A New Approach to the Design of MAC Protocols for Wireless LANs: Combining QoS Guarantee with Power Saving

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***Abstract*— An alternative WLAN protocol which could be adapted in the HCF access scheme defined by IEEE 802.11e, in place of the HCCA mechanism, is introduced. LEPOAC-QG (Low Energy Priority Oriented Adaptive Control with QoS Guarantee) is a centralized access mechanism that supports low energy consumption, guarantees QoS for all types of multimedia network applications, enhances the parameterized traffic with priorities, and supports time division access. It instantly negotiates the quality levels of the traffic streams trying to support multiple streams with best possible quality. LEPOAC-QG, compared with HCCA, exhibits generally superior performance.**

***Index Terms*— QoS guarantee, adaptive control, power saving, wireless access, time-slots, VBR, quality levels, doze mode.**

I. Introduction

MODERN wireless networks are required to integrate background and real-time traffic. Thus, they should meet all types of traffic demands. Moreover, mobile devices have limited battery energy, thus, power saving is essential. Access control plays a crucial role in QoS support [1]-[8]. The Hybrid Coordination Function (HCF), proposed by IEEE 802.11e [9], considers a contention based (Enhanced Distributed Channel Access - EDCA) and a contention free protocol (Hybrid Control Channel Access - HCCA). HCCA is cell based and able to guarantee QoS in many cases. However, it does not efficiently support Variable Bit Rate (VBR) traffic, while it causes some bandwidth waste. Also, HCCA appears highly energy consuming, since it employs no power saving. Considering the common use of VBR traffic in multimedia applications, and the demand for power saving, a more efficient protocol could be used.

We propose the Low Energy Priority Oriented Adaptive Control with QoS Guarantee (LEPOAC-QG), which is able to operate under HCF. It supports real-time traffic, by providing delay and jitter guarantees even for VBR traffic. The used priorities differentiate the Traffic Streams (TSs). Different Quality Levels (QLs) for the TSs are instantly negotiated, trying to support as many TSs as possible with the best possible quality. Network infrastructure is required. It is assumed 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 provides a Direct Link Protocol (DLP) as an extra feature.

This paper is organized as follows: In Section II, HCCA is briefly reviewed. The LEPOAC-QG protocol is presented in Section III. In Section IV, LEPOAC-QG is compared to HCCA via simulation. Section V concludes the paper.

II. IEEE 802.11e HCCA

The superframe employed by HCF is called beacon interval and is composed by 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. The HCCA mode can be started by the AP several times during a CP and these periods are called Controlled Access Periods (CAPs). The AP polls a station to grant a HCCA-TXOP (Transmission Opportunity: A time interval during which a station is allowed to transmit) according to the station's QoS requests. These are defined using traffic specifications (TSPECs) which describe characteristics of the TSs, such as the mean data rate, the MAC Service Data Unit (MSDU) size and the maximum Required Service Interval (RSI). The scheduling algorithm employed by HCCA uses the TSPECs to calculate the TXOPs. Specifically, a TXOP should be long enough to transmit all packets generated during a SI (Service Interval: the time interval between any two successive TXOPs allocated to a station).

There are some drawbacks concerning the operation of HCCA. Since the scheduler considers fixed TXOPs, it is unable to efficiently support VBR traffic, while this type of traffic is generated by numerous applications. Furthermore, the use of polling packets and acknowledgements are bandwidth costly. Also, it fails to efficiently differentiate the TSs, because it does not employ real-time traffic priorities. Lastly, no energy conservation is supported. Thus, it becomes clear that a more efficient protocol could be probably used.

III. The LEPOAC-QG Protocol

LEPOAC-QG considers a superframe separated into realtime traffic (RT) and background traffic (BT) periods. It operates during the RT periods, which are contention free. Every station can freely participate in the BT period, which involves the independent use of a contention-based scheme, like EDCA. The periods defined in the HCF superframe are suitable for adapting LEPOAC-QG in place of HCCA (BT periods in place of CPs and RT periods in place of CFPs-CAPs). A TDMA scheme is employed in order to reduce

Manuscript received February 27, 2006. The associate editor coordinating the review of this letter and approving it for publication was Prof. Carla-Fabiana Chiasserini.

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Digital Object Identifier 10.1109/LCOMM.2006.060290.

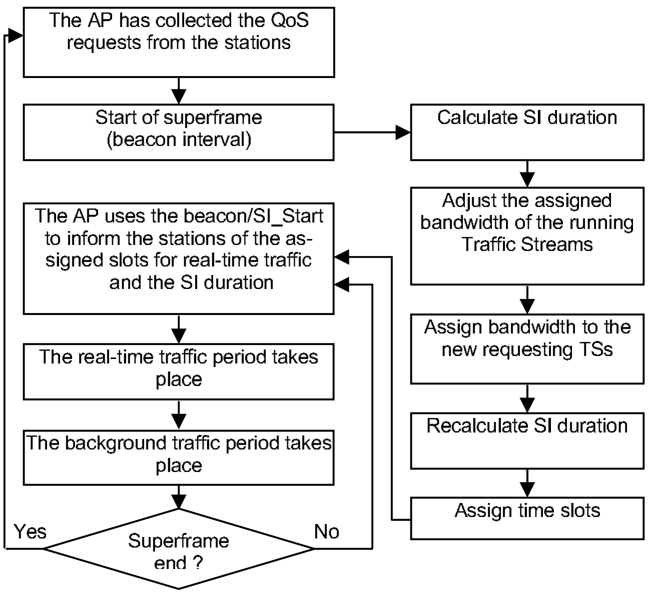

Fig. 1. LEPOAC-QG operation overview.

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. We exploited the latter feature to implement a power saving mechanism. Specifically, since stations are aware of the scheduled TS transmissions, they can stay in a low power "doze" mode during those slots that do not involve any data exchange concerning them. Thus, there are no packets to buffer during the doze period, so no forwarding is needed. The AP uses the beacon signal in the beginning of the superframe to inform stations of the assigned slots and the duration of the SIs. In the beginning of every SI, except from the first one in the superframe, the AP broadcasts a SI_Start message which carries the same information with the beacon signal. If a station fails to receive the latter, it stays awake and defers, until it successfully receives a SI_Start message (or a new beacon). Generally, LEPOAC-QG and HCF adopt the same superframe structure. Of course, in LEPOAC-QG, the AP is enhanced with new admission control and dynamic bandwidth assignment, while the TSPECs involve multiple QLs. Standard HCF stations can still operate in a LEPOAC-QG WLAN only during the BT periods using EDCA.

Commonly, a multimedia application supports multiple QLs. The admission control negotiates simultaneously all the QLs. The higher the QL is, the higher are the resource requirements (bandwidth, delay). The point is to serve as many TSs as possible, favor the higher priority TSs, and provide the higher possible QLs. A station's QoS request includes the TSPECs of the QLs for both running and new TSs. This way VBR traffic can be supported. In Fig. 1, an overview of the LEPOAC-QG operation is presented. Actually, the only additional control overhead introduced by LEPOAC-QG is the SI_Start message, however, no polling messages are employed, thus, the total overhead is lower than that of HCF.

Initially, the new requesting TSs are sorted (highest priority first). The admission control examines first the highest priority TS and checks if there is enough bandwidth to serve it with maximum QL. Otherwise, the QoS requirements of the next

TABLE I

EXAMPLE OF THE TRAFFIC SREAM ADMISSION PROCEDURE

	Priority_A TS	Priority_B TS	Priority_C TS	Priority_D TS
Case 1	High QL	Out (Rejected)	Low QL	High QL
If more than the available bandwidth is required, then proceed to case 2				
Case 2	High QL	Out (Rejected)	Low QL	Low QL
If more than the available bandwidth is required, then proceed to case 3				
Case 3	Low QL	Out (Rejected)	High QL	High QL
If more than the available bandwidth is required, then proceed to case 4				
Case 4	Low QL	Out (Rejected)	High QL	Low QL
If more than the available bandwidth is required, then proceed to case 5				
Case 5	Low QL	Out (Rejected)	Low QL	High QL
If more than the available bandwidth is required, then proceed to case 6				
Case 6	Low QL	Out (Rejected)	Low QL	Low QL
If more than the available bandwidth is required, then proceed to case 7				
Case 7	High QL	Out (Rejected)	Low QL	Out (Rejected)

highest QL are checked. If neither the minimum QL can be served, then the TS is rejected and the TS of the next highest priority is examined. When there is not enough bandwidth to serve a TS with minimum QL, then the QLs of the previously examined higher priority TSs are lowered so as to save some bandwidth for the new TS. When the QLs of the high priority TSs are lowered, we also check if it becomes possible to increase the QLs of the low priority TSs. Thus, the best combination of QLs is served. An example is presented in Table I, where we have two QLs (High QL, Low QL) 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. Each time, we check if there is enough bandwidth to serve the TSs with the corresponding QLs. If there is not, we proceed to the next best QLs combination. The final case is the rejection of the examined TS (QL: OUT).

LEPOAC-QG efficiently supports VBR traffic by adapting to the dynamic requirements of the TSs. Each station calculates the current traffic rate of all its running TSs by counting the generated bits for a short time. The result is included in the QoS request along with the size of the corresponding packet buffer. The AP tries to provide the bandwidth needed for the transmission of all the new and buffered packets of a TS. When the RT bandwidth is not enough, a proportion of the requested bandwidth is assigned 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 the current rate is $CurrentTR$. Sharp and consecutive alterations of the allocated bandwidth are undesirable, thus, a proportion of the requested bandwidth accession or reduction is considered to be the target. Finally, the 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 0.8) is the percentage of the requested bandwidth accession or reduction which is considered to be the target. The algorithm calculates the percentage of the available bandwidth that each requesting TS deserves (eligible bandwidth). The weights W_PR (default 5) and W_BW (default 1) control the contribu-

TABLE II
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

tion of the traffic priority and the requested extra bandwidth, respectively, 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 requested extra bandwidth. In order to favor the AP TSs, we multiply the AP's $Per[i]$ with the factor W_AP (default 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 II. This dynamic bandwidth assignment completes the support provided by LEPOAC-QG to VBR traffic.

IV. Simulation Results

A simulator in C++ was developed in order to compare LEPOAC-QG against HCCA. The considered physical layer protocol is IEEE 802.11g. The condition of any link was modeled using a stochastic finite-state machine. The maximum percentage of the superframe reserved for RT period is 0.95. We have live voice and video communications (bidirectional transmissions) between the adjacent stations and a video on demand TS transmitted by the AP to each station.

In Fig. 2 we plotted the results regarding packet jitter of the live video VBR traffic in a 10-station (that is 30 TSs) WLAN. It is obvious that LEPOAC-QG exhibits lower jitter than HCCA. Fig. 3 represents the total energy consumption during the real-time traffic communications as the number of stations varies. Because of the proposed power saving mechanism, in LEPOAC-QG, the devices stay for a significant proportion of time in doze mode instead of being idle, resulting in clearly lower total power consumption. The considered values of power are 1.65W, 1.4W, 1.15W, and 0.045W in transmit, receive, idle, and doze modes, respectively, while the doze-idle transition time is 0.8ms [10]. Of course, the low-power doze mode concept is known, however, the presented mechanism which involves power saving according to the slots allocation and without any performance degradation is innovative.

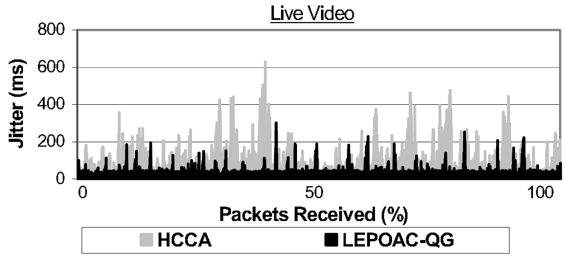

Fig. 2. Packet jitter measurements concerning live video traffic

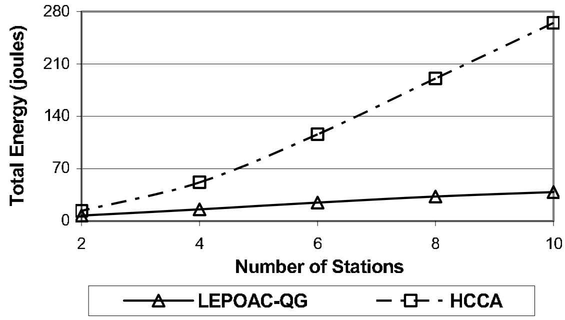

Fig. 3. Total energy consumption during RT communications

V. Conclusion

This paper proposed the LEPOAC-QG protocol which can be adapted into the HCF protocol of the IEEE 802.11e standard in place of HCCA. A TDMA scheme is adopted. It guarantees QoS even for VBR traffic. Extended traffic priorities differentiate the TSs. The proposed superframe decreases the total overhead, provides better synchronization, and it allows the use of an efficient power saving mechanism. LEPOAC-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 show that LEPOAC-QG always performs superiorly than HCCA, while it conserves significant amount of energy with no performance degradation. As future work, LEPOAC-QG can be combined with an efficient background traffic protocol in place of EDCA in order to form a complete high performance protocol for WLANs.

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