Low Energy Priority Oriented Adaptive Control with QoS Guarantee for Wireless Networks

T. D. Lagkas, G. I. Papadimitriou, *Senior Member, IEEE*, P. Nicopolitidis, and A. S. Pomportsis

Department of Informatics, Aristotle University, Box 888, 54124 Thessaloniki, Greece.
e-mail: tlagkas@csd.auth.gr

This work introduces an alternative WLAN protocol which could be adapted in the HCF access scheme defined by IEEE 802.11e, in place of the HCCA mechanism. LEPOAC-QG (Low Energy Priority Oriented Adaptive Control with QoS Guarantee) is a complete centralized channel access mechanism that supports power saving, 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. 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.

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. Thus, today's WLANs should be able to meet all types of traffic requirements. Furthermore, the mobile devices used in WLANs have limited battery lifetime, thus, the adoption of a power efficient scheme is needed.

Medium access control plays a crucial role in QoS support [1]-[9]. The Hybrid Coordination Function (HCF), proposed by IEEE 802.11e [10], 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. Also, HCCA appears highly energy consuming, since it employs no power saving. Considering the importance of the VBR traffic support, the fact that bandwidth is scarce, and the need for energy conservation, a more efficient protocol could be used.

This work proposes the Low Energy Priority Oriented Access Control with QoS Guarantee (LEPOAC-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). LEPOAC-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.

The IEEE 802.11e Hybrid Control Channel Access

The HCF access control uses a superframe, defined as beacon interval, 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 (Traffic Streams), 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 of the requesting TSs to calculate the TXOPs. The scheduler concept is that 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).

HCCA is able to guarantee QoS in many cases. However, there are some drawbacks concerning its operation. Since the scheduler considers fixed TXOPs, it is unable to efficiently support VBR traffic, while this kind of traffic is generated by numerous multimedia network 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. It becomes obvious that a more efficient protocol could be probably used. Lastly, as it is already mentioned, it does not adopt any power saving mechanism.

The LEPOAC-QG Protocol

The proposed LEPOAC-QG protocol considers a superframe separated into real-time traffic (RT) and background traffic (BT) periods. It 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 LEPOAC-QG into it, in place of HCCA. A TDMA scheme is employed in order 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. We exploited this feature to implement a power saving mechanism in our model, which seems essential due to the scarce battery power of the mobile devices. Specifically, since stations are aware of the coming TS transmissions, they can stay in a low power "doze" mode during the RT period and "wake" only to exchange data. In a real network, each station spends most of the time in "idle" mode, thus, the proposed mechanism can save a significant amount of power. The AP uses the beacon signal to inform the stations of the assigned slots decided by the scheduler based on the TS QoS requests.

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. A running TS can ask for a new 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 running TSs are examined first to keep the quality of the existing communications steady. The rest of the bandwidth is then assigned to new TSs, according to the admission control. Finally, the slots are assigned to the running and the new accepted TSs. In Fig. 1, an overview of the processes defined by LEPOAC-QG is presented.

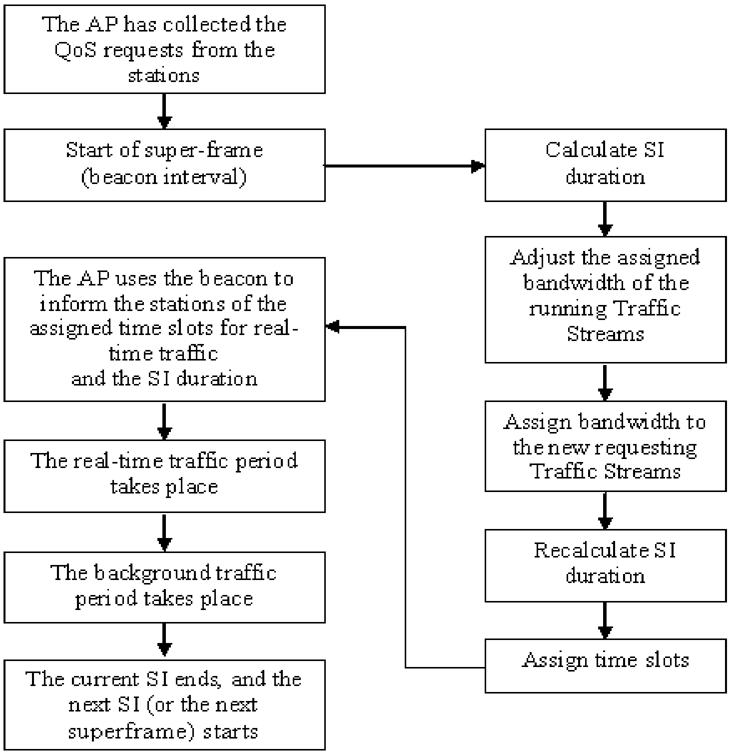

Fig. 1. LEPOAC-QG operation overview

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 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 the TS admission process is depicted in Fig. 2, 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, always trying to ensure the best possible quality levels combination. The final case is the rejection of the examined TS (quality level: OUT).

The LEPOAC-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. 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

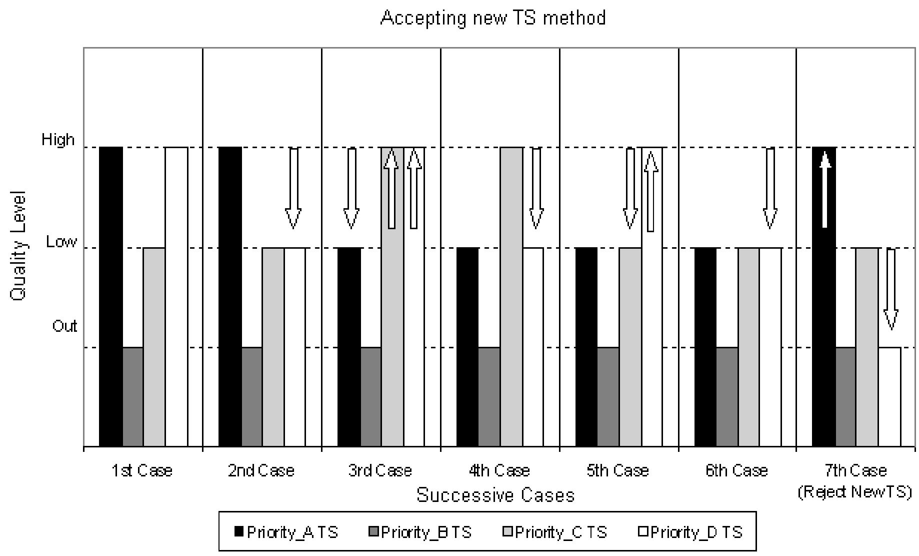

Fig. 2. Example of the quality levels negotiation when examining the admission of new traffic streams

the running TSs according to their new QoS requests, trying to provide the bandwidth needed for the transmission of all the new and buffered packets. 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. Sudden and continuous alterations of the allocated bandwidth are undesirable, thus, a proportion of the requested bandwidth accession or reduction is considered to be the target. 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. The algorithm which distributes the available bandwidth initially calculates the percentage of it 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 LEPOAC-QG to VBR traffic.

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

Table I: Example of assigning extra requested bandwidth

The proposed power saving mechanism is based on the knowledge of the coming RT transmissions. The stations that receive the beacon signal are aware of the slots assigned to the TSs of the requesting stations. Thus, apart from knowing when they are supposed to transmit data, the stations also know when to expect data destined for them. During these time intervals, they have to be fully operational, however, in the rest of the RT period they can transit to “doze” mode instead of being “idle”. A station in doze mode is extremely low consuming, since its antenna is actually turned off. However, there is no performance degradation, because a station gets into doze mode only when it is certain that there would be no data exchange concerning it.

Performance Evaluation

In order to compare LEPOAC-QG against HCCA, we developed a simulator in C++. The considered physical layer protocol is 802.11g [11]. The maximum percentage of the superframe reserved for RT period is 0.95. The results are produced by “sequential simulation”. 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 WLAN consists of 10 stations (that is 30 TSs).

In Fig. 2, we plotted the results regarding packet jitter of the live video VBR traffic. It is obvious that LEPOAC-QG exhibits lower jitter than HCCA. In Fig. 3, the average power consumption per station is depicted. Because of the proposed power saving mechanism, in LEPOAC-QG, the mobile 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 [12].

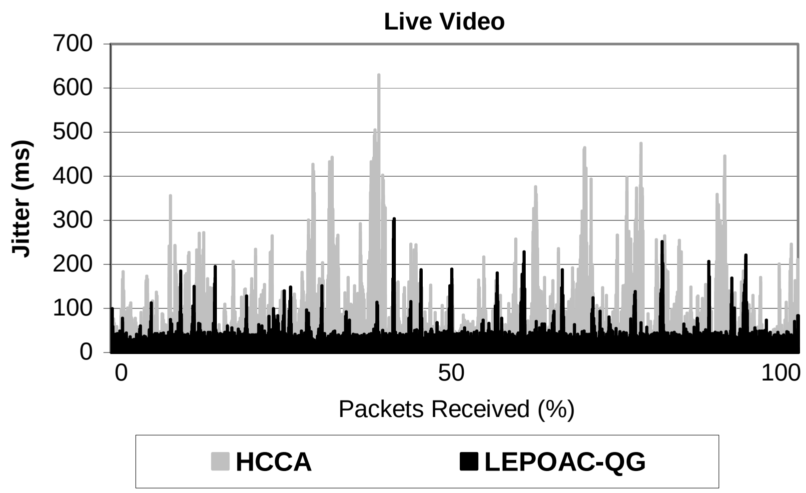

Fig. 3. Packet jitter measurements concerning live video VBR traffic

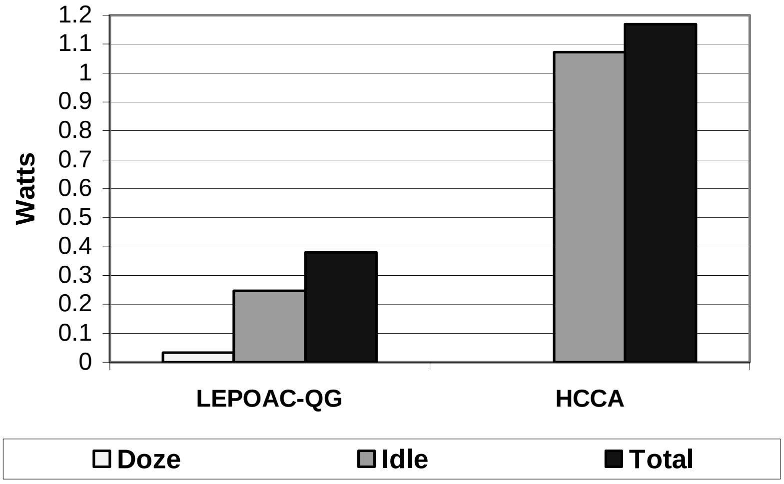

Fig. 4. Average power consumption per mobile station

Conclusively, the LEPOAC-QG protocol appears able to provide full QoS support and significant power saving compared to IEEE 802.11e HCCA, in a WLAN. As future work, it could be combined with an efficient alternative of the EDCA BT access control.

References

[1] T. D. Lagkas, G. I. Papadimitriou, and A. S. Pomportsis, "A High Performance QoS Supportive Protocol for Wireless LANs," Proceedings of IEEE MELECON 2004, pp. 571-574, Croatia, 2004.

[2] P. Nicopolitidis, M. S. Obaidat, G. I. Papadimitriou and A. S. Pomportsis, "Wireless Networks", Wiley, January 2003.

[3] T. D. Lagkas, G. I. Papadimitriou, and A. S. Pomportsis, "HIPERSIM: A Sense Range Distinctive Simulation Environment for HiperLAN Systems," Simulation, Transactions of The Society for Modelling and Simulation International, Volume 79, Number 8, pp. 462-481, August 2003.

[4] P. Nicopolitidis, G. I. Papadimitriou and A. S. Pomportsis, "Distributed Protocols for Ad-Hoc Wireless LANs: A Learning-Automata-Based Approach", Ad Hoc Networks, Elsevier, vol.2, no.4, October 2004, pp. 419-431.

[5] P. Nicopolitidis, G. I. Papadimitriou, A. S. Pomportsis, "Learning-Automata-Based Polling Protocols for Wireless LANs", IEEE Transactions on Communications, vol.51, no.3, pp. 453-463, 2003.

[6] P. Nicopolitidis, G. I. Papadimitriou, and A. S. Pomportsis, "Using Learning Automata for Adaptive Push-Based Data Broadcasting in Asymmetric Wireless Environments", IEEE Transactions on Vehicular Technology, vol.51, no.6, pp. 1652-1660, Nov. 2002.

[7] Imrich Chlamtac, Marco Conti, Jennifer J.-N. Liu, "Mobile ad hoc networking: imperatives and challenges," ELSEVIER Ad Hoc Networks 1, 13-64, 2003.

[8] Ajay Chandra, V. Gumalla, and John O. Limb, "Wireless Medium Access Control Protocols," IEEE Communications Surveys, pp. 2-15, Second Quarter 2000.

[9] Ian F. Akyildiz, Janise McNair, Loren Carrasco, Ramon Puigjaner, "Medium Access Control Protocols for Multimedia Traffic in Wireless Networks," IEEE Network Magazine, vol. 13, no. 4, pp. 39-47, July / August 1999.

[10] IEEE 802.11e WG, "Draft Amendment to Standard for Information Technology--Telecommunications and Information Exchange Between Systems-LAN/MAN Specific Requirements-- Part 11 Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 7: Medium Access Control (MAC) Quality of Service (QoS) Enhancements," D13 2005.

[11] IEEE 802.11g WG, International Standard for Information Technology–Telecommunications and Information Exchange between systems-Local and metropolitan area networks-Specific Requirements-Part 11:Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 4: Further Higher Data Rate Extension in the 2.4GHz Band, 2003.

[12] Eun-Sun Jung, N.H. Vaidya, "An energy efficient MAC protocol for wireless LANs," in Proc. INFOCOM, IEEE Vol. 3, 23-27 June 2002, Page(s):1756 – 1764.