POAC-QG: Priority Oriented Adaptive Control with QoS Guarantee for wireless LANs

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Abstract **This work introduces an alternative WLAN protocol which could be adapted in the HCF scheme defined by IEEE 802.11, in place of the HCCA mechanism. POAC-QG (Priority Oriented Adaptive Control with QoS Guarantee) is a complete centralized channel access mechanism, it is able to guarantee QoS for all types of multimedia network applications, it enhances the parameterized traffic with priorities, and it supports time division access using slots. It instantly negotiates the quality levels of the traffic streams trying to support multiple streams with best possible quality. POAC-QG, compared with HCCA, exhibits generally superior performance.**

Keywords **— 802.11e, HCCA, HCF, MAC, POAC-QG**

I. Introduction

IN the recent past, the advance of the wireless local area networks (WLANs) have made them a very attractive networking solution. All modern networks need to integrate data with multimedia traffic. Voice, audio and video have to be efficiently transmitted along with the traditional data traffic. The multimedia network applications that concern real-time traffic have some special transmission demands regarding the quality of the communication. Real-time applications require QoS guarantee, because they are time-bounded, while slightly unreliable connections are allowed. On the other hand, data traffic does not demand low delay or jitter, but reliability is essential. Thus, today's WLANs should be able to meet all types of traffic requirements.

Medium access control in wireless networks [1]-[9] is challenging, especially for QoS support. The IEEE 802.11e [10] workgroup proposes the Hybrid Coordination Function (HCF), which considers a contention based (Enhanced Distributed Channel Access - EDCA) and a contention free protocol (Hybrid Control Channel Access - HCCA). HCCA, which requires central control, can guarantee QoS in many cases. However, it does not efficiently support Variable Bit Rate (VBR) traffic, while the bandwidth utilization is not high. Considering the importance of the VBR traffic support and that bandwidth is scarce, a more efficient protocol could be used.

This work proposes the Priority Oriented Access Control with QoS Guarantee (POAC-QG) protocol which is able to operate under HCF. It supports real-time applications, by providing delay and jitter guarantees for both CBR (Constant Bit Rate) and VBR traffic. Priorities are used to differentiate the Traffic Streams (TSs). POAC-QG instantly negotiates the quality levels of the TSs, trying to support as many TSs as possible with the best possible quality. Central control is required. We assume that stations are able to communicate directly when in range, however the model where the AP (Access Point) acts as a packet forwarder could be also used. HCF also supports direct inter-station links as an extra feature.

This paper is organized as follows. Section 2 presents HCF, focusing on HCCA. In Section 3, the operation of POAC-QG is analyzed. Section 4 presents the simulation environment and results. Section 5 concludes the paper.

II. The IEEE 802.11e HCF Medium Access Control

In HCF, the transmission opportunity (TXOP) is the time interval in which a station is allowed to transmit. In HCCA, the TXOP assigned to a station is decided by the AP according to the station's QoS requests. The superframe is defined as the beacon interval. It is composed of alternated modes of Contention Period (CP) and optional Contention-Free Period (CFP). EDCA operates only in CP while HCCA can operate both during CP and CFP. HCCA mode can be started by the AP several times during a CP and these periods are called Controlled Access Periods (CAPs). When the AP wants to initiate a CAP, it occupies the channel and uses the CF-Poll message to grant a HCCA-TXOP to a station. In HCCA, every TS has its own packet buffer. The traffic specification (TSPEC) describes characteristics of TSs, such as the mean data rate, the MAC Service Data Unit (MSDU) size and the maximum Required Service Interval (RSI). Each TS first sends a QoS request to the AP containing its TSPECs. The scheduler calculates first the minimum value of all the RSIs, and then chooses the highest submultiple value of the beacon interval duration as the selected Service Interval (SI), which is less than the minimum of all the maximum RSIs. SI is the time interval between any two successive TXOPs allocated to a station.

The scheduling algorithm used in HCCA calculates the TXOPs as follows. The TXOP corresponds to the duration required to transmit all packets generated during a SI in a TS buffer. The mean number of packets (N_{ij}) generated in the TS buffer (j) for a station (i) during a SI is:

$$N_{ij} = \left\lceil \frac{\bar{r}_{ij} SI}{M_{ij}} \right\rceil$$

where $\bar{r}_{ij}$ is the application mean data rate and M_{ij} is the nominal MSDU size. The TXOP (T_{ij}) is finally:

$$T_{ij} = max\left(\frac{N_{ij} M_{ij}}{R} + 2SIFS + T_{ACK}, \frac{M_{max}}{R} + 2SIFS + T_{ACK}\right)$$

where R is the transmission rate and M_{max} is the maximum MSDU size. The time interval $2SIFS + T_{ACK}$ corresponds to the overhead during a TXOP. The station's TXOP is:

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$$TXOP_i = \sum_{j=1}^{Fi} T_{ij}$$

where F_i is the number of TSs in station i. The fraction of time assigned to a station i is: $TXOP_i / SI$. If the number of stations that are assigned TXOPs is K, the admission control needs to check if a new request of $TXOP_{K+1}$ will keep the fraction of time allocated for TXOPs lower than the maximum fraction of time that can be used by HCCA:

$$\frac{TXOP_{K+1}}{SI} + \sum_{i=1}^{K} \frac{TXOP_i}{SI} \leq \frac{T_{CAPLimit}}{T_{Beacon}}$$

where $T_{CAPLimit}$ is the maximum duration of HCCA in a beacon interval (T_{Beacon}).

There are some drawbacks concerning HCCA. First of all, some bandwidth is spent because of the polling packets. The use of acknowledgements is bandwidth costly, too. Also, all stations have to stay constantly awake waiting for packets, so there is increased power consumption. Another major drawback is the fact that the TXOPs are fixed. Thus, VBR traffic cannot be supported efficiently. Furthermore, no prioritized TSs are considered. This means that the traffic is not efficiently differentiated.

III. The POAC-QG Protocol

A. *Overview of the Protocol*

The need that has led to the development of this protocol is the necessity for bandwidth saving, strict QoS with efficient VBR traffic support, and traffic differentiation. The superframe is separated into real-time traffic (RT) and background traffic (BT) periods. POAC-QG operates during the RT periods, which are contention free. During the BT periods a contention based access mechanism can be used. The 802.11e superframe is suitable for adapting POAC-QG into it. The CFPs and CAPs correspond to the RT periods, and the CPs during which EDCA takes place correspond to the BT periods. POAC-QG is not based on polling, but on a TDMA scheme. The concept is to reduce the bandwidth waste due to polls, keep the stations synchronized by dividing the RT period into slots, and keep them informed of the time, source and destination of the coming transmissions. Thus, a potential power saving model could be employed, since stations can stay in "sleep" mode during the RT period and "wake" only to exchange data. The AP uses the beacon signal to inform the stations of the assigned slots and the SI. Stations send their QoS requests for every TS during the BT periods or the last RT slots assigned to them. An overview of the superframe is shown in Fig. 1.

It is known that a multimedia application can be carried out with different quality levels. The admission control negotiates instantly multiple quality levels that can be supported by the requesting TS. The corresponding algorithm tries to serve the higher priority TSs with maximum quality level, but it can lower the provided quality levels in order to allocate slots for lower priority TSs, too. It is of course assumed that the higher the quality level is, the higher are the resource requirements (bandwidth, delay). The main purpose of the protocol is to serve as many TSs as possible, favor the higher priority TSs, and provide the higher possible quality levels. When a station sends a QoS request to ask for slots for its TSs, it includes the TSPECs of the different quality levels (traffic rate, maximum inter-transmission interval, maximum nominal packet size). Every running TS can ask for a different number of RT slots, according to its current traffic rate and the total size of its buffered packets. So, the QoS request frame includes TSPECs for both running and new TSs. This way VBR traffic can be efficiently supported. The algorithm calculates first the SI duration, similarly to HCCA. Then, the AP allocates slots for the running TSs according to their latest requests. The running TSs are examined first to keep the quality of the existing communications steady. The rest of the bandwidth is then assigned to the new TSs, according to the admission control mechanism. The new SI duration is calculated, based on the requests of the accepted TSs and finally the time slots are assigned to the running and the new accepted TSs. In Fig. 2, an overview of the processes defined by POAC-QG is presented.

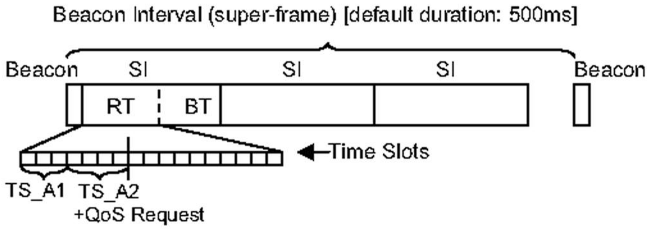


Fig. 1. The POAC-QG superframe

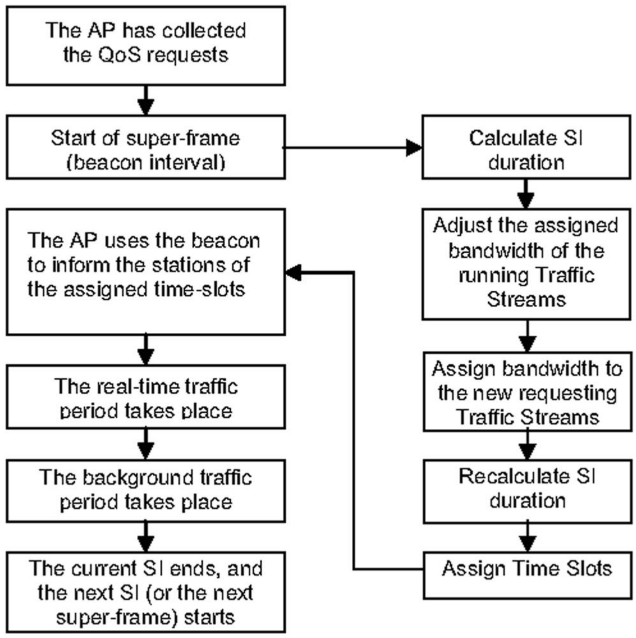


Fig. 2. POAC-QG operation overview

B. *Admission Control*

Before assigning bandwidth to the new requesting TSs, these are sorted according to their priorities (highest priority first). The corresponding algorithm starts with the highest priority TS and checks if there is enough available bandwidth in order to serve the specific TS with maximum quality level. Otherwise, the QoS requirements of the lower quality level are checked. If neither the minimum quality level can be supported, then the TS is rejected and the next priority TS is examined. When there is no bandwidth left to serve a TS with minimum quality, then the quality levels of the previously examined higher priority TSs are lowered in order to save some bandwidth for the new TS. When the quality levels of the high priority TSs are lowered, then we also check if it becomes possible to increase the quality of the low priority TSs. This way, the best combination of supported quality levels is provided. An example of this process is depicted in Fig. 3, where we assume two quality levels and four TSs with different priorities (Piority_A is the highest, while Priority_D is the lowest). The first three TSs are already examined and the Priority_D TS is under examination. There are seven possible cases. Each time, the algorithm checks if there is enough available bandwidth in order to serve the TSs providing the corresponding quality levels. If there is not, we proceed to the next case. The final case is the rejection of the examined TS (quality level: OUT).

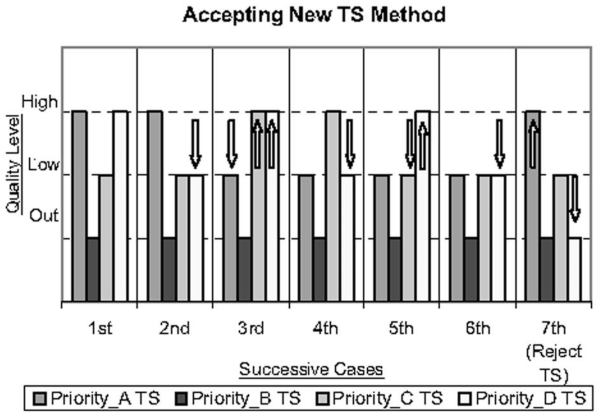


Fig. 3. Example of the quality levels negotiation when examining the admission of new traffic streams

C. Control Adapted to Requirements

The POAC-QG protocol efficiently supports VBR real-time traffic by adapting to the changing requirements of the running TSs. Before sending a QoS request, the station calculates the current traffic rate of all the running TSs by counting the generated bits for a short time interval (default value is 2 sec). It also includes in the QoS request the size of the corresponding packet buffer. At the start of every superframe, the AP assigns slots to the running TSs according to their new QoS requests. The rest of the RT bandwidth is then assigned to the new TSs as we have already discussed. It should be noticed that the quality level initially provided to a TS remains static, because our aim is to have steady transmissions. The algorithm that assigns slots to the running TSs tries to adapt to the variable traffic rate. When there is not enough RT bandwidth, it assigns a proportion of the requested bandwidth to each TS according to its priority. It is considered that all generated and buffered packets of a TS can be transmitted during a SI, if the allocated bandwidth corresponds to the theoretical traffic rate:

$$TheoreticalTR = CurrentTR + BufferedBits / SI$$

where *CurrentTR* is the current traffic rate defined in the QoS request. This mechanism tries to avert sudden and continuous alterations of the allocated bandwidth, thus a proportion of the requested bandwidth accession or reduction is considered to be the target. Specifically, the considered target traffic rate is:

$$TargetTR = PreviousTR + \\ BW\_DifPercent \times (TheoreticalTR - PreviousTR)$$

where *PreviousTR* is the traffic rate corresponding to the bandwidth assigned during the previous superframe, and *BW_DifPercent* (default value is 0.8) is the percentage of the requested bandwidth accession or reduction which is considered to be the target.

An issue arises when there is not enough bandwidth to cover all the extra requests of the running TSs. For this reason, an algorithm that distributes the available bandwidth taking into account the traffic priorities has been developed. It initially calculates the percentage of the available bandwidth that each requesting TS deserves (eligible bandwidth). The available bandwidth corresponds to the slots left in the maximum RT period, after assigning to all the running TSs the slots that already occupied in the previous beacon interval and freeing the returned slots. The eligible bandwidth percentage depends on the traffic priority and the extra bandwidth requested by the TS. The weights *W_PR* (default value is 5) and *W_BW* (default value is 1) control the contribution of the traffic priority and the extra bandwidth requested to the eligible extra bandwidth. The non-normalized eligible bandwidth percentage for TS i is:

$$Per[i] = W\_PR \times PerPR[i] + W\_BW \times PerBW[i]$$

where *PerPR* is the normalized traffic priority and *PerBW* is the normalized extra bandwidth requested. In order to favor the AP TSs, we multiply the corresponding *Per[i]* with the factor *W_AP* (default value is 5). Then, we normalize to get the final eligible bandwidth percentage for each TS. At each step, if the eligible bandwidth of a TS is higher than its requested bandwidth, then the latter is immediately granted to this TS. Finally, a proportion of the requested bandwidth is assigned to the TSs that cannot be fully served. An example is given in Table I. This mechanism of dynamic bandwidth assignment completes the support provided by POAC-QG to VBR traffic.

TABLE I: EXAMPLE OF ASSIGNING EXTRA REQUESTED BANDWIDTH

Step	TS	Priority	Requested Bandwidth	Available Bandwidth	Eligible Bandwidth	Assigned Bandwidth
1	A	6	5 Mbps	10 Mbps	5.6 Mbps	5 Mbps
	B	3	3 Mbps		2.9 Mbps	-
	C	1	4 Mbps		1.5 Mbps	-
2	B	3	3 Mbps	5 Mbps	3.3 Mbps	3 Mbps
	C	1	4 Mbps		1.7 Mbps	-
3	C	1	4 Mbps	2 Mbps	2 Mbps	2 Mbps

IV. PERFORMANCE EVALUATION

In order to compare POAC-QG against HCCA, we developed a simulation environment in C++. The considered physical layer protocol is 802.11g [11]. It provides up to 54 Mbps data rate, but to simulate realistic wireless links, we used the ERP-OFDM (Extended Rate PHY Orthogonal Frequency Division Multiplex) technique at 36 Mbps. IEEE 802.11e was employed by our network. First, we used the pure HCF to evaluate HCCA, and then we adapted the POAC-QG protocol.

In the developed simulation environment, the condition of any wireless link was modeled using a finite-state machine with three states (low BER, high BER, and "out of range") [12]. The time spent by a link in each state is exponentially distributed. The status of a link probabilistically changes between the three states. The default values of the network parameters agree with the standard's specifications. The maximum percentage of the superframe reserved for RT transmissions is 0.95, and the overhead considered for every real-time traffic packet includes the physical, MAC, RTP, UDP, IP, and SNAP headers. The simulation results are produced by a statistical analysis based on the "sequential simulation" method. We used 95% confidence intervals.

In our scenario, we have live voice and video communications (two-way transmissions) between the adjacent stations and a video on demand TS transmitted by the AP to each station. The characteristics of the network traffic can be found in Table II. The simulated WLAN consists of 10 stations (that is 30 TSs). It should be noticed that we do not drop the packets that exceed their delay bound, so as to get results from all packet transmissions.

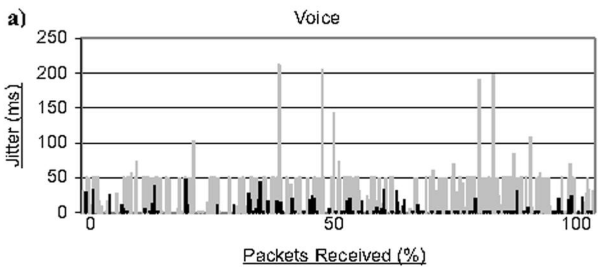
TABLE II: CHARACTERISTICS OF THE TRAFFIC USED IN OUR SIMULATION

Application	Coding	Packet Data Size (bytes)	Packet Interarrival Time (ms)	Data Bit Rate	Packet Delay Bound (ms)
Voice (Priority: 6)	G.711 (PCM)	160	20	64 Kbps (CBR)	50
Live Video (Priority: 5)	H.261 [QCIF]	Exponential [20-1024] Mean: 660	Exponential Mean: 26	~200 Kbps (VBR)	100
Video on Demand (Priority: 4)	MPEG-4 [4CIF]	800	2	3.2 Mbps (CBR)	200

In Fig. 4, we have plotted the results regarding packet jitter. It is obvious that in all cases POAC-QG exhibits much lower jitter than HCCA. This superior performance of POAC-QG is owed in its ability to adapt to the special resource requirements of every TS and continuously provide the bandwidth actually needed.

V. CONCLUSION

This work proposed the Priority Oriented Adaptive Control with QoS Guarantee (POAC-QG) protocol for WLANs. It can be adapted into the HCF protocol of the IEEE 802.11e standard in place of HCCA. A TDMA scheme is adopted. POAC-QG guarantees QoS both for CBR and VBR traffic, by continuously adapting to their special requirements. It makes extended use of traffic priorities in order to differentiate the TSs. The proposed superframe decreases the total overhead, provides better synchronization, and it potentially allows the use of an efficient power saving mechanism. POAC-QG employs a direct QoS negotiation mechanism that supports multiple quality levels for the TSs. This mechanism and the use of dynamic bandwidth allocation provide support to multiple TSs with best possible quality. The simulation results reveal this behavior and show that POAC-QG always performs superiorly than HCCA. As future work, POAC-QG can be enhanced with a power saving mechanism and it can be combined with an efficient background traffic protocol in place of EDCA in order to form a complete high performance protocol for infrastructure WLANs.



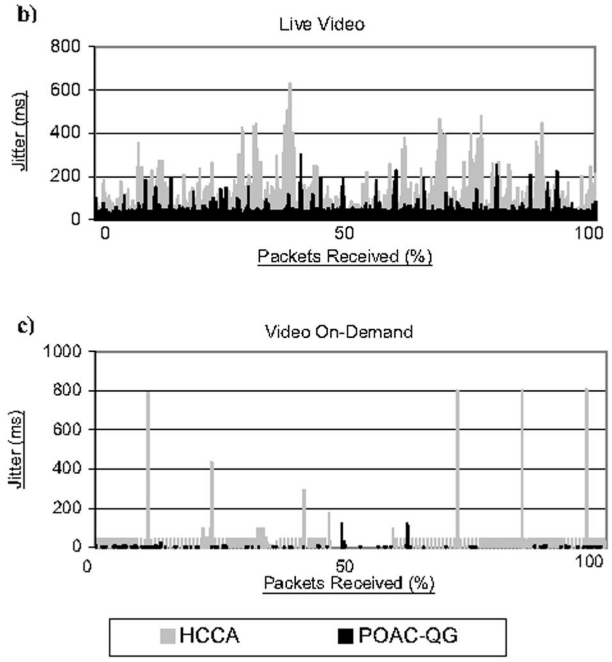


Fig. 4. Packet jitter measurements concerning a) voice, b) live video, and c) video on demand traffic

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