Policy-Based Channel Access Mechanism Selection for QoS Provision in IEEE 802.11e

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Abstract: *The appearance of the 802.11e standard made the 802.11 Wireless Local Area Networks (WLANs) capable of providing different levels of Quality of Service (QoS). This standard defines two new Channel Access Mechanisms (CAMs), namely the Enhanced Distributed Channel Access (EDCA) and the HCF Controlled Channel Access (HCCA). The introduction of two CAMs increases the complexity of traffic management, since now not only the available resources have to be distributed, but also the optimal CAM for each data flow has to be selected. However, the best CAM selection algorithm is still not clear. This paper presents and analyses different CAM selection policies in order to derive the best-suited strategy in terms of system performance. From this study, an optimal policy, based on traffic type and direction (uplink or downlink), is proposed. The best user QoS satisfaction shown in the results confirms the good performance of this new selection policy.*

Introduction

During the last years, WLANs based on the IEEE 802.11 standard [1] have become widespread in the high speed wireless communications market. At the same time, real time (RT) multimedia services, such as Voice over IP (VoIP) or video calling, have also gained a lot of popularity. In contrast with non real time (NRT) services, RT services have tight delay and jitter requirements that must be fulfilled by the network in order to provide the adequate experience to the end user. Until the specification of the 802.11e extension, the 802.11 standard was not able to provide any QoS. Neither an admission control nor a service differentiation was

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specified by the standard. RT traffic was handled by the system as best effort traffic with the exactly same treatment as the rest of services. Hence, the lack of quality was continuously amended with the appearance of new 802.11 versions with higher and higher throughput. Due to the recent increase of RT services demand, the 802.11e standard was developed and finally incorporated to the 802.11 family in 2005. This standard intends to provide the definitive solution to the QoS provision problem.

The 802.11e standard introduces a new Medium Access Control (MAC) protocol called Hybrid Coordination Function (HCF) which includes two new channel access mechanisms (CAMs), the EDCA, distributed and contention based, and the HCCA, centralized and contention free. These two mechanisms are similar to the Distributed Coordination Function (DCF) protocol and the Point Coordination Function (PCF) protocol introduced by the 802.11 legacy standard. The main difference is the ability of the two new protocols to offer some degree of QoS. Both, EDCA and HCCA, must be implemented in all 802.11e compatible devices. For that reason, any 802.11e network can alternate EDCA and HCCA transmissions if necessary. The improvement brought into the 802.11 WLANs by these two new CAMs in the presence of RT services has been validated in several studies [2], [3].

Although the 802.11e specification focuses on fulfilling user QoS requirements, the optimisation of the channel access for the correct QoS provision in WLAN is far from settled. In the 802.11e standard, several important aspects such as the CAM selection policy, the scheduling mechanism or the call admission control are not fully specified. This fact allows early and simplistic implementations of the standard, and at the same time, permits the development of more elaborated schemes that can dramatically improve the performance of the WLAN as compared with the reference version.

In this context, numerous suggestions of CAM selection algorithms along with improvements in the reference schedulers for each of these CAMs have come to the fore. These proposals aim at achieving the best end user experience. Some studies are focused on guaranteeing the requirements demanded by RT services as VoIP or video calling [4], [5], while others cope with the improvement in the performance of low priority traffic in the presence of heavy RT traffic [6].

This paper studies both approaches and presents several alternatives about how to handle the traffic generated in an 802.11e WLAN by means of different CAM selection policies for QoS provision. The important repercussions that an adequate CAM selection can introduce in a WLAN are also demonstrated. Moreover, as a result from the study of these policies, a novel scheme in alternating both HCCA and EDCA is proposed. This new selection policy called Hybrid HCCA-EDCA Centralised System (HHE-CS) achieves the best performance for both RT and NRT services.

The 802.11e Standard

In the 802.11e standard, super-frames are divided into contention and contention free periods. Distributed protocols like EDCA or DCF are used only during the contention period whereas the contention free period is exclusively reserved for polling protocols such as HCCA and PCF. The duration of contention free periods can be as long as desired or even could not be considered at all. Therefore, the different CAMs are alternated inside this super-frame.

The Enhanced Distributed Channel Access

The EDCA mechanism is an improvement of the old DCF mechanism and operates during the contention periods. The objective of EDCA is to provide QoS by means of traffic differentiation, achieving what is usually referred to as soft QoS. There are four different types of traffic classes, which are referred to in the standard as Access Categories (ACs). These ACs are, in order of decreasing importance: voice, video, best effort (for interactive NRT services) and background.

In EDCA, each station, including the access point (AP), has to content for the medium in order to transmit each data frame. Before transmitting, any active station has to sense the channel occupancy during an Arbitrary Inter-Frame Spacing (AIFS). If the station detects activity, a back-off process consisting in a random number of time slots is carried out. The number of waiting slots is randomly chosen between 0 and a Contention Window (CW) which starts with a value of CWmin. When two stations try to transmit a frame into the medium at the same time, a collision occurs. Every time a frame is not positively acknowledged because of either channel errors or collisions, the CW is doubled until it reaches the maximum value CWmax.

All 802.11e wireless stations, AP included, have four different queues to choose from in order to send a packet. Each of these queues corresponds to an AC and has an independent contention process working under different sets of contention parameters: AIFS, CWmin, CWmax and TXOP (Transmission Opportunity) limit. AIFS, CWmin and CWmax control the random backoff time that a station has to wait before transmitting whereas the TXOP is the time a station is allowed to transmit when it has seized the channel. This way, each AC has different statistical probabilities of achieving and maintaining control of the channel. For instance, VoIP queues must wait less time in the queues to access the channel and have more time to be transmitted than best effort traffic due to their tighter requirements.

The HCF Controlled Channel Access

The HCCA inherits the bases of the PCF legacy protocol which was rarely implemented in 802.11 devices. HCCA incorporates several enhancements in order to improve its efficiency, converting it in a viable and even recommendable solution for RT services with QoS requirements. Contrary to the EDCA mechanism, HCCA can guarantee a user-specific QoS distinguishing each user state and achieving what is usually referred to as hard QoS. HCCA employs a higher priority of the AP to gain control of the medium any time it senses the channel idle, beginning what is called as Contention free Access Phases (CAPs). In a CAP, the AP can either serve downlink traffic or transmit poll frames to the associated stations. Only after receiving a poll frame, stations can start transmitting uplink traffic. The main difference between HCCA and PCF is precisely that in HCCA the AP can seize the channel not only during the contention free periods but also during contention periods. The AP can take control of the channel for CAP transmissions as long as the time reserved for CAP phases is not totally consumed.

Thanks to HCCA, the AP is able to allocate downlink and uplink traffic and is also able to treat each flow in the network in an isolate manner. In HCCA, any scheduling algorithm can be implemented to serve both downlink and uplink traffic, although a reference scheduler is described in the standard. In this reference proposal, every service interval time (SI), the AP polls every station with uplink flows previously admitted for transmission in strict round robin order. A polled station has the right to transmit frames only during the TXOP time granted by the AP. This TXOP is calculated for each user as the minimum time needed to fulfil the user-specific QoS requirements.

Analysis and Comparison of EDCA and HCCA

The performances of the two channel access mechanisms standardised in 802.11e have been studied in quite a few articles [2], [3]. Although the two new channel access mechanisms offer a certain degree of QoS, they have different pros and cons.

EDCA employs a distributed mechanism and, therefore, is able to achieve a relative good performance with low complexity. However, since each AC has to carry out a contention process before transmitting, it is still likely to not gain control of the medium the minimum time required to fulfill the user QoS. Also, as the AP has the same probability of seizing the channel as the rest of the associated stations and usually has to serve much more amount of data, a downlink bottleneck is inevitable, just as stated in [2]. Therefore, HCCA is the most logical CAM to transmit RT services since in this case the satisfaction of the QoS requirements is of paramount importance. However, the polling mechanism employed by HCCA has some flaws. Obviously, the main disadvantage is the overhead introduced in the form of poll frames. Moreover, this polling scheduling is inefficient when handling uplink variable bit rates (VBR) services due to the difficult TXOPs adaptation to the instantaneous changes in the bit rate. Grilo et al. proposed in [4] an algorithm called SETT which employs a token bucket philosophy. Basically it consists in granting tokens to each station according to the mean bit rate of the data flows admitted in the system. A station is allowed to transmit during a TXOP equal to the tokens stored by the station. Whenever a station transmits in uplink, a number of tokens proportional to the time employed is subtracted. This scheduler algorithm achieves good performances when serving uplink VBR services in HCCA and, hence, it is the algorithm used in this paper for this kind of traffic.

The different characteristics of the two CAMs have made some authors to state that only by alternating the HCCA and EDCA mechanisms a network can offer optimal performance [2]. In agreement with this suggestion, several CAM policies can be formulated by selecting the adequate CAM for each traffic flow admitted in the network.

CAM Selection Policies for WLAN IEEE 802.11e

The CAM employed to transmit a traffic flow is a determinant factor in the final performance of any 802.11e network. This choice should be made following a certain CAM selection policy conceived to achieve the best experience for the end user. The system should identify the different types of user QoS requirements, serving the traffic with an adequate policy in order to maximise the best effort throughput without compromising the satisfaction of RT users. In the case of 802.11e WLAN, a policy can be defined as a function that, given a set of different input parameters, provides the CAM that will be used to transmit a certain traffic flow.

The rest of this section describes the main features of RT and NRT services. This description is needed to understand the fundamentals of the allocation policies. Next, some basic policies are defined. And finally, the combination of two basic policies and the novel CAM selection scheme HHE-CS are presented.

Main Features of RT and NRT Services

Generally speaking, packet data services can be classified in RT and NRT services. For NRT services, like web browsing or email traffic, the delay constraint is not as important as the transmission reliability. Although a maximum delay is usually not considered in NRT services, the service response time, defined as the period elapsed since the instant of the data request until the complete message reception, is a good measure of the quality perceived by the end user, especially for interactive NRT services. In this sense, it is commonly defined a maximum desirable delay for NRT services that the operator tries to ensure. However, if the network is highly loaded then users have no choice but to wait until the arrival of the information. On the other hand, RT services such as VoIP or video streaming, must be served fulfilling certain requirements; otherwise the service experienced by the end user will become intolerable.

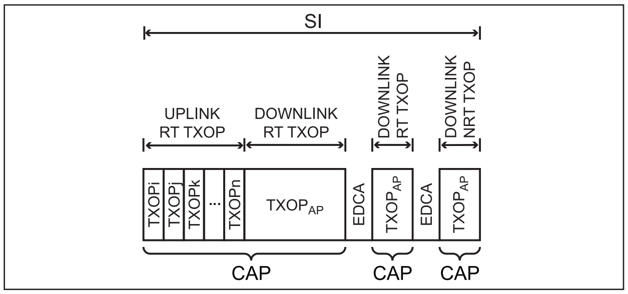

FIGURE 1 Functioning scheme of the HHE-CS scheme.

TABLE 1 CAM selection policies based on the type of service.

Service	**Policy**	
	EDCA	**HCCA+EDCA**
RT	EDCA	HCCA
NRT	EDCA	EDCA

Basic Policies

The first policy has only one input: if service is RT or NRT. In case of NRT traffic, EDCA is obviously the best option since HCCA is designed to transport only traffic with tight constraints in terms of throughput and delay. However, RT traffic could be served through EDCA or HCCA thanks to the QoS control that both channel access incorporate to protect high priority streams. A priori, HCCA protects better RT traffic but at the expenses of an increasing overhead. This question has been widely discussed by different authors [7], but conclusions are contradictory. Therefore, as summarised in Table 1, two different QoS policies can be formulated, a policy that employs EDCA for all kinds of traffic and a policy that trusts the RT traffic to HCCA.

However, the type of service is not the only factor to be taken into account. The trans- mission direction, which can be either downlink or uplink, has an important effect on the performance of the WLAN. As explained before, EDCA suffers from a downlink bottleneck due to the contention process that all stations (including the AP) have to perform. HCCA can use the ability of the AP to seize the medium at any moment to attenuate and even eliminate this bottleneck. However, because of the aforementioned inefficiencies of the polling mechanism in the uplink transmissions, the use of HCCA with best effort uplink traffic is not recommended. For this reason, a new CAM selection policy is proposed in Table 2. This policy only takes as input parameters the direction of the traffic flow to be transmitted.

TABLE 2 CAM selection policies based on the direction of the traffic flow.

Traffic Flow Direction	**Policy**
	HCCA+EDCA
Downlink	HCCA
Uplink	EDCA

Combined Policies

It seems obvious that an optimal combination of the two previous policies would entail a better network performance. By mixing both policies it can be possible to take advantage of the benefits of each CAM, avoiding their respective inefficiencies. The policy resulting from this statement has been called Hybrid HCCA EDCA Centralized System (HHE-CS) and its functioning is summarised along with other policies in Table 3. This policy comes from the combination of the HCCA+EDCA policy based on the type of the service and the HCCA+EDCA policy based on the traffic direction. According to this philosophy, HHE-CS transmits downlink best effort traffic not only through EDCA but also through HCCA. Once the traffic with high QoS restrictions has been completely served, the HHE-CS employs all the remaining time for CAP transmissions to transmit downlink best effort traffic. When all the CAP time is depleted, the AP contents for the channel control to send more downlink traffic through EDCA. A scheme summarising the HHE-CS functioning is represented in Figure 1.

As it can be seen, DCF is included also in Table 3 since its performance is afterwards compared with the rest of policies based on the 802.11e extension. On the other hand, EDCA enhanced (EDCAe) is a tuned up version of EDCA. The default contention parameters defined for EDCA by the standard are far from optimal, and its performance can be greatly improved with an optimal parameter selection [6]. Basically, this optimisation is based on granting more priority to the AP than the rest of stations and on enlarging the contention window when the number of stations in the network increases. This way, the downlink bottleneck and the number of collisions are decreased and less throughput is wasted in retransmissions.

TABLE 3 Combined policies based on the direction and the type of service of the traffic stream to be transmitted.

Service	**Dir.**	**Policy**				
		DCF	**EDCA**	**EDCAe**	**HCCA+EDCA**	**HHE-CS**
RT	DL	DCF	EDCA	EDCAe	HCCA	HCCA
RT	UL	DCF	EDCA	EDCAe	HCCA	HCCA
NRT	DL	DCF	EDCA	EDCAe	EDCA	HCCA/EDCA
NRT	UL	DCF	EDCA	EDCAe	EDCA	EDCA

Performance Comparison of Combined Policies

To realise this investigation, an evolved version of the emulator presented in [8] has been employed. RT services have been included in the simulations via the H263 video calling model described in [9]. This model generates instantaneous changes in the output bit rate while maintaining an average bit rate of 256 kbps. Each time a frame is not transmitted before the generation of the next one, the frame is discarded. The percentage of frames not discarded, called in this paper as the User equipment Satisfaction (UeS), is an accurate indicator of the QoS experienced by a video call user. On the other hand, as an example of NRT service, web traffic has been also modelled. The web browsing service has been implemented following the model described in [10]. All stations are transmitting at 6 Mbps according to the 802.11g standard and no channel errors are considered in order to isolate the behaviour of the allocation policies.

Figure 2 compares the performance of all the CAM selection policies in the implemented multi-service scenario. The number of video call users is fixed to 7 whereas the number of web users ranges from 0 to 60.

As it can be observed, the legacy DCF protocol is not valid for managing RT traffic, and consequently the quality of the RT communications decreases enormously when more web browsing stations are admitted in the system. This figure also shows how the EDCA protects the RT traffic up to a certain degree thanks to its traffic differentiation mechanisms. It is worth noting the important improvement in EDCA performance obtained by means of the contention parameter tuning. However, neither the default EDCA nor the EDCAe can maintain the user satisfaction when the number of web browsing stations increase too much. The reason is the incremental channel occupancy of web stations, what damages RT users. On the contrary, the performance of the HCCA+EDCA and HHE-CS policies is basically the same in terms of H.263 UeS, no matter how many web users are admitted in the WLAN.

To see if the HHE-CS policy entails any improvement thanks to its consideration of the traffic direction, the UeS for best effort is analysed and represented in Figure 3. This time the UeS is calculated as the percentage of downlink web pages transmitted in less than 5 seconds. In order to study the repercussions of the CAM selection in both directions of the traffic, the overall web throughput, considering both uplink and downlink traffic, is also depicted in Figure 4. The number of video call users is again 7 and the number of web users ranges from 0 to 60.

The best UeS performance and total throughput is achieved by the DCF protocol. This is obvious, since web browsing users are employing the resources that should be reserved for RT traffic. The most relevant result is the fact that the policies that use HCCA to transmit RT traffic achieve also better web performance than EDCA policies. The absence of collisions in the polling protocol achieves a better use of the WLAN resources. RT stations in HCCA

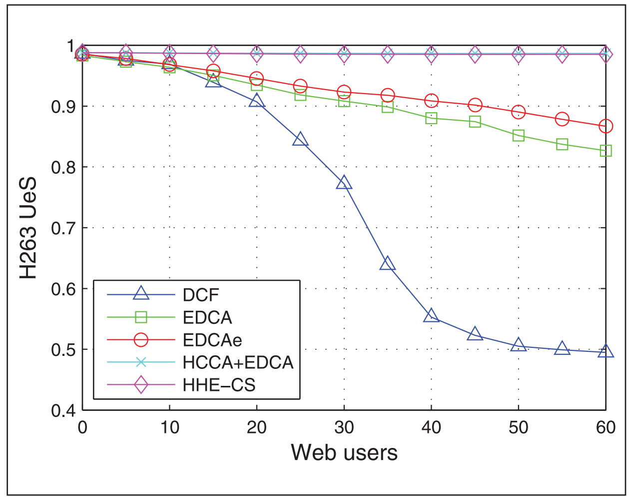

FIGURE 2 Average UeS of H263 bidirectional users with an increasing number of web stations in the WLAN.

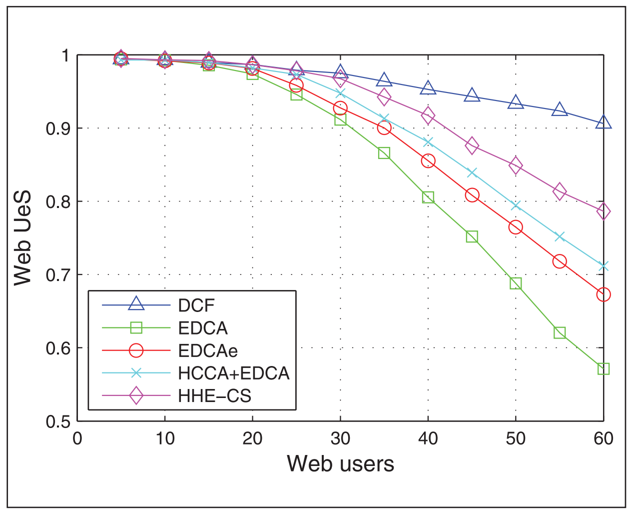

FIGURE 3 UeS of web browsing users with an increasing number of web stations in the WLAN.

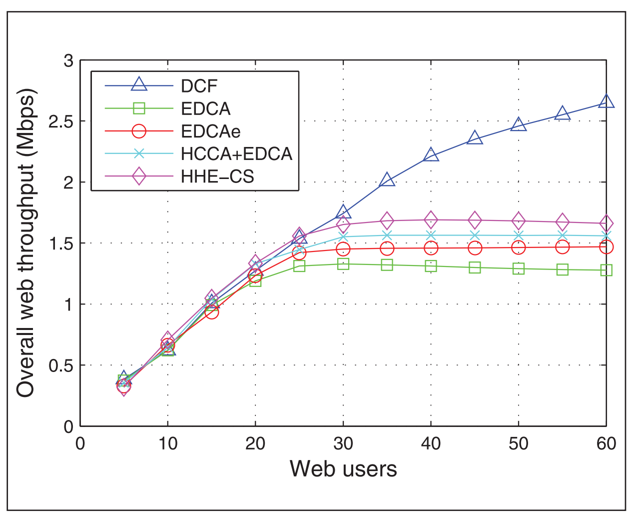

FIGURE 4 Overall throughput of web browsing users with an increasing number of web stations in the WLAN.

ALTHOUGH TWO PARAMETERS HAVE BEEN STUDIED IN THIS ARTICLE, THERE ARE A LOT MORE TO BE INTRODUCED IN A CHANNEL ACCESS MECHANISM SELECTION POLICY SUCH AS THE TRANSMISSION BIT RATE OF THE ASSOCIATED STATIONS OR THE CHANNEL QUALITY.

do not content for the medium control and therefore the number of stations contending for resources is decreased which favours web users. The figures also show clearly how the HHE-CS policy achieves better results than the HCCA+EDCA policy due to its better allocation of the downlink and uplink traffic. Not only HHE-CS contributes to remove the downlink bottleneck caused by contention as the UeS reveals, but it is also able to improve the total throughput of the network. The improvement introduced by the HHE-CS scheme over the HCCA-EDCA policy is about 10% in terms of UeS and about 6% in terms of overall web throughput.

Conclusions

This paper has shown different QoS policies that can be applied to the WLANs based in the 802.11e standard. This study has demonstrated that the way in which the two CAMs are alternated has important consequences in the performance of the network. Two different parameters have been taken into account when defining the CAM selection policy: the type of the service and the direction of the traffic stream. Furthermore, this study has also shown that the best results are obtained when both parameters are considered instead of only one of them. Although two parameters have been studied in this article, there are a lot more to be introduced in a CAM selection policy such as the transmission bit rate of the associated stations or the channel quality. At the end, the more the parameters that a CAM selection policy considers the better the performance achieved by the network.

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