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FILLING THE GAPS IN ORDER TO OFFER QoS GUARANTEES IN IEEE 802.11 WLANs

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Abstract

Current IEEE 802.11 standards are not capable of offering Quality-of-Service (QoS) guarantees to WLAN users. This is mainly due to some gaps existing in their MAC protocol. Even the QoS features of the new extension, IEEE 802.11e draft standard, do not suffice. It still needs connection admission control techniques to avoid saturating the wireless medium and service differentiation in order to fairly and efficiently share the available resources when it comes to packet (or frame) scheduling.

The main goal of this work is to introduce two essential ingredients, connection admission control and packet scheduling, in the MAC protocol of IEEE 802.11 WLANs in order to actually offer QoS guarantees to their users. This is essential if multiple services, with diverse QoS requirements, are to be offered in such networks.

Keywords - WLANs; QoS; MAC; CAC; packet scheduling disciplines.

Introduction

IEEE 802.11-based wireless networks have been widely accepted by home and business users. With the growing interests of new applications such as video and multimedia streaming over wireless network, it also brings unique and challenging QoS requirements. So far, the popular approaches to provide multimedia users with QoS guarantees, proposed by the IETF, are IntServ [1] and DiffServ [2], along with all the underlying technologies and protocols. These resource-reservation and service-differentiation mechanisms are implemented at the network (or IP) layer. This means that WLAN mobile terminals will not be able to receive the treatment they deserve if there is no differentiation when it comes to competing for the wireless medium at the MAC level. Another issue related to IntServ is that resource reservation mechanisms need to have an end-to-end scope, but so far there is no admission control (hence no resource reservation) with local significance within the wireless segment.

The MAC protocol of IEEE 802.11 standards contains an optional mechanism that is supposed to be enough for providing proper QoS services for real-time applications. This mechanism, known as Point Coordination Function (PCF), allows real-time applications to periodically transmit contention-free frames during certain intervals, called Contention-Free Periods (CFPs). The provided guarantee is that at least one frame of one of the registered stations will be sent during each CFP. This is not enough in most situations since not all real-time applications have the same QoS needs in practice. There are some proposed extensions to this MAC protocol under discussion, documented in the IEEE 802.11e draft standard. They allow for CFPs to start anywhere in the transmission superframe, as needed to satisfy QoS criteria. However, the important issues of how to locally limit the amount of traffic that competes for the wireless medium and how to decide which backlogged real-time connection to service first and which next remain open.

The main goal of this research work is to introduce connection admission control techniques and packet scheduling disciplines at the MAC level of IEEE 802.11 WLANs in order to offer QoS guarantees. Though there is previous work related to packet scheduling, some of these differentiation schemes are implemented locally within the AP or within mobile stations. Some of them are performed at the network (IP) layer only. And, in some cases, the decisions are made with incomplete information. Here, we propose a novel scheme that can achieve an effective and efficient service differentiation at the MAC level of a wireless segment.

IEEE 802.11 and 802.11e MAC protocols

The IEEE 802.11-1999 MAC protocol [3] [4] defines two transmission modes for data packets: the CSMA/CA-based Distributed Coordination Function (DCF) and the optional contention-free PCF mentioned above. Both the DCF and PCF modes are time-multiplexed in a superframe formed by a PCF contention-free period (CFP) and a DCF contention period (CP). The boundaries between CFPs and CPs are marked by beacons transmitted by the AP. During each CP, all stations compete with each other to gain access to the available wireless medium. The physical layer provides a clear channel assessment (SSA) signal to the MAC to indicate if the channel is available or not. All waiting stations are equally likely to get to transmit a frame since there is no mechanism in the protocol to give some stations more rights than others. During each CFP, the Point Coordinator (PC) in the Access Point (AP) will poll each terminal in the polling list and accept the response frames. It is a continuous exchange of frames with no backoff or contention. Each terminal that wants its transmissions scheduled by the PCF needs to submit its request to the AP in the previous CP. However, there is no specification of how to select the stations that will be polled and no guarantee of frame delivery within a certain timeframe. So, the MAC protocol defined in the IEEE 802.11 standard cannot fulfill the QoS requirements of multimedia applications.

Since the PCF has limited capability to deliver QoS and has not been widely implemented, the IEEE 802.11 Task Group E has undertaken the definition of a new standard, namely IEEE 802.11e [5] [6] [7], in which two enhanced schemes are introduced, EDCF (enhanced DCF) and HCF (Hybrid Coordination Function). EDCF is basically used to give some stations a higher priority than others by manipulating both the time a station senses the medium to decide if it is free (called AIFS) and the backoff time. The AIFS period is shorter for higher-priority stations allowing them to win over the lower-priority ones. Likewise, even though the backoff time is selected randomly, the set of possible values for a higher-priority station includes smaller values than those allowed for a lower-priority one, establishing again an advantage for the former. HCF, on the other hand, introduces a Hybrid Coordinator (HC), which extends the notion of PC. In addition to controlling the CFPs, the HC can also gain access to the channel during the CPs (using its advantage over the other stations) as needed to satisfy QoS criteria. One of the most interesting features of HCF for this work is the introduction of *controlled contention*, which is a mechanism that reserves short periods of time for stations to request the allocation of transmission opportunities (TXOPs) by sending resource requests to the HC. Here, users and traffic streams can be classified into several traffic categories (TCs), depending on the priority they need. A controlled contention starts when the HC sends a specific control frame that includes a filtering mask indicating which TCs are allowed to place a request. Each backlogged station with a TC matching the filtering mask transmits a resource request frame containing either the needed TXOP duration or its queue size. These requests may be to initiate periodic polled TXOPs to handle traffic under a TSPEC, or for one-time TXOPs to handle a traffic burst, or to create an initial TXOP for a newly active traffic stream. Though IEEE 802.11e includes several new features that facilitate and promote the provision of QoS guarantees to the users, there is no mechanism in the protocol to avoid sturating the medium with excessive traffic or a mechanism for the HC to decide how to assign the available resources. It is here where our proposal finds its usefulness.

<u>Survey of previous work related to packet scheduling</u>

In what follows, a brief description will be given about previous work related to packet scheduling disciplines proposed to be used in WLAN MAC protocol.

Sharma et al describe a “Wireless Rether protocol” [8], which consists of a token-passing algorithm where the amount of data a token holder can send depends on its QoS requirements. Since the tokens travel from one terminal to another through the AP, this mechanism is equivalent to a weighted-round-robin (WRR) polling mechanism, which may be easier to incorporate into the IEEE 802.11 MAC protocol than the wireless Rether protocol. We have run some experiments and shown that WRR is not a good option in the sense that it introduces extra delay because of the many wasted polls sent [9].

Zhao and Fan propose to reduce the overhead of the MAC protocol by using hub polling and by avoiding the use of ACKs to acknowledge real-time data frames, based on the assumption that real-time applications are not very sensitive to losses [10]. In hub polling the stations affix a go-ahead message to their data frames in order to signal the next station in the polling list to start transmitting without waiting to be polled. We do not follow any of these two proposals since in our approach the sequence in which stations transmit is not static; hence it is not possible for the mobiles to know beforehand which will be the next station allowed to transmit. In addition, we believe that both real-time and non-real-time applications are to some extent sensitive to losses, which makes ACKs necessary, not to mention the fact that not sending ACKs saves us only an insignificant amount of channel capacity. Moreover, in spite of the title, the proposal in [10] does not introduce service differentiation, which is essential for QoS provision. Though some work has been done related to service differentiation in wireless LANs (e.g. [11]), the differentiation is local, either within the AP or within the mobile stations. So, when a station has an opportunity to send a packet it will decide which packet to send first from among all the backlogged classes it services, but the high-priority packets in this station have no advantage over low-priority packets in another station. Moreover, differentiation is usually done at the network (IP) layer [11] [12], which results to be useless if there is no differentiation among the mobiles when competing for the wireless medium at the MAC level.

There is another proposal of a dynamic bandwidth reservation algorithm based on using opportunities during the CP to reserve bandwidth that will be used during the CFP [13]. The scheme is originally intended to be used in *ad hoc* networks. The relevant paper [13] describes a mechanism that allows terminals running real-time applications to enter a list of terminals that have the right to send frames during the CFP, and dynamically reserve and release bandwidth. Since there is no AP to control the CFP in *ad hoc* networks, this protocol is a good enhancement to improve the performance of the DCF mechanism alone. Nonetheless, it is hard to know if all the active stations, which enter the list at their own discretion, will be able to get the resources they need.

There are also many other schemes introducing QoS guarantees by enhancing the DCF mechanism [14] [15] [16]. Some of them served as the basis for EDCF. However, DCF is based on contention of an unspecified number of competing stations and therefore offers no guarantees. Even EDCF gives only relative guarantees (it gives some users more rights than others) and cannot guarantee absolute bounds on QoS parameters (delays, losses, throughput, jitter, etc). This is why we decided to base our proposal on PCF, which includes some sort of admission control in the sense that the stations must register with the PC before using the service.

In [17], different packet scheduling mechanisms (including round robin, FIFO, priority, and priority ELF) are used with PCF to improve the efficient use of the wireless medium. However, these packet-scheduling mechanisms are implemented in a centralized fashion within the PC and base their decisions on the occupancy of the PC buffers. In other words, the mobile terminals play no role in the decisions and the PC makes no effort to collect and use information about the buffers in those terminals. In [18], on the other hand, DRR (Deficit Round Robin) is employed to share the resources among downlink connections since the packet sizes are known and DDRR (Distributed DRR) to share the resources among uplink connections since the packet sizes are unknown. The problem with this approach is that both uplink and downlink connections share the same medium and it would be better to use only one technique in order to avoid confusions and duplicated calculations.

In our proposal, the mobile stations share information with the PC that will be used to implement an efficient packet scheduling discipline at the MAC level, in which the decisions are made with as much information as possible. The advantage of this approach is that the resource sharing is effectively implemented as part of the MAC protocol, which is where the primary and most critical competition for resources takes place.

Research strategy

1. Study of queue management, service assignment, and bandwidth sharing strategies of several packet-scheduling mechanisms, including WFQ, PWFQ, and DWRR [19] [20] [21].
2. Analysis of the requirements to combine PCF with the above-mentioned packet-scheduling (PS) mechanisms.
3. Simulation of the original PCF and its combination with the above-mentioned packet-scheduling mechanisms.
4. Performance comparison.
5. Study of different GPS-compatible connection admission control (CAC) mechanisms, and selection of the most suitable as a method to avoid overloading the wireless medium.
6. Analysis of the requirements to combine PCF with the above-mentioned CAC mechanism.
7. Simulation of PCF combined with the above-mentioned CAC mechanism.
8. Performance comparison.
9. Preparation of technical report with results, conclusions, and recommendations.

Schedule

ACTIVITY	FIRST QUARTER			SECOND QUARTER			THIRD QUARTER			FOURTH QUARTER		
1. Queue management	••••											
2. Requirements (PCF+PS)		••••										
3. Simulation (PCF+PS)		••••	••••	••••								
4. Comparison				••••	••••							
5. CAC mechanisms						••••						
6. Requirements (PCF+CAC)							••••					
7. Simulation (PCF+CAC)							••••	••••	••••			
8. Comparison									••••	••••		
9. Technical report		••••	••••	••••	••••	••••	••••	••••	••••	••••	••••	••••

Industries where relevant

This work may be of interest to industries related to the following areas:

- Wireless communications and networking (e.g. Cisco, Verizon, Nortel, 3Com)
- Home networking industries (e.g. Belkin, D-link, Microsoft, Motorola, Netgear)

Or to any of the over 200 companies that are members of the Wi-Fi Alliance (e.g. Hewlett-Packard, Intel, Siemens, Hughes, Nokia). The complete list of Wi-Fi Alliance members can be found in the following web page:

http://www.wifialliance.com/OpenSection/members.asp

Conclusions

WLANs based on current IEEE 802.11 standard and IEEE 802.11e draft standard are not yet capable of offering QoS guarantees to their users. The reason for this is the fact that two essential ingredients are still missing in the MAC protocol: connection admission control and service differentiation. We propose here a strategy to introduce both of these ingredients into the PCF mechanism of the MAC protocol in order to have WLANs than can effectively and efficiently provide real-time multimedia services with different QoS requirements.

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