Improving the QoS support in HCCA-EDCA mixed IEEE 802.11e networks

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Abstract The multimedia applications require the network to provide a trustworthy service suitable to meet their Quality of Service and real-time requirements, managing efficiently the available resources. In this paper we present a performing solution for the multimedia support over IEEE 802.11e networks that aims to combine both its Medium Access Control functions, Enhanced Distributed Channel Access (EDCA) and Hybrid Coordination Function (HCF) Controlled Channel Access (HCCA), in order to reduce the experienced delay. The proposed scheduler, local to the node, cooperates with the centralized HCCA scheduler, integrating the offered service using the EDCA available resources. The simulations show that the overall scheduler improves the performance with respect to the HCCA schedulers in terms of scheduling efficiency and delay, allowing to guarantee the expected service level.

Key words: Wireless LAN, Quality of Service, scheduling algorithms, performance evaluation

1 Introduction

The diffusion of the multimedia applications (VoIP, videoconference, multimedia streaming, etc.) requires that the wireless communication networks support efficiently and trustily their *Quality of Service* (QoS) and real-time requirements, expressed, for instance, in terms of delay, delay jitter, packet loss and negotiated bandwidth. The IEEE 802.11e enhancement [18] has been introduced to improve the

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service guarantees assured to the*Wireless Local Area Networks* (WLAN) by the diffused IEEE 802.11b standard and based on the best effort model. It outperforms the IEEE 802.11b *Medium Access Control* (MAC) functions introducing the QoS differentiation by means of the diverse priorities used in the medium access with contention by the new *Enhanced Distributed Channel Access* (EDCA) function and by the parameterized service levels offered by the *Hybrid Coordination Function* (HCF) *Controlled Channel Access* (HCCA) function, based on a polling mechanism. The numerous research works about the HCCA function [6, 12, 16, 25] have shown that its feature to assign fixed value to the protocol parameters is performing only for *Constant Bit Rate* (CBR) traffic, whereas it is not suitable to serve efficiently the *Variable Bit Rate* (VBR) traffic, due to its time-varying characteristics. Thus several alternative scheduling algorithms have been proposed to improve the offered QoS in the case of VBR traffic, [13, 15, 25] and few works have evaluated the real-time issues of the reference scheduler [2, 5–7, 9, 10, 15, 24], and proposed possible solutions. Anyway, to the best of our knowledge, very few works have considered the chance to integrate the service provided by HCCA with the EDCA available resources, even though the IEEE 802.11e standard assumes a further access policy, the *HCCA-EDCA Mixed Mode* (HEMM), where both these functions are used. The HEMM is not well documented and very few works [19, 20, 23, 26] have approached the QoS service management of the whole HCCA-EDCA system.

In this paper we present a QoS-aware scheduler that allows the node to use both the IEEE 802.11e MAC functions for the transmission of the same traffic stream. This scheduler, local to the node, sends the traffic exceeding the assigned HCCA transmission time using the EDCA function, trying to boost the flow performance, thus it has been named "*Overboost*". The simulations show that it is effective in terms of scheduling efficiency and delay experienced during the VBR traffic streams transmissions, using different centralized HCCA schedulers.

The rest of the paper is organized as follows: in Section 2 the IEEE 802.11e standard is illustrated, in Section 3 the analyzed HCCA schedulers are summarized, whereas in Section 4 the proposed local scheduler is described, in Section 5 its performance are evaluated through simulations and, finally, in Section 6 the conclusions are deducted.

2 IEEE 802.11e MAC functions

The mentioned HCCA and EDCA IEEE 802.11e MAC functions are combined during the hyperperiod in order to introduce a flexible service differentiation.

HCCA enhances the contention-free *Point Coordination Function* (PCF), based on a centralized polling mechanism where the *Access Point* (AP) polls the station that have asked the permission to send according to the round-robin polling list. In particular HCCA introduces a parameterized QoS support based on a traffic classification into height *Traffic Streams* (TSs). Each of them corresponds to a specific service level identified by the values of the *Traffic Specification* (TSPEC) protocol parameters (the mandatory fields are: Mean Data Rate, Minimum Physical Rate, Delay Bound, Maximum Service Interval, Nominal Service Data Unit Size). The *Admission Control* phase, that manages the admission to the medium access of the *STAtions with QoS* (QSTAs), has been tailored for the QoS provisioning, allowing a negotiation of the service guarantees for each of their TSs. In order to be included in the polling list, a QSTA sends to the *QoS-aware Hybrid Coordinator* (HC), usually located at the *QoS Access Point* (QAP), a QoS reservation request for each of its TSs. Then, if the acceptance of these TSs does not jeopardize the service guarantees of the already admitted QSTAs, the QAP notifies the QSTA admission with a positive acknowledgement, containing the service start time. The QSTA TSPECs are aggregated in the two basic QoS transmission parameters used to manage the available network resources and sent to the QSTA at the polling time: the *Service Interval*, SI, that is the time interval between two successive polls of the node and the *Transmission Opportunity*, $TXOP$, i.e. the transmission duration, based on the mean TSs data rates. During the *Controlled Access Phase* (CAP), the QAP polls a single QSTA at turn, according to the polling list, generated by the scheduler considering the QoS and real-time requirements.

EDCA improves the contention-based *Distributed Coordination Function* (DCF), based on the *Carrier Sense Multiple Access/Collision Avoidance* (CSMA/CA) mechanism. It provides a prioritized QoS through eight different *User Priorities* (UPs), used in the traffic classification. These UPs are mapped into four *Access Categories* (AC), (background, best effort, video and voice traffic), implemented as *First In First Out* (FIFO) queues. The prioritization is obtained assigning each AC different contention parameters: an increasing *Arbitrary Inter-Frame Space* (AIFS) corresponding to a decreasing AC priority, *Contention Window Min* (CW_{min}) and *Contention Window Max* (CW_{max}), which are used to compute different backoff periods. A QSTA with an higher priority AC traffic has a backoff interval shorter than that of the lower priority ones, acquiring an higher right of access to the medium. Thus, different kinds of applications can receive diverse services according to their QoS requirements.

3 The analyzed HCCA schedulers

In this section we analyze the HCCA IEEE 802.11e reference scheduler and some significant real-time scheduling algorithms introduced to improve its QoS support and considered in this work since, to the best of our knowledge, they are representative of the different proposed solutions. A performance analysis showing their main features and differences can be found in [6].

The IEEE 802.11e *reference scheduler* suggests how to compute the main protocol parameters, SI and $TXOP$, suitable to meet the service expectations globally expressed by each QSTA with admitted streams. Since the QSTAs have a unique SI and different TXOP, they are polled with the same period SI and the different TSs of a $QSTA_i$ are served with the same transmission time $TXOP_i$. The SI is suggested to be less than the beacon interval and than the minimum of the *Maximum SI* (MSI_i) of each QSTA$_i$. Thus the QSTAs are polled at least one time during the beacon duration and within the minimum interval requested for each of their TSs, assuring no missed deadlines. *SI* and $TXOP_i$ have fixed values, based on *worst case* conditions, and they are recomputed only if a new TS arrives with a MSI_i greater than the admitted ones. For this reason the reference scheduler provides a non-optimal resource utilization in the case of VBR traffic and the Admission Control, using not flexible conditions, admits less TSs than possible, wasting the available network resources.

Fair HCF (FHCF) [2] aims to improves the fairness of both CBR and VBR traffic and the delay performances assigning variable $TXOPs$ by means of a mathematical model of the uplink TSs queues length, used to estimate the global packet delay. It distinguishes between the packet queuing delay, influenced by the variations in packet size and data rate, and the waiting time delay, defined as the interval between the packet arrival time and the QSTA polling time.

The *Real-Time HCCA* (RTH) algorithm [9] is designed to provide real-time support to HCCA function, assuring the traffic streams a fixed amount of capacity during a fixed period. This periodic scheduler, based on *Earliest Deadline First* (EDF) [21] plus *Stack Resource Policy* (SRP) [4] algorithms, takes into account the non-preemptability of the frame transmissions, considered as critical sections. The admission control and the scheduling parameters computation, that are time-consuming activities, are performed offline at the stream lifetime timescale.

The *Wireless Capacity Based Scheduler* (WCBS) [6, 7], suitable for serving soft real-time applications, is derived from the *Constant Bandwidth Server* [1], a real-time operating systems scheduling algorithm. WCBS uses static and dynamic parameters to rule the transmission packets scheduling. During the admission control a pair of static parameters are assigned to each TS$_i$: the budget Q_i, i.e. the maximum transmission time during a period, and P_i, the service interval. They are computed taking into account the TSPEC$_i$ and they do not change during normal conditions. The ratio $U_i = Q_i/P_i$ is the factor utilization of the stream, i.e. its bandwidth. The dynamic parameters characterize each TS$_i$ during the scheduling phase: the remaining time c_i assigned to TS$_i$ during the next $TXOP$, the absolute deadline d_i before the budget Q_i has to be exhausted, the next time p_i when TS$_i$ will be polled if it has no more data to transfer or it has exhausted its $TXOP$, and the stream *state* (*transmitting*, *active*, *polling*, *idle*).

4 The Overboost scheduler

The proposed *Overboost* scheduler, local to each node, integrates the activity of the HCCA schedulers when the TSs served with them, at the end of CAP phase, still have some traffic to transmit. In this case, before the contention period begins, Overboost moves these TSs from the HCCA queue to the higher priority Access Category EDCA queue, as shown in Fig. 1.

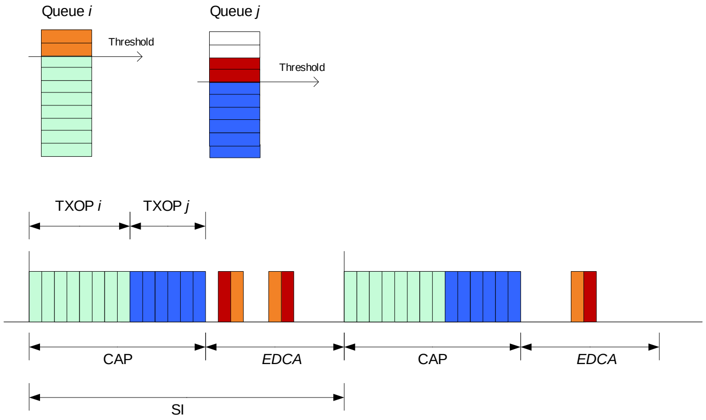


Fig. 1: The Overboost mechanism

Thus the traffic exceeding the assigned HCCA $TXOP$ transmission time, that represents the transmitted traffic threshold, will be not served with parameterized QoS during the next *SI*, but with prioritized QoS during the subsequent contention phase in the same hyperperiod. The use of both the MAC functions limits the delay experienced by the streams waiting for the next HCCA polling time and improves the network performance. The local scheduler combines the services offered by both the HCCA and EDCA mechanisms, "boosting" the performance assured by an HCCA scheduler.

In particular, when the MAC layer retrieves the next packet to send, the temporal evolution of the Overboost algorithm is as follows:

1. If the queue is empty it informs the MAC that there are no packets to send during this $TXOP$.
2. Otherwise it dequeues the first packet and estimates the remaining time before the end of the $TXOP$.
3. If there is no time left to send the first packet it notifies to the MAC:
    - `NULL_PKT`, if no packets has been sent during this $TXOP$,
    - `NO_PKT`, if at least one packet has been sent during this $TXOP$.
4. Otherwise it checks if there is a second packet in the queue and estimates if there is enough time in this $TXOP$ to send it.
5. If there is a second packet and no time left to send it in the current $TXOP$, all the packets after the first are swapped from the HCCA queue to the EDCA queue, while the first one is transmitted using HCCA.

The proposed local scheduler can be used along with any type of MAC scheduling algorithm, collaborating with it. In fact the centralized scheduler located in the QAP continues to manage the QSTAs that ask to send, performing the admission control; it proceeds to compute the scheduling parameters, to create the polling list and to poll the admitted QSTAs. Instead Overboost, located in each station, takes action only if the transmitting QSTA does not deliver all its enqueued traffic streams during its $TXOP$.

5 Performance analysis

In this section we analyze through simulations the benefit introduced by the new local Overboost scheduler to the performance of the previously described HCCA scheduling algorithms (IEEE 802.11e reference, WCBS, RTH, FHCF). We analyze the schedulers efficiency in terms of the experienced null rate and we evaluate their performance about the access delay.

5.1 Simulation settings and traffic model

The software implementation of the Overboost algorithm has required to introduce an extension to use both HCCA and EDCA functions in the HCCA software implementation proposed in [8] for *ns-2* [22] and chosen for his modularity. Overboost has been implemented as a local QSTA scheduler. We used the physical layer parameters specified by the *High Rate-Direct Sequence Spread Spectrum* (HR-DSSS) in the IEEE 802.11b standard, see Table 1. MAC level fragmentation, multirate support, RTS/CTS protection mechanism are disabled and all nodes are assumed to communicate directly with each other, without the hidden node problem.

Parameter	*Value*	*Parameter*	*Value*
Short Interframe Space (SIFS)	10 μs	PHY header	192 μs
PCF Interframe Space (PIFS)	30 μs	Data rate	11 *Mb/s*
DCF Interframe Space (DIFS)	50 μs	Basic rate	1 *Mb/s*
Slot Time	20 μs	Bit error rate	0 *b/s*

Table 1: MAC/PHY simulation parameters

The analysis has been carried out using the method of independent replications, running independent replications of 3600 s each with 100 s warm-up periods until the 95% confidence interval is reached for each measure. We consider two types of uplink (UL) traffic streams requiring QoS guarantees: VoIP and video.

The VoIP traffic is simulated using a VoIP generator module for ns-2 described in [3]. The VoIP streams are modeled as an ON/OFF source: during the ON (*talkspurt*) periods the traffic is CBR with parameters depending on the encoding scheme; during the OFF (*silence*) periods no packets are generated. Talkspurt and silence periods are distributed according to the Weibull distribution that models a one-to-one conversation. The used encoding scheme is the G.729A [11]; we set the TSPEC delay bound to the packet interarrival time (*period*) and the mean data rate to the peak rate during talkspurts.

Parameter	G729A	*Parameter*	VideoConf.	VideoStr.
Frame size (B)	10	Mean frame size (B)	660	3800
Period (s)	0.02	Period (s)	0.033333	0.040
Sample per packet	2	Max frame size (B)	11386	16745
Payload size (B)	20	Mean data rate (b/s)	157712	770000
IP/UDP/RTP Header size (B)	40	Peak data rate (b/s)	2732640	3300000
SDU size (B)	60			
Data rate (b/s)	24000			

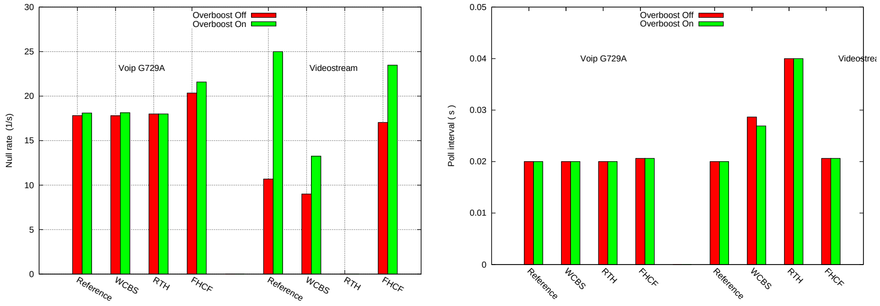
Table 2: G729A VoIP and video streams parameters values

The video stream traffic is generated using pre-encoded MPEG4 trace files [17]. The MPEG4 streams of variable size frames at fixed intervals [14] are chosen to represent a videoconference session (*LectureHQ-Reisslein* trace file) and a video streamed over the network (*Jurassic Park High Quality* trace file). The TSPEC parameters for VoIP and video streams are shown in Table 2.

All the simulations include one station with background data traffic operating in asymptotic conditions, i.e. it always has a frame to transmit. The best effort data traffic is transmitted using legacy DCF and its packet length is constant and equal to 1500 bytes.

5.2 Efficiency analysis

The efficiency of the schedulers is analyzed considering the null rate experienced during the QSTAs polling phase and defined as the number of *Null* packets received by the QAP when it has sent a *CF-Poll* frame to a QSTA without packets to transmit. The null rate evaluation is useful to verify if the polling time computation is taylored for the considered traffic or more frequent than necessary, increasing the system overhead. In Fig. 2a we show the null rate for the analyzed four schedulers with and without the Overboost mechanism, in a scenario composed by three VoIP G.729A and three video stream uplink TSs. In the case of G.729A TSs Overboost does not improve the schedulers performance and the null rate is almost the same for all the schedulers, with and without Overboost. In fact they compute the same $TXOP$ value and the same *SI* value, equal to the packet interarrival time, thus their polling rate is suitable to empty the queue. The Null packets are only due to the silence periods. Instead with video stream TSs the Null packets significantly increase when Overboost is activated: at the end of the $TXOP$, the packets in the HCCA queue are swapped in the higher priority EDCA queue therefore, when the QAP polls the QSTA in the next CAP, there is more chance to find the queue empty. However, even in the case of increased null rate the delay is reduced, as resulting in Section 5.3.



(a) Null rate

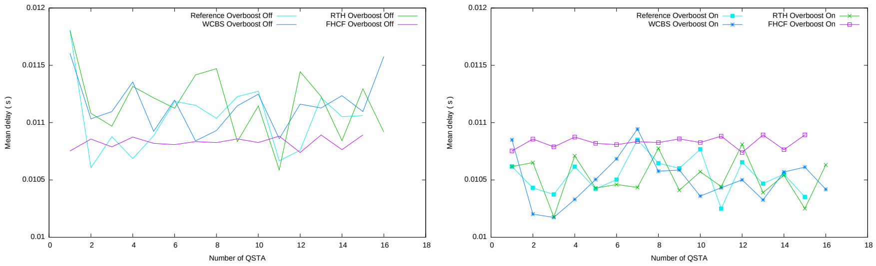
(b) Polling intervals

Fig. 2: UL VoIP and video stream TSs

Finally, the analysis of the polling intervals duration highlights as Overboost does not modify the feature of the HCCA scheduling algorithms, their polling list and timings, as shown in Fig. 2b, confirming that it integrates their activity.

5.3 *Delay analysis*

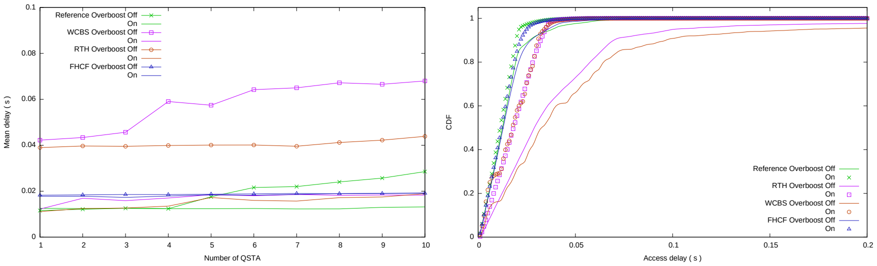
The access delay is defined as the time elapsed from the packet reaching the MAC layer to the packet being successfully acknowledged. We consider a scenario with an increasing number of VoIP G729A TSs. As expected the differences between using or not Overboost, are minimal, see Fig. 3a and Fig. 3b, since it does not affect this kind of traffic.



(a) without *Overboost*

(b) with *Overboost*

Fig. 3: Mean delay of G.729A UL TSs



(a) Mean delay of videoconference UL TSs without and with *Overboost*

(b) CDF of access delay with videoconference and video stream UL TSs

Fig. 4: Delay with videoconference UL TSs and CDF of the access delay in a mixed scenario

Fig. 4a shows that, in a scenario with an increasing number of UL videoconference TSs, the EDF-based schedulers produce a greater mean delay, since they execute a new sorting at each CAP, while the other schedulers maintain a fixed TSs order. In presence of Overboost this gap between the schedulers is lower, since it exhausted the exceeding traffic.

Finally we consider a mixed scenario with two VoIP G.729A TSs, four videoconference TSs and two video stream TSs. Fig. 4b shows the *Cumulative Distribution Function* (CDF) of the access delay of last admitted QSTA transmitting videoconference TS. The slope of each probability curve is increased, meaning that every scheduler has more probability to keep the access delay under a specific value. As in the previous case the delay is lower when Overboost is activated, especially with EDF-based schedulers, confirming the benefit introduced by the use of this local scheduler to improve the HCCA scheduling algorithms.

6 Conclusions

In this paper a novel local node scheduler for IEEE 802.11e networks, *Overboost*, is presented. Cooperating with the HCCA centralized schedulers and exploiting the EDCA function it is suitable to assure a trustworthy service with QoS, as expected by the multimedia applications. Overboost switches the data traffic exceeding the HCCA transmission time limit to the queue of the higher priority EDCA access category. The simulations shown that it improves the QoS provided by the HCCA schedulers when variable bit rate traffic streams are transmitted: it increases the algorithm efficiency in the resource management evaluated in terms of null rate, and it reduces the access delay enhancing the real-time performances of the centralized schedulers.

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