Wireless Networks 10, 413–421, 2004

Adaptive QoS Management for IEEE 802.11 Future Wireless ISPs

HAKIMA CHAOUCHI *
Center for Telecommunications Research, King's College, and University of London, London WC2R 2LS, UK

ANELISE MUNARETTO
Laboratoire Informatique Paris VI – LIP6, University of Paris VI, 8, rue du Capitaine Scott, 75015 Paris, France

Abstract. Wireless Internet Service Providers (WISPs) are expected to be the new generation of access providers using the emerging IEEE 802.11 technology. Face to the high competition of providing network services, the WISP have to offer the best service to the users. For this purpose, the WISP networks' managers need to provide Quality of Service (QoS) with a minimum cost in their wireless networks. The current link layer IEEE 802.11b provides fair sharing of the radio resource with no service differentiation mechanism; similarly to the Internet best effort service. However, the ongoing standard IEEE 802.11e should implement a priority mechanism at the link layer to differentiate the users' traffic. In order to overcome the lack of differentiated mechanism in the current link layer IEEE 802.11b, hence controlling the utilization of the scarce radio resource, we propose in this article to deploy *Diffserv* architecture coupled with an adaptive provisioning of QoS to provide better services to the users with minimum WISP cost and improve the utilization of the radio resource. Compliant with the current and future IEEE 802.11 link layer, the proposed adaptive QoS provisioning mechanism reacts to the radio resource fluctuation and improves the number of accepted clients in the IEEE 802.11 wireless cells based on the WISP business policies. The network layer differentiation provided by the *Diffserv* architecture intends to control the concurrent access of the traffic to the scarce radio resources at the IP layer of the mobile hosts for the uplink traffic on one hand, and at the IP layer of the base stations for the downlink traffic on the other hand.

Keywords: wireless network, IEEE 802.11, QoS framework, policy-based management, ISP business model, traffic differentiation

1. Introduction

Wireless ISPs are deploying IEEE 802.11 wireless networks in strategic places hotspots such as airports, public transport stations, public gardens, and hotels. The IETF defines IntServ, Diffserv and MPLS frameworks to support the QoS in the current Internet [2]. These frameworks are designed for wired networks. However, supporting the QoS in the ongoing IEEE 802.11 wireless access networks is still a challenging issue. In fact wireless networks face new problems compared to the wired networks such as the error prone of the radio resource, signal interference, location and mobility of users, and the fair sharing method of the radio resource provided by the current CSMA/CA access mechanism.

In our approach, we propose to use a Diffserv architecture extended to the mobile hosts. We also, design a policy-based architecture [10] to support the adaptive management of the QoS service in the wireless network. The adaptive provisioning of QoS intends to react to the fluctuant radio resource in order to provide a best service to the users with a minimum cost to the WISP, and minimizing the rejection of the new coming clients in the wireless. The framework uses Diffserv mobile hosts and base stations composed by the Diffserv edge and core router functionalities.

In the Diffserv mobile hosts, packets are classified according to the user contract and scheduled in the class of service queues. There, they wait for a corresponding queuing time before gaining access to the radio resource. This waiting time at the IP Layer provides control on the packets going in the link layer, hence control the concurrent access packets to the radio resource providing differentiated treatment to packets. For instance, the packets in the class with the highest priority have a faster access to the link layer and will have prior access to the medium than the lower priority packets.

We are interested in the elastic applications, such as video streaming, because they can support an adaptive provisioning of QoS. Such elastic applications can be supported by the assured forwarding (AF) service of the Diffserv architecture. The Diffserv expedited forwarding (EF) class has more QoS constraints; it is used for the applications such as VOIP (Voice over IP) with strict QoS constraints (delay, jitter, and throughput). The Best effort (BE) class is used for the applications with no strict constraints such as web application.

We propose in addition to the classical EF, AF and BE classes of service, to use different levels of QoS of the assured forwarding (AF) service class. The WISP will offer an adaptive service by downgrading and upgrading the QoS of the client according to the users' contracts, the QoS requirements of the client applications, the current state of the wireless radio resource, and the WISP policy. The downgrading or upgrading of QoS is triggered by different events. Some triggering events are the mobility of the users such as the arrival of a new mobile host in the cell requesting the radio resource, or the user perception of the QoS. For instance, the user may request to change his QoS due to the price or the current class of service or due to the unacceptable perceived QoS. The WISP

* Corresponding author.
E-mail: hakima.chaouchi@lip6.fr

policies are also triggering events of the adaptive QoS mechanism. For example, the WISP may set a policy to release the allocated resources when the mobile host is inactive during a certain period specified by the WISP. These released resources will be used by the adaptive QoS mechanism to accept new clients or to upgrade the previously downgraded clients QoS.

This article is structured as follows. First, we present background on IEEE 802.11. After, we describe the IEEE 802.11 wireless QoS related work. Then, we present the QoS architecture and the adaptive QoS provisioning management system. After, we describe the application of the proposed framework to some WISPs business model scenarios. Furthermore, to evaluate our work, we present our implementation and test bed platform followed by discussions about the proposed approach. Finally, we conclude this work.

2. Background

The current standard IEEE 802.11 [7] has two different access methods, the mandatory Distributed Coordinator Function (DCF) and the optional Point Coordinator Function (PCF).

The MAC architecture can be described as shown in figure 1 as providing the PCF through the services of the DCF.

The basic medium access protocol is a DCF that allows for automatic medium sharing between compatible physicals using CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) with the backoff algorithm. For a station to transmit, it shall sense the medium to determine if another station is transmitting. If the medium is not determined to be busy, the transmission may proceed. The CSMA/CA distributed algorithm mandates that a gap of a minimum specified duration exist between contiguous frame sequences. A transmitting station shall ensure that the medium is idle for this required duration before attempting to transmit. If the medium is determined to be busy, the station shall defer until the end of the current transmission. After deferral, or prior to attempting to transmit again immediately after a successful transmission, the station shall select a random backoff interval and shall decrement the backoff interval counter while the medium is idle.

A refinement of the method may be used under various circumstances to further minimize collisions. It is given by

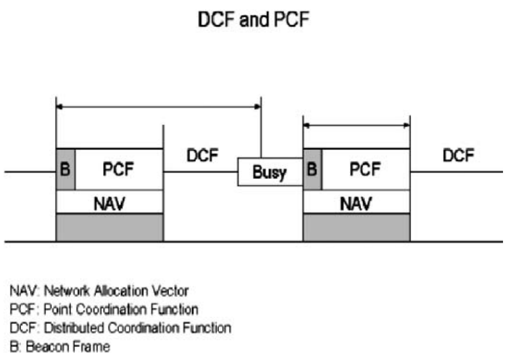

Figure 1. DCF and PCF access methods.

the transmitting and receiving station exchange short control frames (request to send (RTS) and clear to send (CTS) frames) after determining that the medium is idle and after any deferrals or backoffs, prior to data transmission.

The IEEE 802.11 MAC may also incorporate an optional access method called a PCF, which is only usable in infrastructure network configurations. This access method uses a point coordinator (PC), which shall operate at the access point of the cell, to determine which station currently has the right to transmit. The operation is essentially based on polling, with the access point PC performing the role of the polling master. The operation of the PCF may require additional coordination, not specified in the standard [7], to permit efficient operation in cases where multiple point-coordinated cells are operating on the same channel, in overlapping physical space.

The PCF uses a virtual carrier-sense mechanism aided by an access priority mechanism. The PCF shall distribute information within Beacon management frames to gain control of the medium by setting the network allocation vector (NAV) in stations. In addition, all frame transmissions under the PCF may use an interframe space (IFS) that is smaller than the IFS for frames transmitted via the DCF. The use of smaller IFS implies that point-coordinated traffic shall have priority access to the medium over stations in overlapping cells operating under the DCF access method. The access priority provided by a PCF may be utilized to create a contention-free (CF) access method. The PC controls the frame transmissions of the stations so as to eliminate contention for a limited period of time. Thereby, the PCF aims at supporting real-time traffic, which is not yet implemented in the products.

3. IEEE 82.11 QoS

In [1,9], the authors present interesting surveys on the IEEE 802.11 related QoS research. The authors introduce QoS in the IEEE 802.11b by changing low layer related parameters such as the *contention window* in the *backoff* algorithm and the *interframe spaces*. These changes bring access priority in the CSMA/CA access mechanism and hence provide a differentiated service to the traffic.

The first standard introducing a QoS within IEEE 802.11 networks is called IEEE 802.11e [8]. This standard is based on a new access mechanism called Enhanced DCF (EDCF). EDCF combines two measures to provide differentiation. The minimum *contention window* determined for different classes of priority, and different traffic classes can use different values of the *interframe space*.

A recent work [5] introduces a high-level differentiation of the traffic in IEEE 802.11 by implementing a *Diffserv* mechanism in the mobile terminals in the wireless network. They consider the standard Diffserv service classes; Expedited Forwarding (EF), Assured Forwarding (AF) and Best Effort (BE) and they propose an extension of the ICMP protocol to support the QoS signaling mechanism.

As we have mentioned in our paper, the access method (CSMA/CA) of 802.11 is designed to provide mobile hosts with a fair share of the radio channel capacity. If we want to provide different performance behavior to traffic sources at mobile hosts, we need to constrain them in a configurable way so that sources of low priority benefit from different resource allocations than high priority ones. For example, we can use traffic shapers to constrain sources at mobile hosts and keep in this way the aggregated traffic lower than the available link capacity. Also, the authors in [5] show that to provide quality of service over the 802.11 link, traffic sources should be constrained by configuring traffic shapers in hosts to obtain desired QoS effects.

All these research works lack a management layer in the wireless network to react dynamically to the continuous fluctuation of the radio resource.

In our work, we propose a management system to provide an adaptive provisioning of the QoS by monitoring, and reacting to the evolving state of the wireless network resources using the mobile hosts requested QoS information along with the available resource and the WISP specific policies.

4. Adaptive QoS provisioning management framework

4.1. System architecture

We consider the network architecture illustrated in figure 2. It is composed by a set of WISP IEEE 802.11 cells connected to a core network via an access network. Diffserv architecture is used to provision QoS in the wireless network. We suppose that there is a mobility support, and we focus on the provisioning of QoS in a wireless network cell.

The base stations are Diffserv based nodes. They integrate the Diffserv edge and core router functionalities to provide the differentiated treatment to the mobile hosts downlink traffic arriving in the wireless cell. The SMM (Server Management Module) or policy server located in the base station of the wireless cell performs resource allocation.

Mobile hosts are also Diffserv based nodes, they integrate the edge and the core Diffserv router functionalities to achieve the differentiated treatment for the uplink traffic going to the wireless cell. CMM (Client Management Module) is the client module that interacts with the policy server to achieve the adaptive QoS provisioning management of QoS in the wireless cell. There is no dynamic reservation signaling mechanism; the policy server provides the provisioning of QoS based on the state of the wireless network resources.

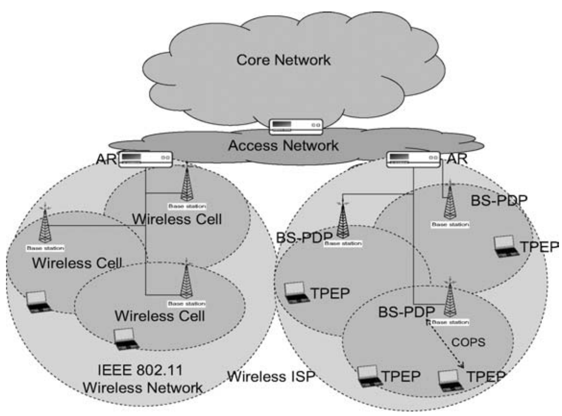

Figure 2. System architecture.

Figure 3 illustrates the mobile hosts, and the base stations main functionalities.

Note that, we made some assumption related to the design of the wireless IEEE 802.11 cells. In fact, wireless IEEE 802.11 networks have special characteristics compared to the wired networks. These characteristics are very important to be considered in the design of any QoS framework.

One important characteristic of the current IEEE 802.11b is the throughput variation with the number of active users supported by the base station. In fact, as the CSMA/CA access method provides an equal channel probability for all active hosts, the throughput will decrease as the number of active hosts' increases. One possible solution to be considered in any QoS framework design is to limit the number of hosts using the channel.

Another important characteristic is the throughput variation which is related both to the distance of the mobile users from the base station and to the signal interference and fading [6]. In fact, IEEE 802.11 network is designed to lower the bit rate when the repeated frame drops are detected, that often happens when the mobile host moves far from the base station. However, since the CSMA/CA access method provides the same probability to access the medium, the hosts that are transmitting at a lower rate will strongly influence the throughput of the hosts that are transmitting at a higher rate. One possible solution is to limit the size of the cell so that all hosts would perceive a good signal and would be sending at the same bit rate.

Based on these characteristics, and in order to provide QoS in a wireless network, we assume that the size of the cell and the maximum number of supported users in the cell are limited. Again, due to the fair sharing access of the CSMA/CA, we need a mechanism at the higher layer such as the network layer to provide the differentiation mechanism of the traffic above the current IEEE 802.11b or any other IEEE 802.11 link layer.

4.2. Adaptive QoS description

As defined in the Diffserv model, the EF service class is designed for traffic that requires strict delay bounds as well as assured bandwidth. An instinctive description of the EF PHB is that network elements must be able to service the packets of EF flows at a higher rate than they arrive. Further, traffic of other classes must not affect the EF traffic. Thus, it provides a virtual leased line service. EF is the most strictly provisioned service class and is as a result, the most costly. Scheduling

Transport Layer: Management module
IP Layer: Classifier, marker, meter, shaper, scheduler
Link Layer: 802.11b
Physical Layer: Radio

Figure 3. Mobile hosts and Base Stations network layers.

Table 1
Example of WISP QoS levels of the Diffserv Assured Service class.

AF QoS level	Packet loss probability	Bandwidth
High (AF1)	l_1	b_1
Medium (AF2)	l_2	b_2
Low (AF3)	l_3	b_3

mechanisms such as Priority Queuing are recommended for this PHB.

The AF behavior group was designed to be a less costly alternative to EF. It is intended for traffic that requires guaranteed bandwidth with less strict delay bounds than EF. AF comprises four classes of service, each containing three-drop precedence. Active scheduling mechanisms such as RED (Random Early Detection) or RIO (RED with In/Out of Profile) have been proposed to implement the AF class of service in the network core. RED and its variants are attractive because they eliminate the need for core network elements to store per-flow state. This improves the scalability of the solution.

In our framework, we propose that each WISP based on his business model specifies the standard EF, AF, and BE classes, also, in order to support the elastic applications and to adapt there QoS level according to the changing state of the wireless network, the WISP specifies different levels of QoS to the Diffserv assured service (AF).

Table 1 illustrates an example of three possible QoS levels of the assured service class, the corresponding packet loss probabilities (l_1, l_2, l_3), and the allocated bandwidth (b_1, b_2, b_3). The packet loss and allocated bandwidth parameter are specified based on the user perception of the quality of the service.

4.3. Policy based management of the adaptive QoS provisioning

4.3.1. WISP management levels

The management system architecture and the functions performed by each layer, is illustrated on figure 4. We suppose that the WISP provides three kinds of services with different QoS: Premium, Gold and Bronze services.

The management abstraction levels illustrated on figure 4, are used by the WISP to translate business high-level QoS requirements decisions to low level in the network.

Starting from the business level, the WISP defines policies to provide a best service to users. These policies will adjust the lower level policies to enforce a best SLA (Service Level Agreement).

At the service level, the goal is to ensure the negotiated QoS parameters defined in the customer contract (SLA) and maximize the service availability by reducing connection refusals. At this level, the WISP defines traffic mapping policies to control the mapping of the user applications in the Diffserv PHBs. According to the availability of the radio resource, this mapping can be changed by applying the mapping policy which downgrade or upgrade the class of service of the traffic in the cell. In addition to the mapping policies in the

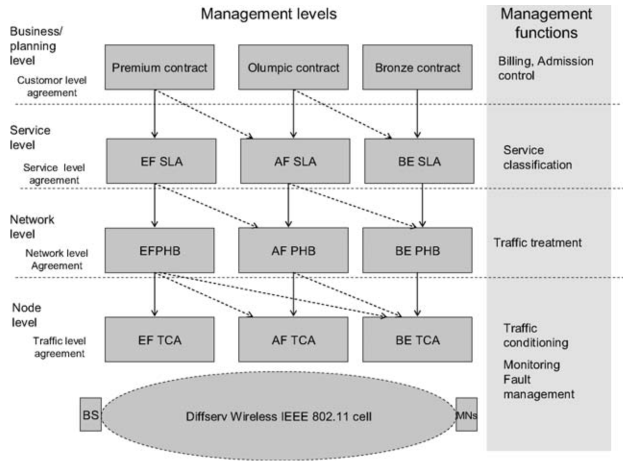

Figure 4. WISP management architecture.

service level, there is also monitoring policies that may adjust the lower level policies to ensure that, they actually provide the negotiated contract by the user.

At the network level, the goal is to maintain connectivity in the network respecting the constraints of each class of service. At this level, the WISP defines policies for the bandwidth management and the admission control.

At the node level, the WISP defines policies to dynamically adjust the relative priorities of each class of service, and maintain the best QoS for the EF class, followed by the AF class and managing the out of profile of the AF traffic, and finally the worst QoS for the best effort class.

4.3.2. Policy server admission control

One of the important parameters to be maintained in the cell is to limit the number of accepted clients in the cell. The policy server on the base station performs an admission control to the wireless cell by using the WISP defines admission control policies. When a mobile host arrives in the wireless cell, or when the active mobile host needs to start a new service in the wireless cell, the policy server is involved to accept or reject the incoming request based on the requested resources, the available resources in the wireless cell, and the WISP policies.

In order to control the allocation of the resource in the wireless cell, some parameters need to be determined. First, the WISP specifies the proportion of the allocated bandwidth for each class of service in the Diffserv architecture. Then, the policy server dynamically configures all the mobile hosts in the cell limiting there traffic to the calculated proportions, and hence providing an adaptive QoS provisioning.

The WISP needs to specify the acceptable probability of new calls blocking in the wireless cell, in order to define the maximum number of active sessions in the cell. The number of active hosts in the wireless cell is defined based on the base station capacity, the WISP policy and prices. Note that for 802.11b networks operating at 11 Mbps, the total throughput capacity of an access point is about 6 Mbps, due to protocol overhead and access delays. As a result, since the CSMA/CA access mechanism provides fair sharing of the radio resource, then the access point in case of users with web application at 100 kbps would support approximately 60 users (6 Mbps/100Kbps) actively surfing the web. If all users were viewing high quality streaming video at 2 Mbps, then the access point would only effectively handle about three users (6 Mbps/2 Mbps).

Let us work out the proportions p_{EF}, p_{AF}, p_{BE} of the bandwidth to be allocated for each class EF, AF, and BE, respectively.

The useful bandwidth C in the cell changes according to the number of active sessions. Let say $C(n)$ the useful bandwidth when n sessions are active in the cell. $C(n) = C/n$ for $n \neq 0$. When $n = 0$, then the useful bandwidth $C(n)$ is equal to the useful bandwidth C of the cell.

In order to provide quality of service over the 802.11 link, traffic sources should be constrained by configuring traffic shapers in hosts to obtain desired QoS effects. By implementing Diffserv traffic shapers in hosts, we can limit the bandwidth of the output traffic shaper of each class.

Therefore the useful bandwidth for each class of Diffserv in the cell will be $C(n_{\mathrm{class}})$, when n_{class} hosts are active in the cell of each class of service. The bit rate of the active sources for each class of service is represented by b_{EF}, b_{AF}, b_{BE}. The Policy server has to maintain in the wireless cell these values:

$$b_{\mathrm{EF}} \leqslant p_{\mathrm{EF}} \cdot C(n_{\mathrm{EF}}),$$
$$b_{\mathrm{AF}} \leqslant p_{\mathrm{AF}} \cdot C(n_{\mathrm{AF}}),$$
$$b_{\mathrm{BE}} \leqslant p_{\mathrm{BE}} \cdot C(n_{\mathrm{BE}}).$$

In addition, if the WISP policy set up an over provisioning strategy, then the policy server should maintain the sum of all the proportions $p_{\mathrm{EF}} + p_{\mathrm{AF}} + p_{\mathrm{BE}} < 1$, elsewhere

$$p_{\mathrm{EF}} + p_{\mathrm{AF}} + p_{\mathrm{BE}} = 1.$$

In order to maintain these proportions in the wireless cell, the policy server uses policy mappings to constrain the classification of the application traffic in the Diffserv classes, and an admission control policies to constrain the number of active client in each class of service. This will allow the WISP to set up policies whether to accept more clients of the highest class of service with high prices, or accept much more clients of lower classes of services with low prices.

4.3.3. Adaptive QoS provisioning

Policy-based management has been adopted by the IETF mainly to provide automation in the network configuration process by providing an automatic translation of high level business policies to a network configuration and their enforcement in the network [10]. The management architecture introduces new elements in the network. A policy server (PDP: Policy Decision Point) that is located in the network to monitor and configure the network elements, policy clients (PEP: Policy Enforcement Point) that are located in the network elements to enforce the policies sent by the PDP and a policy repository where the policies are stored. A policy transport protocol COPS (Common Open Policy Service) has been introduced to support the interaction between the PDP and the PEPs [4].

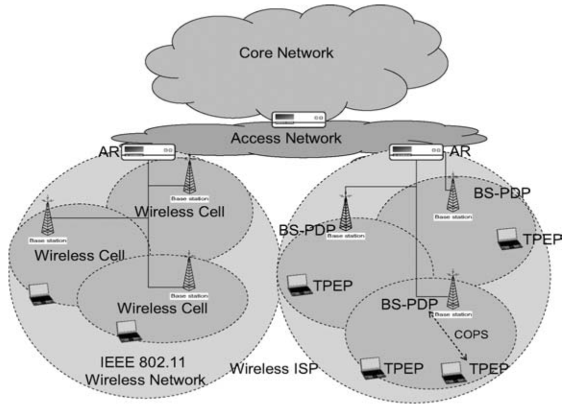

Figure 5. PBM architecture in the wireless network.

We propose to use a policy based management framework in the wireless network, because the provisioning of the adaptive QoS needs an automatic and dynamic management process. Figure 5 illustrates the proposed framework showing the management entities added in the considered system architecture.

Terminal Policy Enforcement Points (TPEP) are the management clients supported by the mobile hosts. They interact with the policy server to dynamically configure the Diffserv module of the mobile hosts and report the state of the network resource.

BS-PDP (Base Station Policy Decision Point) is the policy server responsible of the adaptive provisioning of the QoS in the wireless cell. It is located on the base station. It uses the WISP policies to perform the admission control to the wireless cell and configure the mobile hosts according to the specified Diffserv parameters.

To achieve the proposed adaptive framework, the Terminal Policy Enforcement Points (TPEP) interacts with the BS-PDP. We propose to use COPS (Common Open Policy Service) protocol, which is introduced by the IETF to transport the network policies. COPS is a generic protocol, it transports the network configuration resulted from the WISP policies. The WISP policies can change without changing the protocol structure. COPS provides a mechanism to allow the PDP and the PEPs to maintain an active state of the connections. That is interesting to react automatically to the fluctuation of the radio resource in the wireless network by sending new configuration to the mobile hosts.

When the mobile terminal arrives in the cell, the TPEP tries to establish a connection with the BS-PDP in order to be authenticated and requests resources in the wireless cell. If the mobile host is authorized to use the resources of the wireless cell, the BS-PDP decides, taking into account the available radio resource, whether to accept or reject the new user and allocating him the requested resources.

4.3.4. WISP scenario

Let consider different WISP policies at the business plan and analyze the different network behavior results in the wireless

Table 2
WISP mapping policies example.

Application	Policy1	Policy2	Policy3
Video	No restriction	EF → AF1	AF2 → BE
VOIP	No restriction	EF	AF1
Web	No restriction	AF1	AF2 → BE
Telnet	No restriction	AF2	BE
FTP	No restriction	AF1 → AF2	BE

cell with and without our proposed adaptive QoS provisioning.

Here is an example of the application mapping policies defined at the service level. Note that in the example we consider two quality levels of the AF class of service; AF1 and AF2. The mapping policies are used to downgrade the traffic classes in case of congestion in the cell, or upgrade the traffic classes to their authorized class of service in case of available radio resource.

Policy1 in table 2 provides no restriction on the traffic. It is the policy applied before reaching the maximum clients authorized by the WISP in each class. Policy2 and Policy3 provide the adaptive mechanism by downgrading the application traffic classes from the higher class to the lower class when decided by the policy server. The WISP decides, which classes of service to be allocated for each user application, and which are the classes of service to be downgraded in case of wireless cell congestion. These decisions depend on the WISP business model and the WISP acceptable satisfaction degree of the perceived QoS by the users. For instance, the WISP may decide based on his service prices to never downgrade the quality of the EF class applications, or simply downgrade all the high quality class applications even the EF class. The mapping policies given in the table would never downgrade the VOIP application from the EF class of service. However, the video application is downgraded by the Policy3 from the EF class to the AF1 class.

In addition to the mapping policies, we consider some examples of WISP admission control policies applied by the policy server:

1. The policy server accepts new users until the maximum number in the cell is reached.
2. The policy server accepts new users in each class until the maximum number of each class is reached.
3. The policy server accepts new users until the maximum number in the cell is reached. Then downgrade only the new AF clients in the cell by applying mapping policies 2 and 3.
4. The policy server accepts new users until the maximum number in the cell is reached. Then downgrade all the AF clients in the cell by applying mapping policies 2 and 3.

5. Approach discussion

In this section, we discuss two important points. The first one is related to the deployment of the Diffserv architecture in the wireless IEEE 802.11 networks with an adaptive management of different QoS levels. The second one is related to the forces and weaknesses of the proposed policy based management in the wireless environment.

On the first hand, due to the radio resource scarcity, controlling the traffic sent in the wireless network at the mobile host IP layer, Diffserv is an interesting approach to improve the utilization of the radio resource with the current or the future access method of IEEE 802.11 standard. In fact, the current access method in the IEEE 802.11b link layer provides a fair-shared access to the radio resource. Controlling the traffic at the IP layer of the mobile hosts will minimize the number of the mobile hosts' packets attempting to access the radio resource at the link layer, hence providing a differentiated treatment for the IP packets. In addition to the better utilization of the radio resource provided by the deployment of Diffserv architecture in the wireless network, when the wireless network is connected to a Diffserv core network, then an end-to-end QoS is provided without QoS mapping from the Diffserv core network to the Diffserv wireless access network. However, Diffserv model provides only a statistical guarantee of QoS because there is no resources reservation in the network. In [5], the authors consider the deployment of the Diffserv architecture in the wireless network with the standard Diffserv classes of service BE, AF, and EF. They test the effect of the BE traffic on the AF traffic in a wireless network with and without Diffserv architecture and they conclude that the BE traffic will less perturb the AF traffic in the Diffserv architecture.

Using different levels of QoS of the assured service (AF) class combined with an adaptive QoS management as proposed in our work, would improve the utilization of the radio resource. This, by providing a smooth adaptation of the mobile hosts' services to the wireless radio resource fluctuation, thanks to the WISP policies. In fact, leveling down the QoS level of the active hosts allows the wireless cell to support new incoming or handoff mobile hosts in the wireless cell.

On the other hand, we propose a policy based management (PBM) to achieve the QoS adaptation. PBM brings dynamicity and automation in the network management. In our framework, it allows the WISP business model policies control the evolution of the wireless network resources provisioning. In [5], the authors propose a signaling mechanism to achieve the configuration of the Diffserv architecture in the wireless network. It is an extension of the ICMP protocol. They introduce QoS request and configuration commands in ICMP. This approach is interesting to modify the Diffserv parameters in the mobile hosts. However, it does not support the configuration triggering event other than the starting or the end of a mobile host session such as the WISP policies.

In our framework, we can introduce all the WISP policies that can automatically trigger the reallocation of the radio resource. For instance, the policy server may be configured to change the allocation of the radio resource according to a scheduling time policy or a user' related constraints such as service classes' price.

One important issue of our architecture is the deployment of the policy client management module in the mobile hosts. In fact, since the terminal is the best place to represent the users' requirements it is interesting to have the PEP in the terminal. Such a concept makes the terminal more aware about the network resources availability. In addition, it is interesting to exploit the computing resources of the terminal to achieve some processing mechanisms on behalf of the network nodes. However, such a terminal architecture needs a highly secure mechanism to block the terminal user attempts to change the configuration of this environment, hence violate the service contract. The resource configuration in the terminal is supposed to be done only by the WISP. One possible solution investigated in [3] is to secure the terminal PEP environment using a Smart card technology. Therefore, the wireless ISP would provide a smartcard PEP to his subscribed users, in order to ensure the non-violation of service contracts.

Finally, using COPS protocol to achieve the interaction between the mobile hosts and the base station enforces the dynamicity and the automation of the management. In fact, COPS framework has the ability to transport the translated high-level policies to network levels policies and achieve the automatic configuration of the network. It also allows the policy enforcement points to report the state of the network making the policy server react to the evolving state of the network by automatically reconfiguring the network elements. The current uniqueness of such automatic and dynamic, and high-level policy-aware management framework makes it very suitable to provide the adaptive provisioning of QoS in the wireless network. In addition, it is interesting and easy to integrate the accounting and billing system with COPS framework. However, since it is TCP-based, we need more investigation regarding the performance of the protocol deployment in the wireless environment.

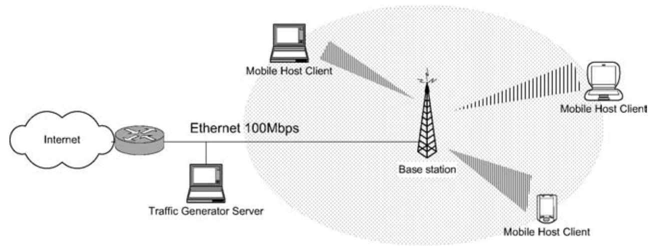

Figure 6. Implementation schema.

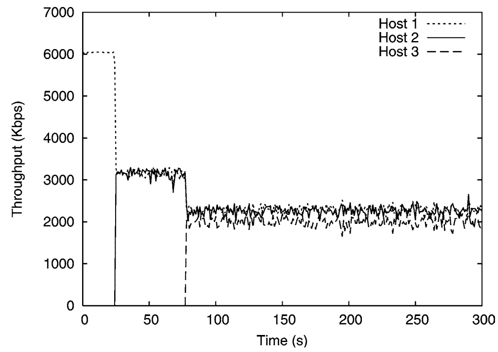

Figure 7. CSMA/CA based hosts results.

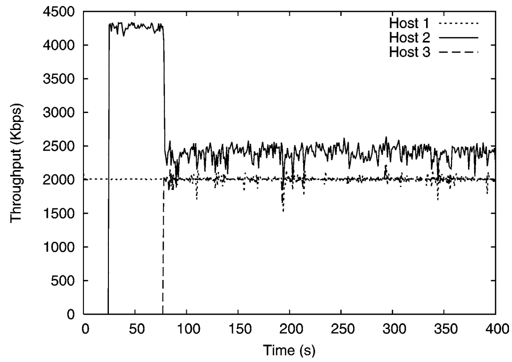

Figure 8. Diffserv over CSMA/CA based hosts.

6. Performance measurements

We have implemented three different scenarios over a wireless cell as shown on figure 6. The first one is a fair sharing CSMA/CA scheme. The second one is the Diffserv over CSMA/CA scheme, and the last one is the Diffserv over CSMA/CA scheme with the proposed adaptive QoS management mechanism.

We use Linux Red Hat 2.4 notebooks in the wireless cell and we consider two UDP BE sources and one UDP AF source sending packets of 1500 bytes.

In addition, to measure the performance of our approach and to compare with the implemented Diffserv mechanism, we consider the following class proportions used in the scenario 2 and 3:

- 35% of the useful bandwidth for the BE traffic.
- 65% allocated for the AF traffic.

6.1. Scenario 1: CSMA/CA based hosts

As shown on figure 7, the effective bandwidth is shared among the active clients in the cell due to the CSMA/CA fair channel access method [6].

Following the CSMA/CA access method, the first client in the cell attain the useful bandwidth (6 Mbps) which is decreased to 3 Mbps when a second client arrives in the cell and to 2 Mbps with the arrival of the third client and so on.

6.2. Scenario 2: Diffserv over CSMA/CA based hosts

The second experiment tests the isolation of both classes by means of the Diffserv control mechanisms. The output traffic shaper limits the bandwidth of the BE class to the defined BE proportion (35%) that is 2 Mbps.

Figure 8 shows the bandwidth obtained by the first BE source.

A new AF client arrives in the cell after 25 seconds. We have limited the AF clients' traffic to the defined 65% AF

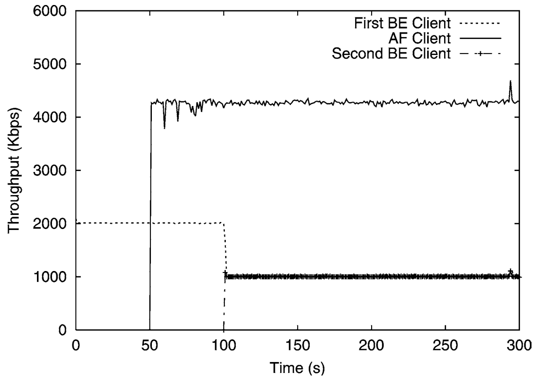

Figure 9. Diffserv over CSMA/CA based hosts with the adaptive mechanism.

proportion that is 4.5 Mbps. After 75 seconds, we see that the AF class is very disturbed due to the contention with the BE clients arriving in the cell and exceeds the BE overall useful bandwidth.

The specified proportions in our implementation limit the bandwidth of the BE class to 2 Mbps. When the second BE client arrives in the cell, and as all the BE clients use the limit defined by the output traffic shaper, therefore the remained bandwidth for the AF class is decreased to 2.5 Mbps due to the contention characteristic of the CSMA/CA.

These measurements show that for specified classes' proportions, it is possible to isolate different QoS classes if the number of clients in each class is correctly designed. This is fixed in our proposed adaptive management by the admission control policies.

6.3. Scenario 3: Diffserv over CSMA/CA based hosts with the adaptive management

Figure 9 shows the bandwidth obtained by the proposed adaptive mechanism. Note that in this scenario, we have implemented the PDP in the server connected to the base station via 100 Mbps Ethernet and the PEPs in the hosts.

The first BE client arrives in the cell. Its PEP interacts with the PDP asking to be accepted in the network.

The PDP based on the available resources in the cell and the available resources allocated for this class, can accept or reject the new BE client in the cell. If the BE client is accepted, the PDP sends a traffic shaper configuration to the terminal PEP. In this case, for the BE traffic, we have a specified proportion of 35% of the useful bandwidth, that corresponds to 2 Mbps. Also, as there is no other BE active client in the cell, then the allowed bandwidth is 2 Mbps.

After 50 seconds, another client arrives in the cell. It is an AF client. The same procedure will be enforced.

Applying the defined AF proportion, the AF clients use 65% of the useful bandwidth, in our implementation it is around 4.2 Mbps.

After 100 seconds, another BE client arrives in the cell. Again, the same interaction happens between the terminal PEP and the PDP.

Since there is already a BE active client in the cell, the PDP decides to adapt the bandwidth for BE clients in order to maintain the same BE proportion of the useful bandwidth (35%). The BE bandwidth is shared between the two BE clients, which is 1 Mbps for both. Therefore, the PDP requires for each BE client PEP to configure the traffic shapers to 1 Mbps.

The outstanding performance results illustrated in figure 9 shows that the AF class is not disturbed by the arriving BE clients. This is due to the proposed adaptive management which achieves the admission control for the acceptance of new clients in the cell and the dynamic configuration of the traffic shapers of the BE clients in the hosts.

7. Conclusions

Wireless ISPs are the emerging access networks, thanks to the IEEE 802.11 technology. Face to the high competition, WISPs need to offer best services to the users with a minimum cost. Since the wireless IEEE 802.11 network has a very fluctuant resource due to the error prone radio resource, the number of active users in the wireless cell, the location and the mobility of the users, the definition of a QoS framework is a challenging issue.

In this paper, we use Diffserv architecture in the wireless network; in addition, we introduce an adaptive QoS management to adjust the QoS according to the fluctuant radio resource. This adaptive provisioning of the QoS is based on the mobile hosts requested QoS, the available resource, the user QoS perception and the WISP policies.

The deployment of the Diffserv model at the mobile hosts allows the control of the traffic at the IP layer and introduces a differentiated treatment to the current IEEE 802.11b standard that actually provides a fair sharing of the radio resource. Note that the proposed management framework is still compliant with the ongoing link layer standards such as IEEE 802.11e which intends to provide a differentiated treatment of the traffic at the link layer.

We analyze our approach implementing the proposed framework in different WISP scenarios.

Finally, the performance measurements of our implementation based on Diffserv over CSMA/CA with the adaptive QoS management are described and we conclude by the outstanding performance of our approach.

Future work, intends to analyses the performance of the proposed framework including the mobility functionality.

Acknowledgements

This work has been produced in the framework of the project “ANWIRE” (`www.anwire.org`), which is funded by the European Community, under the contract IST-2001-38835”.

References

[1] I. Aad and C. Castellucia, Differentiation mechanisms for IEEE 802.11, in: *Proceedings of Infocom 2001*, Anchorage, AK (2001).

[2] U. Black, *QoS Wide Area Networks* (Prentice Hall, 2000).
[3] H. Chaouchi, A new policy-aware terminal, in: *Proceedings of Net-Con 2002*, Paris, France (2002).
[4] D. Durham, J. Boyle, R. Cohen, S. Herzog, R. Rajan and A. Sastry, The COPS (Common Open Policy Service) Protocol, RFC 2748 (January 2000).
[5] J.A. García-Macías, F. Rousseau, G. Berger-Sabbatel, L. Toumi and A. Duda, Quality of Service and mobility for the wireless Internet, in: *Proceedings of the 1st ACM Wireless Mobile Internet Workshop*, Rome, Italy (2001).
[6] M. Heusse, F. Rousseau, G. Berger-Sabbatel and A. Duda, Performance anomaly of 802.11b, in: *Proceedings of IEEE INFOCOM 2003*, San Francisco, CA (2003).
[7] IEEE 802.11, Wireless LAN medium access control (MAC) and physical layer (PHY) specifications.
[8] IEEE Std 802.11e/D2.0a (November 2001).
[9] A. Lindgren, A. Almquist and O. Schelén, Evaluation of Quality of Service schemes for IEEE 802.11 wireless LANs, in: *Proceedings of the 26th Annual IEEE Conference on Local Computer Networks (LCN 2001)* (November 2001).
[10] D.C. Verma, *Policy-Based Networking: Architecture and Algorithms* (New Readers, 2000).

Hakima Chaouchi received in Algeria her Ing. degree in computer science in 1997 from University of Tizi Ouzou, and M.Sc. degree in computer security in 2000 from Institut National d'Informatique (INI). In 2001, she obtained her M.Sc. degree in network and performance from University Pierre et Marie Curie (UPMC) in France. Directed by the Prof. Guy Pujolle, she is preparing her Ph.D. at Paris 6 Lab (LIP6) Network & Performance team, and currently she joins the Network team at the Centre for Telecommunication Research (CTR) of King's College, United Kingdom. Her research interest includes mobile networking and mobility management protocols, QoS management in mobile and wireless environments, AAA and Policy based management.
E-mail: hakima.chaouchi@lip6.fr

Anelise Munaretto received her Dipl.-Ing. degree in computer engineering from Pontifical Catholic University of Parana of Brazil in 1994 and her M.S. degree in computer networks from the University Pierre et Marie Curie, Paris (UPMC) in 2001. Currently she is pursuing Ph.D. degree in computer science at UPMC in the Network and Performance group of the LIP6 Laboratory under the guidance of Prof. Guy Pujolle and Prof. Khaldoun Al Agha. Her research interests include mobile networking, ad hoc networks, quality of service in wireless networks, wireless network performance measurement and evaluation.
E-mail: anelise.munaretto@lip6.fr