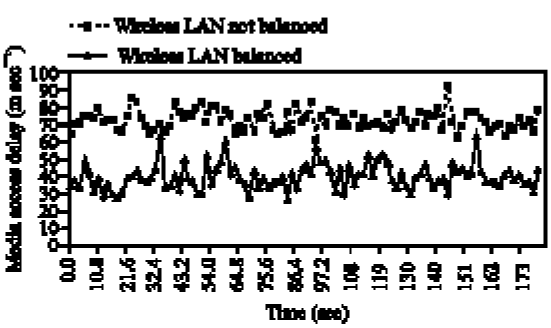


Fig. 13 : Global media access delay in the wireless LAN

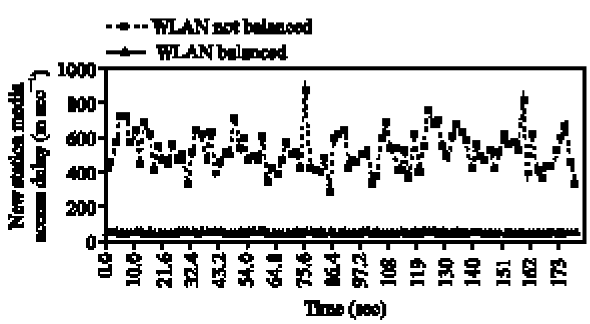


Fig. 15: New_Station media access delay

## CONCLUSION

This study is a contribution in the field of QoS management in IEEE 802.11 (2001, 2003) WLAN. It focuses on the problem of application requirements and Access Point (AP) bandwidth availability. Its main contribution is the presentation of a new network structure-organization to support communication with quality of service in hotspots environment. So, it presents the specification of a new protocol between mobile stations and access points to negotiate QoS requirements during the mobile station attachment. This protocol defines new primitives related to the QoS management that must operate with the IEEE 802.11 (2001, 2003).

This protocol is being formally validated and simulated with SDL pattern approach using SDL and MSC languages. To analyze the performances of this approach, we used the Opnet Tool to simulate this proposal architecture. Some results show the importance of this approach. Now, we are looking at the implementation of this protocol on IEEE 802.11 architecture.

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