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Extended EDCA for delay guarantees in wireless local area networks

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ABSTRACT

Despite their very broad diffusion, IEEE 802.11 Wireless Local Area Networks (WLANs) are not able to provide service differentiation and to support real-time multimedia applications, due to their channel access methods. To overcome these limitations, the 802.11e working group has proposed the Enhanced Distributed Coordination Access (EDCA) scheme, which achieves service differentiation on a statistical basis by properly mapping user Quality of Service (QoS) requirements to channel contention parameters. Such a scheme will be included in the emerging 802.11n standard and in the revision of the 802.11 standard. However, it has been widely demonstrated that, especially at high network loads, EDCA does not provide an effective usage of the channel capacity. In particular, it is unable to provide a bounded delay service to all kinds of multimedia flow because flows with lower channel access priorities are starved to advantage only those with the highest priority. To fix this undesired behavior and improve wireless LAN performance, this paper proposes a new Extended EDCA (E^2DCA) scheme, that is compliant with 802.11e specifications. By exploiting a closed-loop control algorithm, E^2DCA performs a distributed dynamic bandwidth allocation, providing guarantees on average/absolute delays to real-time media flows, regardless of their priorities. Moreover, an innovative Call Admission Control (CAC) procedure has been developed. Using the *ns*-2 simulator, the effectiveness of the algorithm has been investigated in realistic network scenarios, involving a mix of audio, video, and FTP flows, at several network loads and with random losses. Results have shown that the proposed scheme is able to provide a bounded delay service to multimedia flows in a wide range of network loads and frame loss ratios.

1. Introduction

IEEE 802.11 Wireless Local Area Networks (WLANs) are widely employed for ensuring ubiquitous networking due to their easy installation, flexibility, and robustness against failures [1]. Despite its very broad diffusion, the 802.11 Medium Access Control (MAC) cannot support real-time applications, characterized by strict constraints on packet delay and jitter [2–4]. In fact, the 802.11 MAC employs a mandatory contention-based channel access scheme, known as the Distributed Coordination Function (DCF), which, being based on CSMA/CA [5], does not provide guaranteed services.

To overcome this limitation, the 802.11e working group proposed some innovations: the Hybrid Coordination Function (HCF), which is an enhanced access method; specific signaling messages for service request and Quality of Service (QoS) level negotiation; and four Access Categories (ACs) with different priorities to map users' QoS requirements [6]. In particular, the HCF is in charge of assigning TXOPs (Transmission Opportunities) to each AC in order to satisfy its QoS needs, where TXOP is defined as the time interval during which a station has the right to transmit and it is characterized by a starting time and a maximum duration.

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Table 1
EDCA contention parameters.

Designation	AC	Minimum *CW*	Maximum *CW*	AIFS
Background	AC_BK	$CW_{\min}$	$CW_{\max}$	7
Best effort	AC_BE	$CW_{\min}$	$CW_{\max}$	3
Video	AC_VI	$\frac{CW_{\min}+1}{2}-1$	$CW_{\min}$	2
Voice	AC_VO	$\frac{CW_{\min}+1}{4}-1$	$\frac{CW_{\min}+1}{2}-1$	2

Such modifications to the MAC layer are included in the ongoing new revision of the 802.11 standard [7], which has been conceived to incorporate 802.11a [8], 802.11b [9], and 802.11g [10] standards, and several other 802.11 amendments (e.g., 802.11e standard [6]).

Moreover, it is worthwhile to note that the importance of the HCF scheme is not only restricted to 802.11a/b/g WLANs. In fact, the emerging IEEE 802.11n standard is designed for achieving a data rate up to 100 Mbps by considering a new physical layer and by using just the HCF as the access function at MAC layer [11].

In the HCF, time is divided into repeated periods (i.e., superframes), and two new channel access methods are introduced: Enhanced Distributed Coordination Access (EDCA), which is a contention-based access scheme; and HCF Controlled Channel Access (HCCA), which requires a centralized controller, generally located at the Access Point (AP).

EDCA operates as the basic DCF method [1], but using different contention parameters per AC. A queue is associated to each AC at any station with QoS capabilities (i.e., QoS station, QSTA), acting as a virtual station with its own QoS parameters. Each queue within a station contends for a TXOP and defers its transmission until the channel is sensed idle for a time interval, known as the Arbitration Interframe Space (AIFS), plus an additional random backoff time, a multiple of a slot time by an integer taken from a uniform distribution in the interval from 0 to the *Contention Window* (CW). For each class AC_i, a contention window CW_i and an $AIFS_i$ are defined as shown in Table 1[1] [12]. If several backoff timers reach zero within the same station at the same time slot, then the highest priority frame will be transmitted and any lower priority frame will be deferred with a retry procedure, modifying the backoff timer [2,6].

A substantial difference with respect to the DCF is that a virtual station can transmit more than one frame when it gains the access to the wireless medium. In particular, a virtual station will occupy the channel for a TXOP, whose maximum duration limit is advertised by the AP in the beacon frame at the beginning of each superframe. If this advertised maximum TXOP limit is zero, only one frame can be transmitted during each TXOP.

The EDCA scheme statistically pursues a service differentiation among traffic streams [13], but tuning its parameters to provide prioritization of ACs is a research topic [14]. In [15], a method for setting EDCA parameters in order to provide throughput guarantees has been described. Regarding the goal of providing delay guarantees, several papers have pointed out that the EDCA can provide a real-time service to highest priority flows, at the price of starving flows with lower priority, especially at high network load [16–18]. Moreover, it can provide only a relative differentiation among service classes, but not absolute guarantees on throughput/delay performance [13,19].

To overcome these limitations, adaptive algorithms that dynamically tune EDCA parameters have been proposed in [20–26]. In [27], the Enhanced Distributed Contention Control is proposed, which mitigates the contention level on the channel by exploiting an estimate of channel congestion level; it improves the EDCA performance at high loads. In [28], a dynamic mechanism is proposed to adapt the data rate and priority of multimedia wireless stations equipped with IEEE 802.11e network cards. In [29], an adaptive transmission probability has been introduced to ensure the QoS requirements of higher priority classes at high traffic load conditions. In [30], a deterministic priority channel access has been proposed. The proposed scheme uses a busy tone to limit the transmission of lower priority traffic when higher priority traffic has packets to send.

Several schemes have been studied in the literature to define the TXOP limit over EDCA. In [31], a Surplus TXOP Diverted (STXD) scheme has been proposed to define the TXOP limit for per-flow but not for per-AC. The fundamental of the STXD scheme is to regulate the TXOP limit according to per-flow behavior to provide an absolute delay guarantee of VBR flows. In [32], a distribution of the multimedia frame size is used off-line to dimension the TXOP limit in order to minimize the packet delays. In [33], a dynamic TXOP scheme has been proposed to adjust the TXOP limits according to the state of the transmission queue length. When the queue length is below a given threshold, the TXOP limit is set at the default one; on the other hand, if the queue length exceeds the threshold, the algorithm sets a new larger TXOP limit value than the default one to better manage a bursty traffic.

It is important to note that the summarized approaches have the main limitations of being not compliant with the standard (such as those proposed in [31–33]), or of being proved only using simulations without giving any theoretical bounds on their performance in a general scenario (such as those proposed in [20–30]).

This paper proposes a new Extended EDCA (E^2DCA) scheme (compliant with 802.11e specifications) which performs a distributed dynamic bandwidth allocation among wireless stations, providing to real-time media flows guarantees on average and absolute delays. In particular, each station evaluates its bandwidth needs by exploiting a closed-loop control scheme which uses the transmission queue length as a feedback signal. It is worth noting that E^2DCA requires that each

[1] The contention window limits $CW_{\min}$ and $CW_{\max}$ in Table 1, are not fixed, as with the DCF, but can be variable and are assigned by a management entity or by an AP.