Evaluation of QOS Enhancements Provided by EDCF Medium Access Scheme in IEEE 802.11 WLAN

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Abstract - **This paper presents an evaluation of the effects that have the prioritizing parameters introduced by the EDCF access scheme (adopted in an upcoming IEEE 802.11e standard) on QoS improvements versus DCF medium access scheme, defined with the legacy 802.11 standard. Also we analyze the impact of the frame length and the contention-free burst (CFB) mechanism on QoS performances produced by the EDCF.**

Keywords - **WLAN, QoS, IEEE 802.11e, EDCF, simulation**

I. Introduction

The support of higher data rates and widespread use of multimedia applications push the demand of IEEE 802.11 WLANs to support both traditional data and multimedia applications in the same infrastructure. However, legacy IEEE 802.11 MAC specification, which follows the best-effort paradigm, doesn't provide any traffic prioritization to meet the QoS requirements imposed by multimedia applications such as real time voice, audio and video. Therefore, the IEEE Task Group E is currently working on a new IEEE 802.11 MAC specification, named IEEE 802.11e [4], which will enhance legacy MAC specification to support QoS sensitive multimedia applications. The legacy IEEE 802.11 MAC specification [2] defines two access schemes: DCF (Distributed Coordination Function) and PCF (Point Coordination Function). DCF uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) algorithm and it is contention-based access scheme supporting asynchronous data transfer, while PCF uses a central-controlled polling method to support synchronous data transmission. The IEEE 802.11e standard introduces two additional access schemes: *EDCF (Enhanced Distributed Coordination Function)* and *HCF (Hybrid Coordination Function)*. EDCF is an extension to the DCF contention-based access scheme which provides service differentiation via prioritization of traffic supporting prioritized QoS, while HCF is a modification to the PCF for more efficient polling method supporting both prioritized and parameterized QoS.

Recently, several authors [1, 5, 6, 7] have shown interest in evaluation of QoS enhancements provided by the new access schemes defined with IEEE 802.11e. Performance analysis show that EDCF can support better QoS than DCF [9], but as the network load is increased QoS improvements of EDCF are diminished, especially for high demand QoS sensitive traffic, such as video. The main reason for this is inadaptable EDCF prioritizing parameters to the network conditions. This paper presents simulation-based evaluation of QoS enhancements provided by the EDCF over the DCF access scheme through analysis of the effects that have the EDCF prioritizing parameters on the QoS performances of high priority traffic flows. Furthermore, this paper analyses the effects of the frame length and the contention-free burst (CFB) mechanism [8] on QoS provided by the EDCF access scheme for given EDCF prioritizing parameters. Simulation model based on Microsoft Visual Basic and SQL Server 2000 is utilized to investigate effects of the EDCF prioritizing parameters, the frame length and the CFB mechanism on two QoS parameters of traffic flows: throughput and MAC frame delay.

The paper is organized as follows: Section II gives short descriptions of the legacy 802.11 MAC/DCF and 802.11e MAC/EDCF. Section III describes the simulation scenarios, while in Section IV are given results and analysis. Conclusions are outlined in Section V.

II. DCF and EDCF

DCF is basically listen-before-talk access scheme. According to DCF, each station senses the medium before initiating a frame transmission. If the medium is found idle for a time interval longer than DCF InterFrame Space (DIFS), then the station can transmit frame immediately. Otherwise the station shall defer until medium has been detected idle for at least DIFS interval and after deferral, the station will start backoff procedure setting its backoff timer at value between zero and current Contention Window (CW) size as follows:

$$BackoffTime = Rnd(0, CW) \times SlotTime \qquad (1)$$

where $Rnd(0,CW)$ is a pseudorandom integer drawn from a uniform distribution over the interval $[0,CW]$ and *SlotTime* is constant which depends on the PHY layer type. During backoff procedure, the station shall sense the medium to determine whether there is activity during each backoff slot. If the medium is free the station shall decrement its backoff timer by *SlotTime*. Otherwise, the backoff timer is paused and is resumed after the medium has been sensed idle for duration of at least DIFS interval. As soon as the backoff timer expires, the station is authorized to access the medium and transmit the pending frame. Since in wireless environment collision detection is impossible due to significant difference between transmitted and received power levels, the DCF uses method of positive acknowledgment to notify the sending station that the transmitted frame has been successfully received. The transmission of the acknowledgment is initiated at a time interval equal to Short InterFrame Space (SIFS) after the end of the successful reception of frame. If the acknowledgment is not received, the sending station assumes that the transmitted frame was lost and starts the backoff procedure again. To reduce the probability of collisions, after each unsuccessful transmission attempt, the *CW* is doubled according to:

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$$CW_k = 2^{k+p-1} - 1 \qquad (2)$$

where k is the number of attempts to transmit the frame, and p is constant (which depends on PHY layer type) defining the minimum contention window for the first attempt, $CW_{min}=2^p-1$. For each unsuccessful transmission, contention window is doubled until a maximum value CW_{max} is reached. After successful transmission, the backoff procedure is also performing for the next frame but contention window is reset to a fixed minimal value CW_{min}. According this, the value of CW that should be used in setting backoff timer Eq.(1) depends on the current attempt to transmit the frame for which the backoff procedure is performed, and $CW_{min} \le CW \le CW_{max}$.

EDCF is simply enhancement of DCF access scheme with possibility of traffic prioritization, thus in what follows we will pay attention on main difference between DCF and EDCF. As it can be seen from DCF access scheme, described above, at least two contention parameters can be used to provide medium access prioritization: DIFS and CW used in calculation of backoff timer. Generally, lower DIFS and CW values will give higher priority for medium access. Following this idea, EDCF allows traffic to be classified into different Traffic Categories (TC) with different values of the above contention parameters. Classification is performed according priority value in the MAC frame header.

Instead of waiting a DIFS interval before trying to access the medium, or continuing to decrement backoff timer after it was paused as in DCF, an interframe space called Arbitration InterFrame Space (AIFS) is used for each TC. The AIFS interval for TC i is set according to the following formula:

$$AIFS(TC_i) = DIFS + \Delta TC_i \times SlotTime \qquad (3)$$

where ΔTC_i is integer and $\Delta TC_i \ge 0$. This means that TC using large ΔTC_i (large AIFS) will have lower priority than TC using small ΔTC_i (small AIFS), since it will wait longer before trying to access the medium or continuing to decrement backoff timer after it was paused. Note that minimal AIFS interval according Eq.(3) is equal to DIFS.

To be able to further differentiate between TCs, the contention window from which the backoff timer is calculated is different for each TC. The backoff timer for TC i is calculated as follows:

$$BackoffTime(TC_i) = Rnd(1, CW(TC_i)+1) \times SlotTime \qquad (4)$$

where $Rnd(1,CW(TC_i)+1)$ is a pseudorandom integer drawn from a uniform distribution over the interval $[1, CW(TC_i)+1]$. $CW(TC_i)$ is current contention window size for TC i, $CW_{min}(TC_i) \le CW(TC_i) \le CW_{max}(TC_i)$, where $CW_{min}(TC_i)$ and $CW_{max}(TC_i)$ is minimal and maximal value of the contention window for TC i. Choosing a smaller $\mathrm{CW_{min}}/\mathrm{CW_{max}}$ for a given TC will cause generating shorter backoff intervals for that TC, thus gaining priority over a TC with larger $\mathrm{CW_{min}}/\mathrm{CW_{max}}$ which generates longer backoff intervals.

According, optional contention-free burst (CFB) mechanism [7, 8], a station that has gained access to the medium can send more then one frame without contending for the medium again. After getting access to the medium, the station is allowed to send multiple frames from given TC, as long as the total access time does not exceed the TXOPLimit parameter for that TC.

III. Evaluation

In order to evaluate influence of the EDCF prioritizing parameters: AIFS and $\mathrm{CW_{min}}$, the frame lengths and the CFB mechanism on the QoS improvements of EDCF over DCF access scheme, an event-driven simulator with support of both DCF and EDCF has been implemented. The simulator was built by using Microsoft Visual Basic and SQL Server 2000. Simulation model assumes ideal PHY channel with negligible propagation delay and no transmission errors, so eventually frame retransmission is a result of collision. We consider an infrastructure-type WLAN where all traffic flows generated from wireless stations are directed to the AP. All PHY dependent MAC parameters were set assuming 802.11b [3] DSSS 11 Mbps PHY layer, i.e. DIFS=50μs, SIFS=10μs, SlotTime=20μs, and for DCF the $\mathrm{CW_{min}}$ and $\mathrm{CW_{max}}$ are set to 31 and 1023, respectively. Table I describes simulated scenario. Three different types of traffic are considered: voice, video and data.

Table I: Traffic types and *default* EDCF parameters

Traffic type	***Inter-arrival frame time***	***Frame Size (bytes)***	***Data Rate***	***default* EDCF parameters** ΔTC_i	CW_{min}	CW_{max}
Voice	Const.(0.025s)	200	64kbps	0	7	15
Video	Const.(0.004s)	1000	2Mbps	0	15	31
Data	Exp. (0.012s)	1500	1Mbps	1	31	1023

Each station generates only a single type of traffic, and hence, we refer to a station according the traffic type that it generates, i.e., the station that generates data traffic we refer as data station. In order to simulate high-load network environment, in considered scenario we simulate with four voice, three video and four data stations, generating total offered load of 10.256Mbps. Furthermore, because each station generates only a single type of traffic, stations are modeled with a single transmission queue (MAC buffer) of infinitive size. Table I also shows *default* EDCF parameters for each traffic type according draft version 4.0 [7] for voice, video and data traffic.

IV. Simulation Results

A. Effects of the EDCF parameters: AIFS, $\mathrm{CW_{min}}$

To evaluate QoS improvements for the prioritized voice and video traffic flows provided by EDCF, we perform simulations of described scenario for both DCF and EDCF access schemes. Furthermore, to examine effects that have solely AIFS or $\mathrm{CW_{min}}$ parameter on the QoS performances of the traffic flows we perform series of simulations under EDCF varying AIFS and $\mathrm{CW_{min}}$ parameter of the data flows, but keeping *default* EDCF parameters for the voice and video flows and *default* values of $\mathrm{CW_{min/max}}$ and AIFS for data flows, respectively. Figs. 1 and 2 show Cumulative Distribution Function (CDF) of MAC frames delay for the voice flows, as the AIFS and $\mathrm{CW_{min}}$ for the data flows are varied. MAC frame delay is measured as a time interval between the moment when the frame enters the MAC buffer and the moment when ACK is received for that frame. Time dependence of throughput achieved by the video stations as the AIFS and CW_{min} for the data flows are varied, are shown on Figs. 3 and 4. Points in throughput characteristics represent mean throughput achieved by all stations generating video traffic. Note that in all simulations the data stations are activated in the 5-th second of simulation time. In graphs AIFS is represented by a number instead of time, the actual AIFS in time is determined if the given value of AIFS is substituted as ΔTC_i in Eq.(3).

By observing CDF of frame delay for the voice flows we can notice that as the AIFS and CW_{min} for the data flows are increased, CDF characteristics become steeper indicating that maximum delay is reduced and more frames have a delay with in small range of values, meaning jitter is reduced. Increasing the AIFS and CW_{min} for data flows, also increase throughput of the video flows and reduce their throughput variance. Analyzing throughput characteristic of the video flows we can notice that there is some saturation in the QoS improvements as the values of AIFS or CW_{min} for data flows are increased.

B. Effects of frame length of the prioritized flows

To analyze the effects of the video frame length on the QoS performances provided by EDCF, simulations of described scenario under EDCF are performed for different lengths of frames generated by the video stations. Note, that in all simulations for voice, video and data flows are set *default* EDCF parameters. Fig. 5 shows CDF of MAC frame delay for the voice flows, while throughput for the video flows is shown on Fig. 6. By observing results for the video flows we can notice that increasing the length of video frame improve their QoS performances. However, increased video frame length has negative impact on QoS performances of the voice flows Decrease of slope for CDF voice delay characteristic indicate that increase of video frame length, also increase jitter and maximum delay of voice frames. This degradation of delay performance for the voice flows is due to extended transmission times of video stations by using longer frames.

C. Effects of Contention-Free Burst (CFB) mechanism

Results from simulation performed in order to evaluate the effect of the CFB mechanism on EDCF QoS performances are presented in this section. Because previous analysis show that QoS performances of the video flows, are far more degraded than QoS performances of the voice flows for low values of the EDCF parameters, in performed simulations, contention-free bursting is enabled only for the video stations. TXOPlimit parameter was set on value of 3.5ms which allows transmitting a burst of up to four video frames with length of 1000 bytes in one access to the medium. Note that again *default* EDCF parameters are set for all traffic flows. Fig. 7 show CDF of MAC frame delay for the voice flows, while on Fig. 8 is presented throughput for the video flows.

From the presented results we can conclude that enabled CFB mechanism for the video flows significantly improve their QoS performances. For the same EDCF prioritizing parameters utilizing CFB, the video flows achieve almost constant throughput with value nearly 2Mbps. CFB also improve the overall throughput for the whole WLAN because the overhead of backoff and deference is reduced. Namely, according simulation results overall throughput without CFB for video was 7.2Mbps; while with enabled CFB for video overall throughput was increased on 7.9Mbps. However, similar like increasing frame length of the video flows, CFB introduces degradation in delay and jitter of the voice flows.

V. Conclusion

This paper presents evaluation of QoS support provided by EDCF medium access scheme, adopted in an upcoming 802.11e standard. Simulation results show that EDCF can provide prioritized channel access, which results in improvements over DCF in the QoS performances for traffic flows categorized as high priority by means of the EDCF prioritizing parameters. However, EDCF can "hardly" provide suitable QoS performances for high-demand prioritized traffic flows, such as video flows, in high-load network condition. In order to provide acceptable QoS performances for the video flows, the EDCF prioritizing parameters (AIFS and CW_{min}) for the low priority data flows should be set on high values, which results in their significant performance degradation. Also, above some value of AIFS or CW_{min} parameter there is a drastic improvement in the QoS performances of the high-demand video flows. Further increasing of AIFS and CW_{min} introduces minimal QoS improvements. Comparing effects of AIFS and CW_{min} we can conclude that AIFS has stronger prioritizing effect than CW_{min}, but simulations show that both have stronger impact on the delay characteristic than on the throughput of the traffic flows. Utilizing longer video frames or enabling CFB for the video flows improve QoS performances for them even at lower values of AIFS and CW_{min} for the data flows, but results in degradation of performances for the other priority flows (voice flows) with shorter frame length. CFB also provide better channel utilization, increasing global throughput in system. Taking into account effects of increased frame length and CFB on QoS provided by EDCF, we can conclude that these methods can be used to provide better QoS performances for high-demand QoS sensitive traffic with fixed low values of the EDCF parameters for low priority traffic.

VI. References

[1] D. Gu, J. Zhang, "QoS enhancement in IEEE 802.11 wireless local area networks", *IEEE Commcations Magazine,* Volume: 41 Issue: 6, Page(s): 120-124, June 2003

[2] IEEE std 802.11-1999, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, 1999

[3] IEEE std 802.11b-1999, Higher-Speed Physical Layer Extension in the 2.4 GHz Band, 1999

[4] IEEE 802.11e draft/D2.0, Medium Access Control (MAC) Enhancements for Quality of Service (QoS), November 2001

[5] P. Garg, R. Doshi, R. Greene, M.Baker, M. Malek, X. Cheng, "Using IEEE 802.11e MAC for QoS over Wireless" *The Proceedings of the IPCCC 2003,* Phoenix, Arizona, April 2003

[6] S. Mangold, S. Choi, P. May, O. Klein, G. Hiertz, L. Stibor: "IEEE 802.11e Wireless LAN for Quality of Service (invited paper)", *Proceedings of the European Wireless*, Vol. 1, pp. 32-39, Florence, Italy, February 2002

[7] S. Choi, J. del Prado, S. Shankar, S. Mangold, "IEEE 802.11e Contention-Based Channel Access (EDCF) Performance

Evaluation" *Proceedings of the ICC 2003*, Anchorage, AL, USA, May 2003

[8] S. Choi, J. del Prado, A. Garg, M. Hoeben, S. Mangold, S.Shankar, W. Menzo, "Multiple Frame Exchanges during EDCF TXOP," *IEEE 802.11-01/566r3*, January 2002.

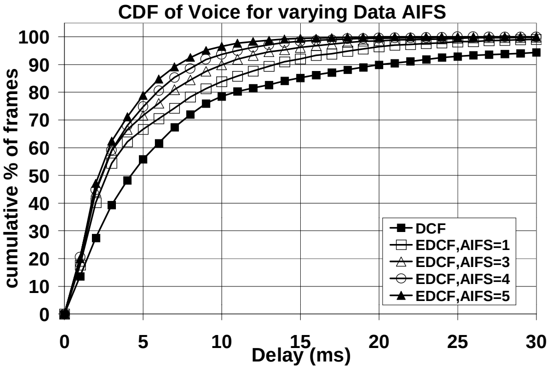

Fig.1. Effects of data AIFS on delay of voice frames

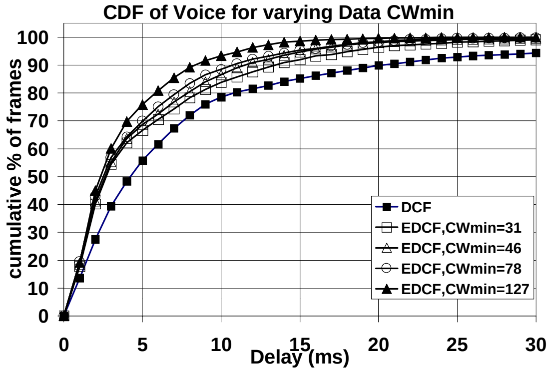

Fig.2. Effects of data CW_{min} on delay of voice frames

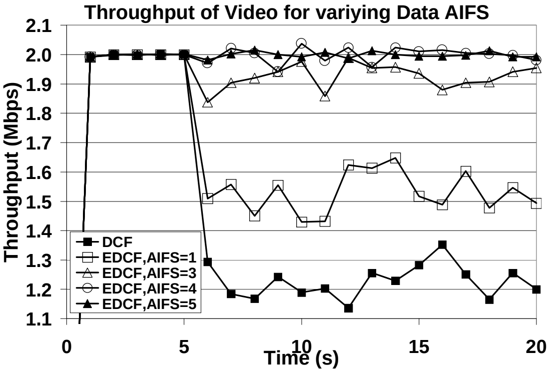

Fig.3. Effects of data AIFS on video throughput

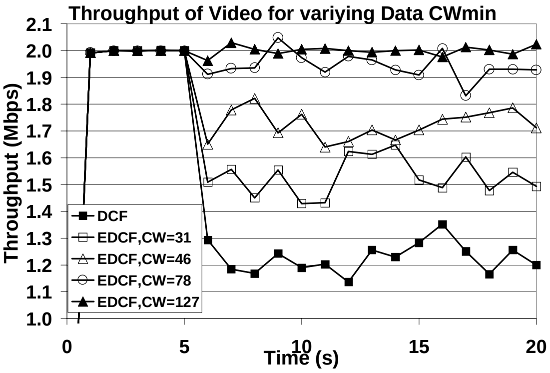

Fig.4. Effects of data CW_{min} on video throughput

[9] Z. Dimitrovski, L. Gavrilovska, "QoS Evaluation of EDCF Medium Access Scheme," CiiT *2003*, Bitola, Macedonia, December 2003

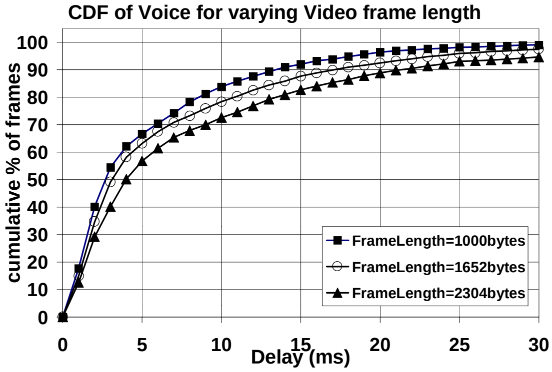

Fig.5. Effects of video frame length on voice delay

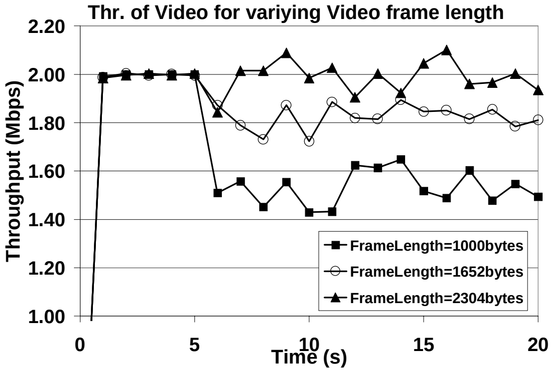

Fig.6. Effects of video frame length on video throughput

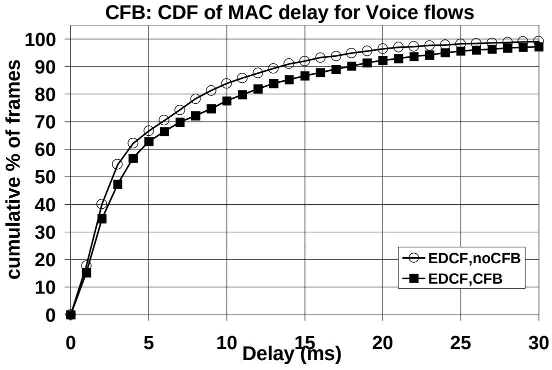

Fig.7. Effects of CFB for video on voice delay

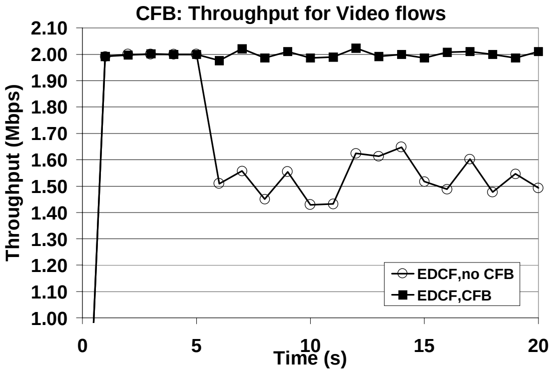

Fig.8. Effects of CFB for video on video throughput