IEEE 802.11e Contention-Based Channel Access (EDCF) Performance Evaluation

Sunghyun Choi[1] Javier del Prado[2] Sai Shankar N[2] Stefan Mangold[2]

[1]Multimedia and Wireless Networking Laboratory (MWNL)
School of Electrical Engineering
Seoul National University, Seoul, Korea
schoi@snu.ac.kr

[2]Wireless Communications and Networking
Philips Research USA
Briarcliff Manor, New York, USA
{javier.delprado,sai.shankar,stefan.mangold}@philips.com

Abstract- **IEEE 802.11e Medium Access Control (MAC) is an emerging supplement to the IEEE 802.11 Wireless Local Area Network (WLAN) standard to support Quality-of-Service (QoS). The 802.11e MAC is based on both centrally-controlled and contention-based channel accesses. In this paper, we evaluate the contention-based channel access mechanism, called enhanced distributed coordination function (EDCF), in comparison with the 802.11 legacy MAC. The EDCF provides differentiated channel access to frames with different priorities. We also consider an optional feature of the EDCF, called contention-free burst (CFB), which allows multiple MAC frame transmissions during a single transmission opportunity (TXOP). Through our simulation study, we conclude that the EDCF can provide differentiated channel access for different traffic types. Furthermore, the CFB is found to enhance the EDCF performance by increasing the overall system throughput and achieving more acceptable streaming quality in terms of frame losses and delays.**

I. INTRODUCTION

In recent years, IEEE 802.11 WLAN [1] has emerged as a prevailing technology for the (indoor) broadband wireless access. Today, IEEE 802.11 can be considered a wireless version of Ethernet by virtue of supporting a best-effort service (not guaranteeing any service level to users/applications). The IEEE 802.11 Working Group is currently defining a new supplement to the existing legacy 802.11 medium access control (MAC) sub-layer in order to support Quality of Service (QoS) [3][6]. The new 802.11e MAC will expand the 802.11 application domain by, for example, enabling such applications as voice and video services.

The mandatory part of the current 802.11 MAC is called the distributed coordination function (DCF), which is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). A new component of the upcoming 802.11e MAC is called the Enhanced DCF (EDCF), which is the enhanced version of the legacy DCF. The EDCF provides differentiated channel access to frames of different priorities as labeled by the higher layer.

In this paper, we compare the legacy DCF and the new EDCF. With the EDCF, a single MAC can have multiple queues that work independently, in parallel, for different priorities. Frames with different priorities are transmitted using different CSMA/CA contention parameters. With the EDCF, a station cannot transmit a frame that extends beyond a time interval called EDCF transmission opportunity (TXOP) limit. If a frame is too long to be transmitted in a single TXOP, it should be fragmented into multiple frames. We also introduce and evaluate a mechanism called the contention-free burst (CFB) [7] that allows a station to transmit multiple MAC frames consecutively as long as the whole transmission time does not exceed the EDCF TXOP limit, which is determined and announced by the access point (AP).

The rest of this paper is organized as follows: Sections II and III describe the 802.11 legacy DCF and the 802.11e EDCF, respectively. After comparing the DCF and the EDCF with/without CFB via simulation in Section IV, the paper concludes with Section V.

II. IEEE 802.11 DCF

The IEEE 802.11 legacy MAC [1] is based on the logical functions, called the coordination functions, which determine when a station operating within a Basic Service Set (BSS)[1] is permitted to transmit and may be able to receive frames via the wireless medium. Two coordination functions are defined, namely, the mandatory DCF based on CSMA/CA and the optional point coordination function (PCF) based on poll-and-response mechanism. Most of today's 802.11 devices operate in the DCF mode only. We explain how the DCF works in this section as it is the basis for the Enhanced DCF (EDCF), which we discuss in this paper.

The 802.11 MAC works with a single first-in-first-out (FIFO) transmission queue. The CSMA/CA constitutes a distributed MAC based on a local assessment of the channel status, i.e., whether the channel is busy (i.e., a station is transmitting a frame) or idle (i.e., no transmission). Basically, the CSMA/CA of DCF works as follows:

When a frame (or an MSDU[2]) arrives at the head of the transmission queue, if the channel is busy, the MAC waits until the medium becomes idle, then defers for an extra time interval, called the DCF Interframe Space (DIFS). If the channel stays idle during the DIFS deference, the MAC then starts the backoff process by selecting a random backoff counter (or BC). For each slot time interval, during which the medium stays idle, the random BC is decremented. When the

---

[1] A BSS is composed of an access point (AP) and multiple stations (STA) associated with the AP.

[2] An MAC Service Data Unit (MSDU) is the unit of data arriving at the MAC from the higher layer.

BC reaches zero, the frame is transmitted. On the other hand, when a frame arrives at the head of the queue, if the MAC is in either the DIFS deference or the random backoff process[3], the processes described above are applied again. That is, the frame is transmitted only when the random backoff has finished successfully. When a frame arrives at an empty queue with no on-going backoff process and the medium has been idle longer than the DIFS time interval, the frame is transmitted immediately.

Each station maintains a contention window (CW), which is used to select the random backoff counter. The BC is determined as a random integer drawn from a uniform distribution over the interval [0,CW]. How to determine the CW value is further detailed below. If the channel becomes busy during a backoff process, the backoff is suspended. When the channel becomes idle again, and stays idle for an extra DIFS time interval, the backoff process resumes with the suspended BC value.

The timing of DCF channel access is illustrated in Fig. 1. For each successful reception of a frame, the receiving station immediately acknowledges by sending an acknowledgement (ACK) frame. The ACK frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. Other stations resume the backoff process after the DIFS idle time. Thanks to the SIFS interval between the data and ACK frames, the ACK frame transmission is protected from other stations' contention. If an ACK frame is not received after the data transmission, the frame is retransmitted after another random backoff.

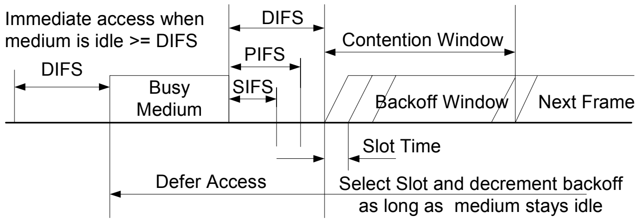


Fig. 1. IEEE 802.11 DCF Channel Access.

The CW size is initially assigned CWmin, and increases when a transmission fails, i.e., the transmitted data frame has not been acknowledged. After any unsuccessful transmission attempt, another backoff is performed using a new CW value updated by $2 \cdot (CW + 1) - 1$, with an upper bound of CWmax. This reduces the collision probability in case there are multiple stations attempting to access the channel. After each successful transmission, the CW value is reset to CWmin, and the station that completed the transmission performs another DIFS deference and a random backoff even if there is no other pending frame in the queue. This is often referred to as "post" backoff, as this backoff is done after, not before, a transmission. This post backoff ensures there is at least one backoff interval between two consecutive MSDU transmissions.

All of the MAC parameters including SIFS, DIFS, Slot Time, CWmin, and CWmax are dependent on the underlying physical layer (PHY). Table I shows these values for the 802.11b PHY [2]. Irrespective of the PHY, DIFS is determined by *SIFS+2·SlotTime*, and another important IFS, called PCF IFS (PIFS), is determined by *SIFS+SlotTime*. With 802.11b, the transmission rate is up to 11 Mbps. There are other PHYs with rates of up to 54 Mbps. As we are discussing MAC enhancements, our evaluation results in the following are valid, irrespective of the underlying PHY.

TABLE I
MAC PARAMETERS FOR 802.11B PHY

Parameters	SIFS (usec)	DIFS (usec)	Slot Time (usec)	CWmin	CWmax
802.11b PHY	10	50	20	31	1023

III. 802.11E MAC ENHANCED DCF (EDCF)

The 802.11 legacy MAC does not support the concept of differentiating frames with different priorities. Basically, the DCF is supposed to provide a channel access with equal probabilities to all stations contending for the channel access in a distributed manner. However, equal access probabilities are not desirable among stations with different priority frames. The emerging EDCF is designed to provide differentiated, distributed channel accesses for frames with 8 different priorities (from 0 to 7) by enhancing the DCF. As distinct from the legacy DCF, the EDCF is not a separate coordination function. Rather, it is a part of a single coordination function, called the Hybrid Coordination Function (HCF), of the 802.11e MAC. The HCF combines the aspects of both DCF and PCF. All the detailed aspects of the HCF are beyond the scope of this paper as we focus on the HCF contention-based channel access, i.e., EDCF.

Each frame from the higher layer arrives at the MAC along with a specific priority value. Then, each QoS data frame carries its priority value in the MAC frame header. An 802.11e STA shall implement four access categories (ACs), where an AC is an enhanced variant of the DCF 0. Each frame arriving at the MAC with a priority is mapped into an AC as shown in Table II. Note the relative priority of 0 is placed between 2 and 3. This relative prioritization is rooted from IEEE 802.1d bridge specification [4].

TABLE II
PRIORITY TO ACCESS CATEGORY MAPPINGS

Priority	Access Category (AC)	Designation (Informative)
1	0	Best Effort
2	0	Best Effort
0	0	Best Effort
3	1	Video Probe
4	2	Video
5	2	Video
6	3	Voice
7	3	Voice

Basically, an AC uses AIFSD[AC], CWmin[AC], and CWmax[AC] instead of DIFS, CWmin, and CWmax, of the DCF, respectively, for the contention process to transmit a frame belonging to access category AC. AIFSD[AC] is determined by

$$AIFSD[AC] = SIFS + AIFS[AC] \cdot SlotTime,$$

where AIFS[AC] is an integer greater than zero. Moreover, the backoff counter is selected from [1,1+CW[AC]], instead

---

[3] This situation is possible due to the "post" backoff requirement as described below.

of [0,CW] as in the DCF. Fig. 2 shows the timing diagram of the EDCF channel access.

The values of AIFS[AC], CWmin[AC], and CWmax[AC], which are referred to as the EDCF parameters, are announced by the AP via beacon frames. The AP can adapt these parameters dynamically depending on network conditions. Basically, the smaller AIFS[AC] and CWmin[AC], the shorter the channel access delay for the corresponding priority, and hence the more capacity share for a given traffic condition. However, the probability of collisions increases when operating with smaller CWmin[AC]. These parameters can be used in order to differentiate the channel access among different priority traffic.

Fig. 3 shows the 802.11e MAC with four transmission queues, where each queue behaves as a single enhanced DCF contending entity, i.e., an AC, where each queue has its own AIFS and maintains its own Backoff Counter BC. When there is more than one AC finishing the backoff at the same time, the collision is handled in a virtual manner. That is, the highest priority frame among the colliding frames is chosen and transmitted, and the others perform a backoff with increased CW values.

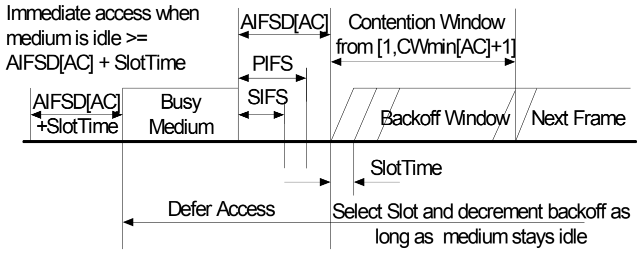


Fig. 2. IEEE 802.11e EDCF channel access.

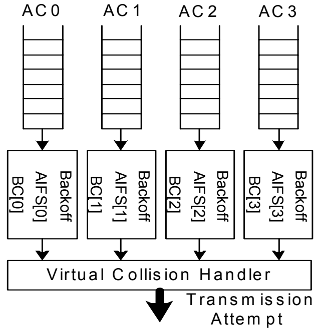


Fig. 3. Four access categories (ACs) for EDCF.

The IEEE 802.11e defines a transmission opportunity (TXOP) as the interval of time when a particular STA has the right to initiate transmissions. Along with the EDCF parameters of AIFS[AC], CWmin[AC], and CWmax[AP], the AP also determines and announces the limit of an EDCF TXOP interval for each AC, i.e., TXOPLimit[AC], in beacon frames. During an EDCF TXOP, a STA is allowed to transmit multiple MPDUs from the same AC with a SIFS time gap between an ACK and the subsequent frame transmission [7][3]. We refer this multiple MPDU transmission to as "Contention-Free Burst (CFB)."[4]

Fig. 4 shows the transmission of two QoS data frames during an EDCF TXOP, where the whole transmission time for two data and ACK frames is less than the EDCF TXOP limit announced by the AP. As multiple MSDU transmission honors the TXOP limit, the worst-case delay performance is not be affected by allowing the CFB. We show below that CFB increases the system throughput without degrading other system performance measures unacceptably as long as the EDCF TXOP limit value is properly determined.

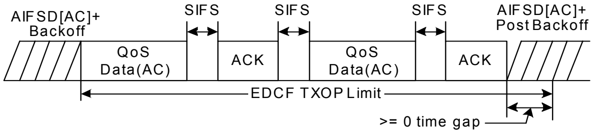


Fig. 4. CFB timing structure.

IV. COMPARATIVE PERFORMANCE EVALUATION

We use the 802.11b PHY for our simulations, and all the stations transmit frames at 11 Mbps, which is the highest transmission rate of the 802.11b PHY. Table II shows the traffic types and their characteristics that we used for our simulations. Basically, three different types of traffic are considered, namely, voice, video, and data. Video traffic is assumed to be of constant bit rate (CBR). Typically, voice and video traffic types are delay-sensitive, but are tolerant of some frame losses. On the other hand, data traffic type is delay-tolerable, but requires loss-free transmission. To utilize the possibility of dropping some frames due to excessive delays, we use buffer sizes of 20 kbit and 1 Mbit for voice and video queues, respectively. Note that in most cases, frames with excessive delays are useless at the receiver anyway. On the other hand, an infinite size buffer is used for data queues.

Table III shows the EDCF parameters used for each traffic type along with the corresponding priorities and AC values. These are the default EDCF parameters in [3]. Each station generates only a single type of traffic, and hence, for example, we refer to a station that generates video traffic as a video station.

TABLE II
THREE TRAFFIC TYPES AND CHARACTERISTICS

Type	Inter-arrival Time (Avg. in sec)	Frame Size (bytes)	Data Rate (Mbps)
Voice	Constant (0.02)	92	0.0368
Video	Constant (0.001)	1464	1.4
Data	Exponential (0.012)	1500	1.0

TABLE III
EDCF PARAMETERS USED FOR SIMULATIONS

Type	Prior.	AC	AIFSD	CWmin	CWmax	TXOP limit (msec)
Voice	7	3	PIFS	7	15	3
Video	5	2	PIFS	15	31	5
Data	0	0	DIFS	31	1023	0

---

[4] Utilizing a CFB is essentially optional since a station is not required to, but allowed to transmit multiple frames during an EDCF TXOP.

A. DCF and EDCF Comparison

In this scenario, we simulate with four voice stations, two video stations, and four data stations for both the DCF and the EDCF. Fig. 5 shows throughput, delay, and data dropping rate for the DCF and the EDCF. By comparing Figs. 5 (a) and (d), which plot the aggregated throughput of each traffic type, we observe that the throughputs of video and data are significantly different for the DCF and the EDCF. Knowing that the aggregate video rate from two stations is 2.8 Mbps, we can easily imagine that the video traffic is well served with the EDCF while many video frames are dropped with the DCF.

This fact is confirmed in Figs. 5 (b) and (e), which show significant reduction in video frame losses with the EDCF. Note that a frame drop occurs when there is a buffer overflow. There is small voice frame loss with the DCF while there is none with the EDCF. On the other hand, we observe that with both the DCF and the EDCF, there is no data frame drop as an infinite size buffer is used for data stations. Instead, data frame delay goes to infinity with both the DCF and the EDCF. Note that the delay for data is not plotted in Fig. 5 (f) so as to clearly show the delay performances for voice and video with the EDCF. We observe in Fig. 5 (f) that voice performance is significantly improved via the EDCF. Note that with the DCF, the voice frame delay sometimes goes over 250 msec, which is not acceptable in most cases. The video delay performance is also improved remarkably with the EDCF. It should be noted that each delay curve is from a single station, e.g., one of four voice stations while the previous throughput and data dropping rate were aggregated from all the same types of stations. That is the main reason why the peaks in data dropping rate and delay curves look totally uncorrelated.

One interesting observation is that even with the DCF, the voice frame delay is much smaller than those of video and data frames. That is because virtually every voice frame arrives at an empty queue thanks to its traffic pattern. That is, each voice frame is transmitted after contention before the next frame arrives at the queue. Note that a voice frame arrives at a transmitting MAC every 20 msec while the voice delay with the DCF is less than 20 msec in most cases.

From the results thus far, we conclude that the EDCF can provide differentiated channel accesses for different traffic types. With the observed delay and error performance, we expect that the EDCF can support real-time applications with voice and video traffic with a reasonable quality of service in certain environments.

B. Contention-Free Burst (CFB)

In this scenario, we simulate with four voice stations and four video stations both with and without the CFB in order to show the utility of the CFB. Fig. 6 shows the EDCF performances for these two different cases: the first with no CFB, i.e., only one frame is transmitted per TXOP; and the second using the CFB option. The EDCF TXOP limit values are shown in Table III for each traffic type. With 5 msec TXOP, a video station can transmit up to three pending frames consecutively at 11Mbps. The rest of EDCF parameters used for the simulation are those shown in Table III, with the exception of AIFSD for video traffic, which is assigned DIFS in this scenario. This is to avoid excessive collisions between 8 stations using the same AIFSD value.

From Fig. 6 (a), we first observe that the global throughput (for the whole BSS) is improved via the CFB as the overhead for the backoff and deference is reduced. The throughput enhancement does not look significant, but the impact on the data dropping rate is significant as the data dropping is mostly gone with CFB as shown in Fig. 6 (b). One interesting observation is that the global dropped data fluctuates significantly while the global throughput does not. This is because the frame drops do not occur across all the stations in a steady manner typically, but a single station tends to experience a buffer overflow with many frame drops due to sustained transmission deference involved with collisions and excessive backoff time accordingly.

We now also observe from Fig. 6 (c) that the video delay performance is significantly improved with CFB as the video stations enjoy reduced overheads for backoff. With CFB, video delay stays regularly below 400 msec, which should be an acceptable value for most video decoders. Finally, Fig. 6 (d) shows that the voice delay performance is degraded with CFB due to the statistically extended transmission times of video stations. However, we also observe that the voice delay stays within 8 msec most of the time, which is acceptable for even the most interactive voice applications. One should be warned not to set the EDCF TXOP limit too large as it will increase the delay experienced by other traffic types.

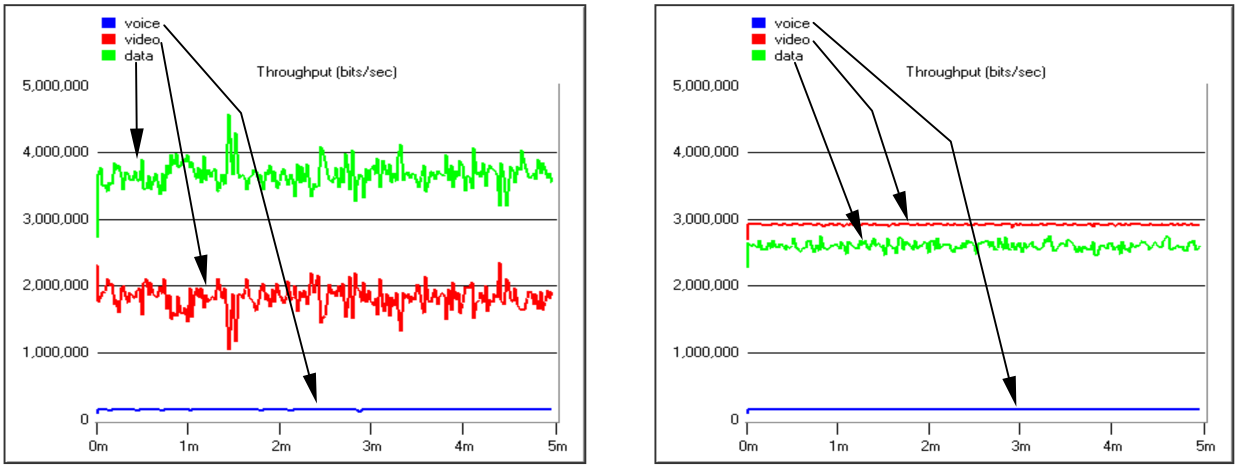
V. CONCLUSION

In this paper, we introduced the contention-based channel access scheme for QoS support, called the EDCF, of the emerging 802.11e MAC. Based on the simulation, we compared the legacy 802.11 DCF and the 802.11e EDCF to show that the EDCF can provide differentiated channel access among different priority traffic. We also evaluated an optional feature called CFB, which allows a station to transmit multiple MPDUs with the SIFS time gaps within the time bound of the TXOP limit. The CFB is shown to improve the global system performance at the cost of a delay increase for certain traffic types.

We would like to remark on two important aspects: first, it should be noted that in this work, we did not attempt to optimize the network performance via the fine-tuning of the EDCF parameters. One should be able to optimize the EDCF channel access by adapting the EDCF parameters including the TXOP limit during the run-time depending on the network load and supported applications. Second, for acceptable QoS provisioning, there should be an admission control process in place along with the properly-chosen EDCF parameters. Actually, the 802.11e draft also defines a distributed admission control algorithm, in which the AP can control the traffic load from each AC as well as each station by announcing the traffic load and available bandwidth for each AC periodically [3]. We would like to note that this admission control mechanism is an interesting piece of the work while the actual performance and its utility are subject to further evaluation.

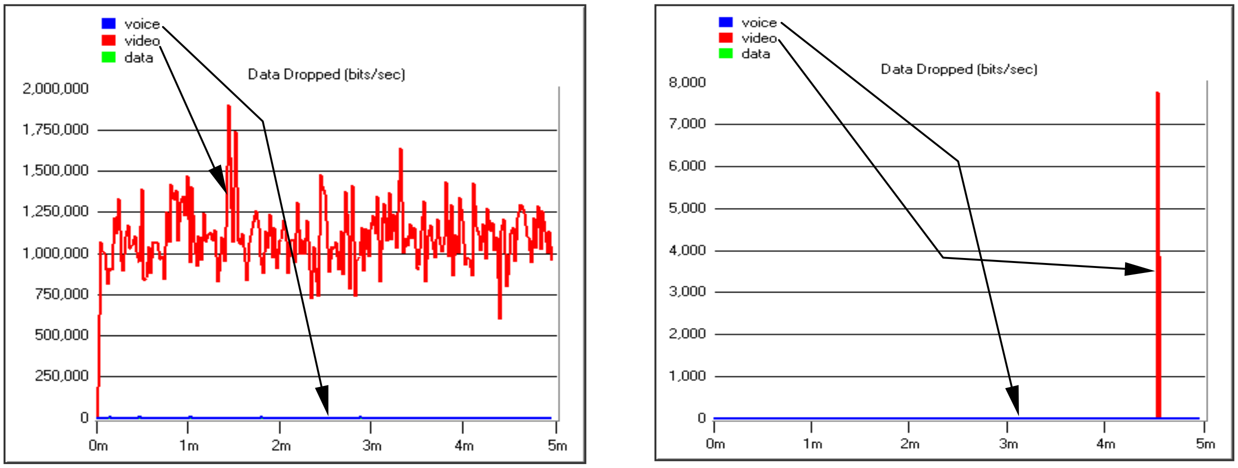
ACKNOWLEDGMENT

The authors would like to thank Zhun Zhong and Dave Bryan at Philips Research USA for their discussion and valuable comments to the earlier version of this paper.



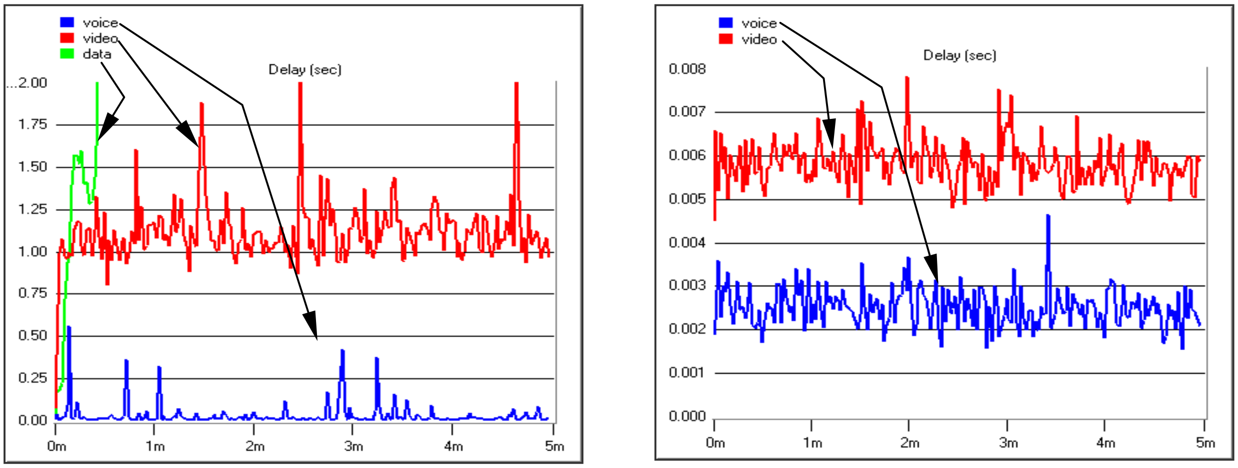
(a) Throughput (bps) with DCF

(d) Throughput (bps) with EDCF



(b) Data dropped (bps) with DCF

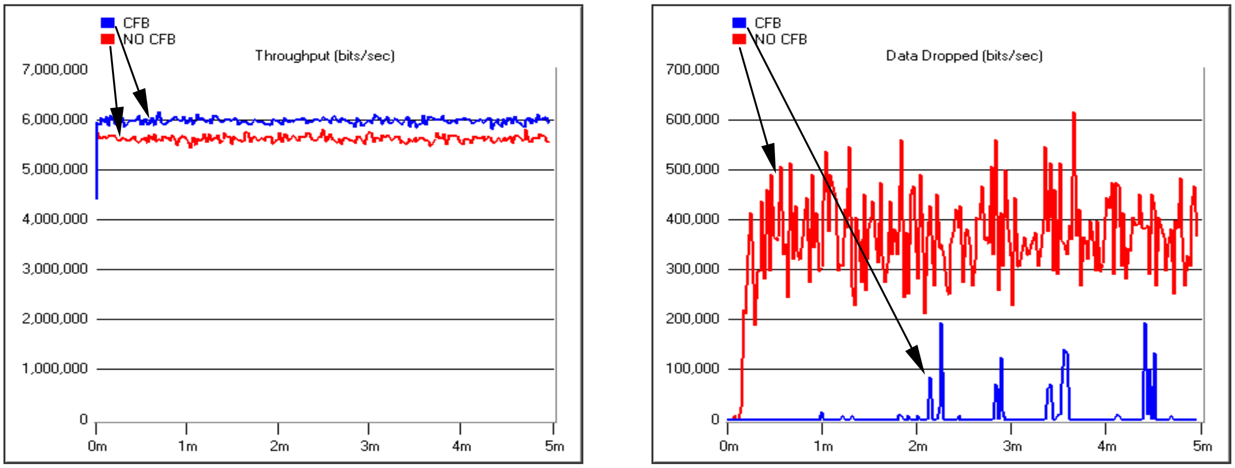
(e) Data dropped (bps) with EDCF



(c) Delay (sec) with DCF

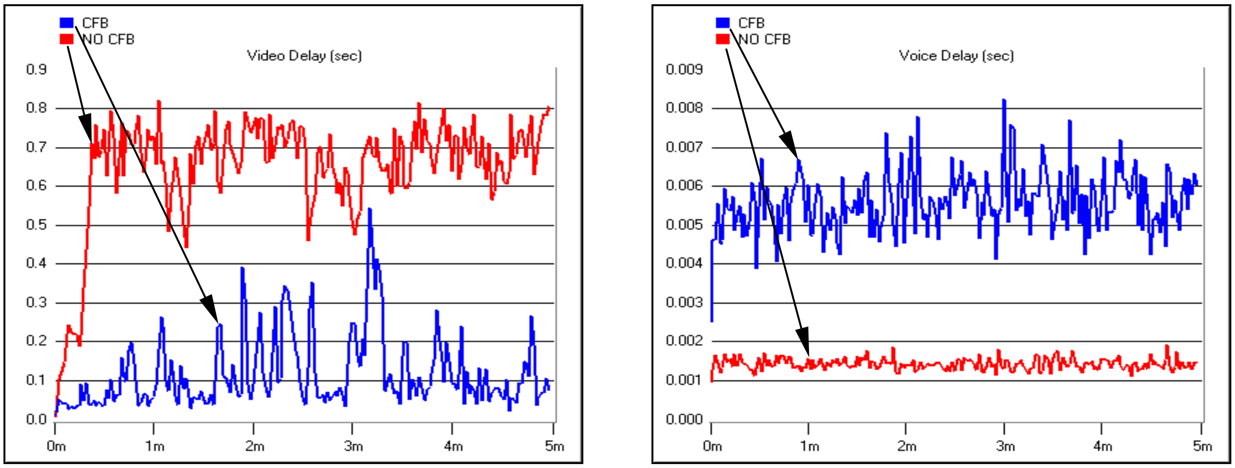
(f) Delay (sec) with EDCF

Fig. 5. Comparison between DCF and EDCF: (a)-(c) DCF for all three traffic types; (d)-(f) EDCF with different EDCF parameters for different traffic types.



(a) Global throughput (bps)

(b) Global data dropped (bps)



(c) Video delay (sec)

(f) Voice delay (sec)

Fig. 6. Comparison of EDCF with and without CFB.

REFERENCES

[1] IEEE Std. 802.11-1999, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications,* Reference number ISO/IEC 8802-11:1999(E), IEEE Std. 802.11, 1999 edition, 1999.

[2] IEEE Std. 802.11b, *Supplement to Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-speed Physical Layer Extension in the 2.4 GHz Band,* IEEE Std. 802.11b-1999, 1999.

[3] IEEE 802.11e/D4.0, *Draft Supplement to Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS),* November 2002.

[4] IEEE 802.1d-1998, *Part 3: Media Access Control (MAC) bridges*, ANSI/IEEE Std. 802.1D, 1998 edition, 1998.

[5] Maarten Hoeben and Menzo Wentink, "Enhanced D-QoS through Virtual DCF," IEEE 802.11-00/351, October 2000.

[6] Stefan Mangold, Sunghyun Choi, Peter May, Ole Klein, Guido Hiertz, and Lothar Stibor, "IEEE 802.11e Wireless LAN for Quality of Service," in *Proc. European Wireless '02*, Florence, Italy, February 2002.

[7] Sunghyun Choi, Javier del Prado, Atul Garg, Maarten Hoeben, Stefan Mangold, Sai Shankar, and Menzo Wentink, "Multiple Frame Exchanges during EDCF TXOP," IEEE 802.11-01/566r3, January 2002.