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Performance Analysis of QoS supported by Enhanced Distributed Channel Access (EDCA) mechanism in IEEE 802.11e

Saurabh Sehrawat, Revoti Prasad Bora, Dheeraj Harihar *

Abstract—With fast deployment of wireless local area networks (WLANs), the ability of WLAN to support real time services with stringent quality of service (QoS) requirements has come into fore. In this paper, we evaluate the capability of QoS support in Enhanced Distributed Channel Access (EDCA) mechanism of the IEEE 802.11e standard, which is the medium access control (MAC) enhancements for QoS support in 802.11.EDCA mechanism allow prioritized medium access for applications with high QoS requirements by assigning different priorities to its four access categories. Its performance is evaluated under real time audio and video traffic through simulations using Network Simulator-2(NS 2), parameters like mean delay, throughput are calculated and graphs has been plotted. Simulation results show that EDCA mechanism provides satisfactory service differentiation among its four access categories. With EDCA mechanism, network capacity is effectively increased to better support real-time audio and video transmissions

***Index Terms*— Quality of service, wireless local area networks, enhanced distributed channel access, access categories, 802.11**

I. Introduction

In RECENT years, Wireless local area network (WLAN) technologies have emerged as a fast-growing market. Among the various WLAN technologies available in the market, IEEE 802.11 standard has emerged as the dominating technology and is vastly used in WLANs. Low cost, ease of deployment and mobility support has resulted in the vast popularity of IEEE 802.11 WLANs. They can be easily deployed in hot-spot zones of airports, hotels, stock markets, residence homes and other places. With ever increasing popularity of multimedia applications, people want voice, audio and broadband video services like High definition television (HDTV) through WLAN connections. Unlike the traditional best effort data applications, multimedia applications require quality of service (QoS) support such as guaranteed bandwidth and bounded delay/jitter. As both the medium access control (MAC) layer and the physical (PHY) layer of 802.11 [1] are designed for best effort data transmissions, the original 802.11 standard does not take QoS into account. Hence to provide QoS support IEEE 802.11 standard group has specified a new IEEE 802.11e standard. IEEE 802.11e supports QoS by providing differentiated classes of service in the medium access control(MAC) layer, it also enhances the physical layer so that it can delivery time sensitive multimedia traffic, in addition to traditional data packets.

The IEEE 802.11e standard introduces the hybrid coordination function (HCF) as the medium access control (MAC) scheme. While backward compatible with DCF and PCF, HCF provides stations with prioritized and parameterized QoS access to the wireless medium. HCF combines aspects of both the contention-based and the contention free access methods, where the contention-based channel access mechanism in HCF is known as the enhanced distributed channel access (EDCA) and its contention free counterpart is known as the HCF controlled channel access(HCCA).The EDCA is an extension of conventional distributed coordination function (DCF). It provides prioritized QoS services which classifies all the traffics destined medium access control (MAC) layer to multiple access categories (ACs) and it differentiate the chance to get a transmission opportunity (TXOP) using unequal channel access parameters. The EDCA is the fundamental and mandatory mechanism of IEEE 802.11e, while HCCA is optional and requires centralized polling and scheduling algorithms to allocate the resources. In this paper, we only consider the EDCA as a channel access scheme.

This paper is organized as follows: Section II describes the 802.11 legacy DCF and the 802.11e EDCA. In section III we compare DCF and EDCA and evaluate the performance of EDCA in supporting QoS traffic. Finally section IV concludes the paper.

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*Department of Electronics and Communication Engineering, Department of Computer Science and Engineering, Motilal Nehru National Institute of Technology, Allahabad, India. Email: saurabhsehrawat@gmail.com, rebathip@gmail.com, dheeraj.mnnit@gmail.com. The order of the authors does not convey their contribution to this paper.

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II. IEEE 802.11E CONTENTION-BASED CHANNEL ACCESS

A. Distributed Coordination Function (DCF)

DCF is the basic and mandatory MAC mechanism of legacy IEEE 802.11 [1] WLANs. It is based on carrier sense multiple access with collision avoidance (CSMA/CA). Working of DCF is explained in this section as it is the basis for the Enhanced Distributed Channel Access (EDCA), 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 or idle. 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. If a certain station does not get access to the medium in the first cycle, it stops its backoff counter, waits for the channel to be idle again for DIFS and starts the counter again. As soon as the counter expires, the station accesses the medium. Hence the deferred stations don't choose a randomized backoff counter again, but continue to count down. Stations that have waited longer have the advantage over stations that have just entered, in that they only have to wait for the remainder of their backoff counter from the previous cycle(s).

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].The larger the contention window is the greater is the resolution power of the randomized scheme. It is less likely to choose the same random BC using a large CW .However, under a light load; a small CW ensures shorter access delays .The timing of DCF channel access is illustrated in Fig. 1.

An acknowledgement (ACK) frame is sent by the receiver to the sender for every successful reception of a frame. The ACK frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. As the SIFS is shorter than DIFS, the transmission of ACK frame is protected from other station's contention. The CW size is initially assigned CWmin and if a frame is lost i.e. no ACK frame is received for it, the CW size is doubled, with an upper bound of CWmax and another attempt with backoff is performed. After each successful transmission, the CW value is reset to CWmin.

. 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 IEEE 802.11b PHY [2]. DIFS is determined by SIFS+2·SlotTime, irrespective of the PHY.

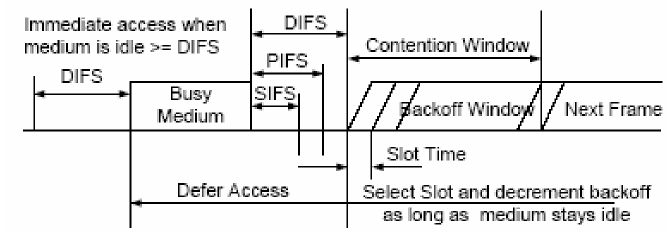

Fig.1. The timing relationship for DCF

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

B. Enhanced Distributed Channel Access (EDCA)

EDCA is designed to provide prioritized QoS by enhancing the contention-based DCF. It provides differentiated, distributed access to the wireless medium for QoS stations (QSTAs) using 8 different user priorities (UPs).Before entering the MAC layer, each data packet received from the higher layer is assigned a specific user priority value. How to tag a priority value for each packet is an implementation issue. The EDCA mechanism defines four different first-in first-out (FIFO) queues, called access categories (ACs) that provide support for the delivery of traffic with UPs at the QSTAs. Each data packet from the higher layer along with a specific user priority value should be mapped into a corresponding AC according to 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]. Different kinds of applications (e.g., background traffic, best effort traffic, video traffic, and voice traffic) can be directed into different ACs. For each AC, an enhanced variant of the DCF, called an enhanced distributed channel access function (EDCAF), contends for TXOPs using a set of EDCA parameters from the EDCA Parameter Set element or from the default values for the parameters when no EDCA Parameter Set element is received from the QAP of the QBSS with which the QSTA is associated.

Table II

Priority	User priority (UP - Same as 802.1D User Priority)	802.1D Designation	Access Category (AC)	Designation (Informative)
lowest	1	BK	AC_BK	Background
	2	-	AC_BK	Background
	0	BE	AC_BE	Best Effort
	3	EE	AC_BE	Best Effort
	4	CL	AC_VI	Video
	5	VI	AC_VI	Video
highest	6	VO	AC_VO	Voice
	7	NC	AC_VO	Voice

Fig. 2 shows the implementation model with four transmission queues, where each AC behaves like a virtual station: it contends for access to the medium and independently starts its backoff after sensing the medium idle for at least AIFS period. In EDCA a new type of IFS is introduced, the arbitrary IFS (AIFS), in place of DIFS in DCF. Each AIFS is an IFS interval with arbitrary length as follows:

$$AIFS[AC] = SIFS + AIFSN[AC] \times \text{slot time}$$

where AIFSN[AC] is called the arbitration IFS number and determined by the AC and the physical settings, and the slot time is the duration of a time slot. The timing relationship of EDCA is shown in Fig 3. The AC with the smallest AIFS has the highest priority. The values of AIFS[AC], CWmin[AC], and CWmax[AC], which are referred to as the EDCA parameters, are announced by the AP via beacon frames. The purpose of using different contention parameters for different queues is to give a low-priority class a longer waiting time than a high-priority class, so the high-priority class is likely to access the medium earlier than the low-priority class. An internal collision occurs when more than one AC finishes the backoff at the same time. In such a case, a virtual collision handler in every QSTA allows only the highest-priority AC to transmit frames, and the others perform a backoff with increased CW values.

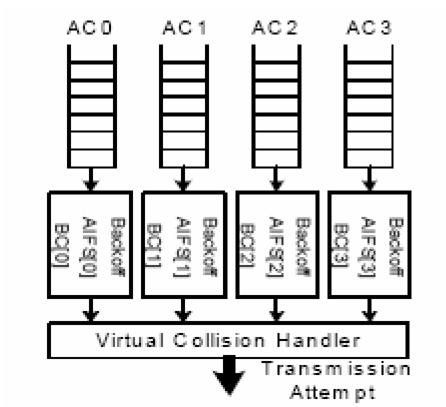

Fig.2. Implementation model

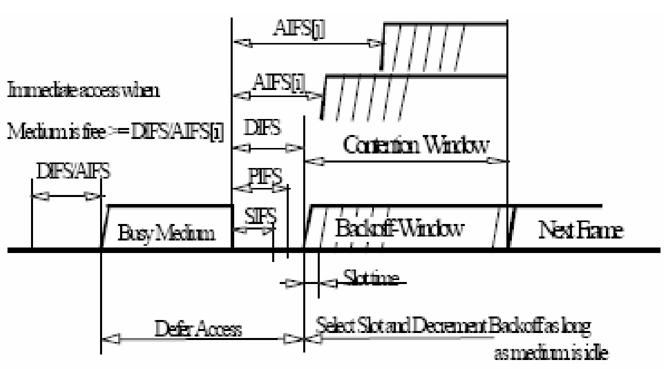

Fig.3. The timing relationship for EDCA

TXOP-Transmission opportunity is defined in IEEE 802.11e as the interval of time when a particular QSTA has the right to initiate transmissions. There are two modes of EDCA TXOP defined, the initiation of the EDCA TXOP and the multiple frame transmission within an EDCA TXOP. An initiation of the TXOP occurs when the EDCA rules permit access to the medium. A multiple frame transmission within the TXOP occurs when an EDCAF retains the right to access the medium following the completion of a frame exchange sequence, such as on receipt of an ACK frame. The TXOP limit duration values are advertised by the QAP in the EDCA Parameter Set Information Element in Beacon frames. During an EDCA TXOP, a STA is allowed to transmit multiple MAC protocol data units (MPDUs) from the same AC with a SIFS time gap between an ACK and the subsequent frame transmission. A TXOP limit value of 0 indicates that a single MPDU may be transmitted for each TXOP. This is also referred to as contention free burst (CFB). In this paper, we only investigate the situation where a station transmits one data frame per TXOP transmission round.

III. Simulation Evaluation

A. Simulation Setup

In this section we use network simulator-2 (NS 2) to evaluate the performance of IEEE 802.11e EDCA mechanism. We choose 802.11b as the PHY layer, and the PHY data rate is set to 11 Mb/s. The simulation parameters are shown in the table III.

In our simulation we have considered three scenarios, namely scenario 1, scenario 2 and scenario 3.In each scenario all the stations are transmitting to the same destination. Scenario 1 consists of two VoIP connections, one video connection and two connections each of background traffic and best effort data. In scenario 2 we have increased the number of VoIP connections to seven, keeping other connections intact. In scenario 3 we have increased the number of BE/BK connections to four each, keeping other connections same as in scenario 1. The best-effort and background traffics have been created using a *Pareto* distribution traffic model with average sending rate of 128 kb/s and 256 kb/s, respectively.

Consistent with 802.11e specifications, VoIP traffic is carried under AC3, video under AC2, background traffic under AC1 and best effort data under AC0.In every scenario the video traffic is starting at 5secs,VoIP traffic is starting at 10 secs and BK/BE traffic is starting at 15 secs.

Table III

	Voice	Video	Background	Best Effort
Transport protocol	UDP	UDP	UDP	UDP
AC	VO	VI	BK	BE
CWmin	7	15	31	31
CWmax	15	31	1023	1023
AIFSN	2	2	3	7
Packet Size	160 bytes	1000 bytes	200 bytes	200 bytes
Sending rate	64 kb/s	1024 kb/s	256 kb/s	128 kb/s

B. *DCF and EDCA Comparison*

We compare the DCF and the EDCA mechanism by simulating the scenario 2, having seven VoIP connections, one video connection and two BK/BE connections each.

By comparing Figs. 4 (a) and Fig. 4 (b) which plot the throughput of each traffic type, we observe that the throughputs of video and BE/BK data are significantly different for the DCF and the EDCA whereas the VoIP traffic is able to maintain its throughput in both the cases. In fig. 4 (a) we can observe that the throughput of video traffic drops from around 1050 kbps to 800 kbps, confirming that the video traffic is well served with the EDCA while many video frames are dropped with the DCF. It can also be seen that the throughput of BE/BK traffic is low in DCF as compared to EDCA.

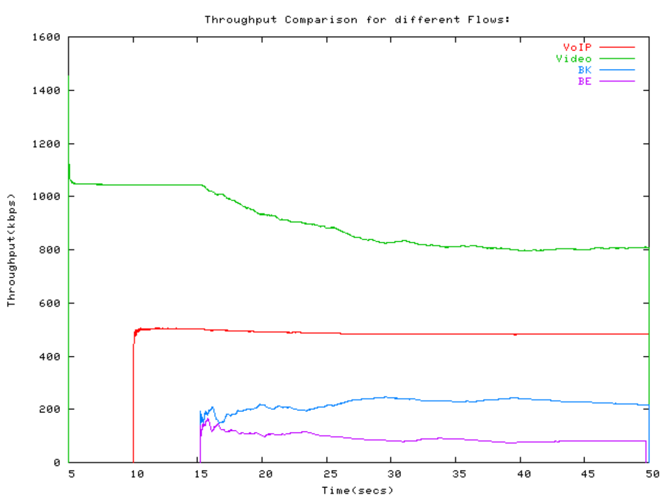

Fig.4 (a) Throughput with DCF

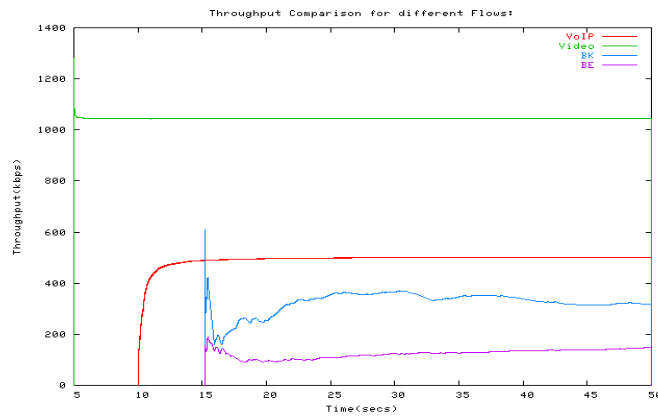

Fig.4 (b) Throughput with EDCA

In fig. 5 (a) and fig. 5 (b) we observe that VoIP performance is significantly improved via EDCA. We can see that when the BE/BK traffic is started at 15 secs, the voice frame delay has increased manifolds in DCF as compared to EDCA. Note that with the DCF, the voice frame delay sometimes reaches 300ms, which is not acceptable in most cases. It can also be seen that the delay for video traffic has increased in DCF as compared to EDCA when all the traffic flows are existing in the network. The delay for BE/BK traffic is also very high in the DCF as compared to EDCA.

These simulation results show that there is no service differentiation between the different types of traffic flows in DCF, which causes a QoS problem for multimedia applications when traffic load is high. The EDCA mechanism provides differentiated channel access for different traffic types and we expect that the EDCA can support real-time applications with voice and video traffic with a reasonable quality of service.

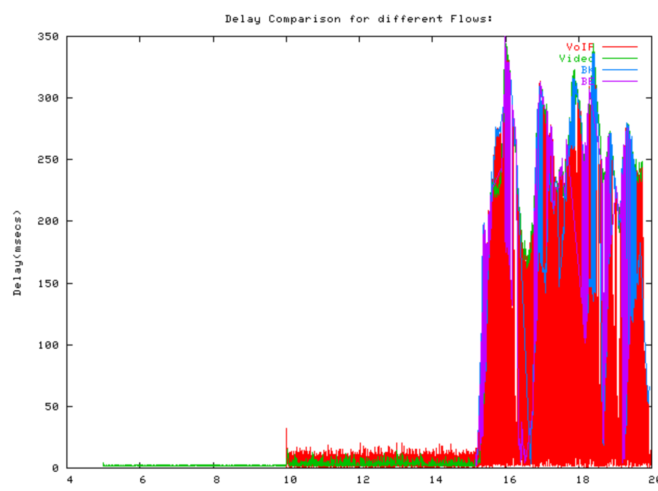

Fig. 5 (a) Delay with DCF

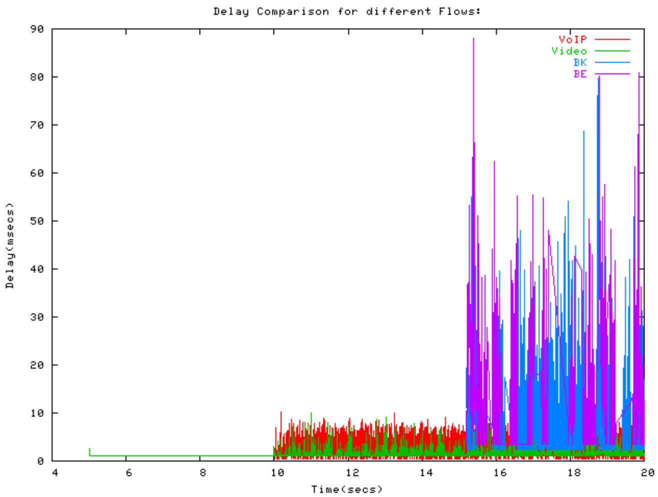

Fig. 5 (b) Delay with EDCA

C. *Simulation Analysis of EDCA*

First we consider the scenario 1, consisting of two VoIP connections, one video connection and two connections each of background traffic and best effort data. As mentioned above the applications are started at different times so as to illustrate the impact of additional traffic streams on existing load. Fig. 6 (a) shows the delay performance of these traffic streams. The delay for video frames is small (about 1ms) from 0s to 5s, as it is the only traffic in the network so that it does not have to contend the channel with other sources. With the introduction of VoIP traffic at 10ms, the delay for video frames increase to 3ms whereas the delay for VoIP traffic is about 1ms.It can be observed from the Fig. 8 that when the BK/BE traffic is started at 15 secs, the delay for video and VoIP has not increased significantly.

Next we simulate the scenario 2, in which we increase the number of VoIP connections to seven. In Fig. 6 (b) the impact of increasing the highest priority VoIP connections can be seen on the delay performance of low priority traffic. When all the traffic streams are present the delay for video frames increases to 10ms as compared to 3ms in scenario 1,also the delay for BK/BE traffic soars to 130ms as compared to 35ms in scenario 1.Thus the negative impact of increasing the higher priority traffic can be seen on the delay performance of lower priority traffic.

In scenario 3 we increase the number of background traffic and best effort data connections to four. In fig. 6 (c) we observe that the increase in low priority traffic does not have any negative impact on the delay of higher priority traffic. It can be seen that the delay for VoIP and video traffic is nearly same for both low BK/BE traffic and high BK/BE traffic. Comparing to VoIP load increases, increases in BK and BE load does not affect video delay in Fig. 6 (c) as much as that in Fig. 6 (b), largely due to the higher AC used by video traffic than BE and BK traffic.

Fig 7 (a), Fig. 7 (b) and Fig. 7 (c) show the throughput performance of traffic streams in the above scenarios respectively. In the above figures we can observe that increasing the lower priority traffic load is not affecting the throughput of higher priority traffic streams. It is worthwhile to note that due to the small CWmax value of 15, the total number of VoIP connections in a BSS should be small to keep the network stable. Otherwise, if the VoIP connection number is larger than CWmax, there may be infinite number of collisions between VoIP connections since at least two VoIP station will have the same backoff timer. We find that adding more BE and BK connections does not affect

VoIP throughput similarly addition of more VoIP and BK/BE connections is not affecting the throughput of video traffic. It can be observed from the Fig. 7 (c) that when the number of VoIP connections have increased the throughput of lower priority streams i.e. BK/BE traffic has decreased.

Hence from the above results we conclude that the EDCA is able to provide service differentiation between different types of traffic flows. The higher priority traffic streams are better served than lower priority traffic streams. The increase in traffic load of higher priority streams leads to decrease in throughput and increase in delay of lower priority streams.

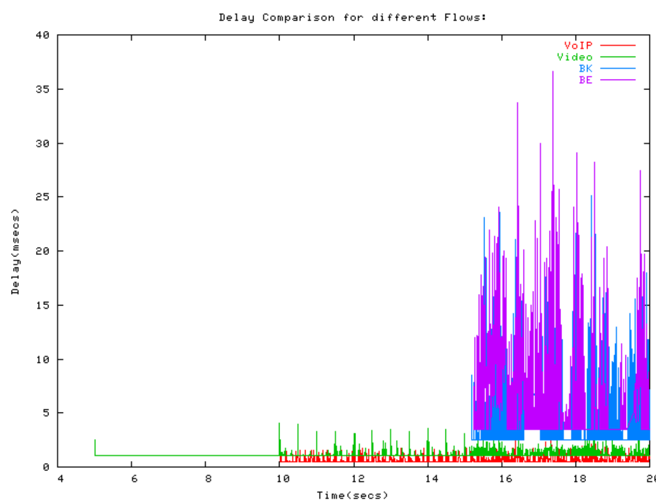

Fig. 6 (a) Delay for scenario 1

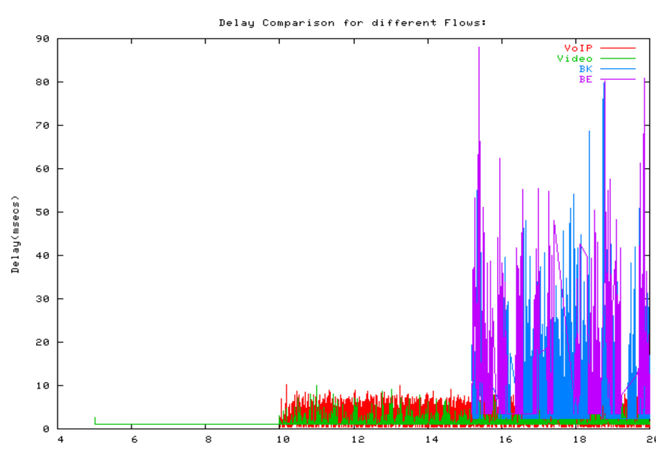

Fig. 6 (b) Delay for scenario 2

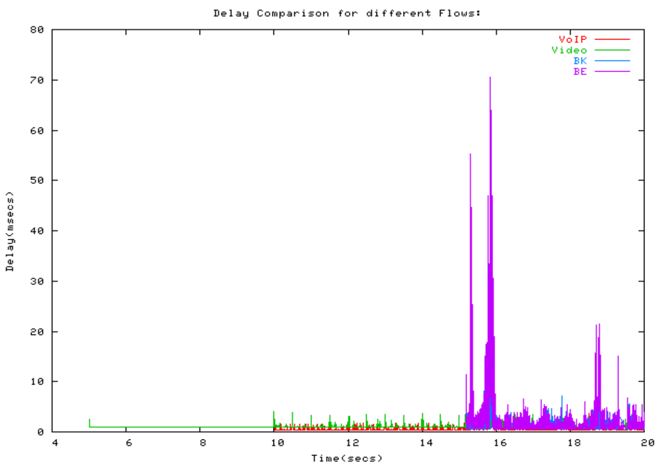

Fig. 6 (c) Delay for scenario 3

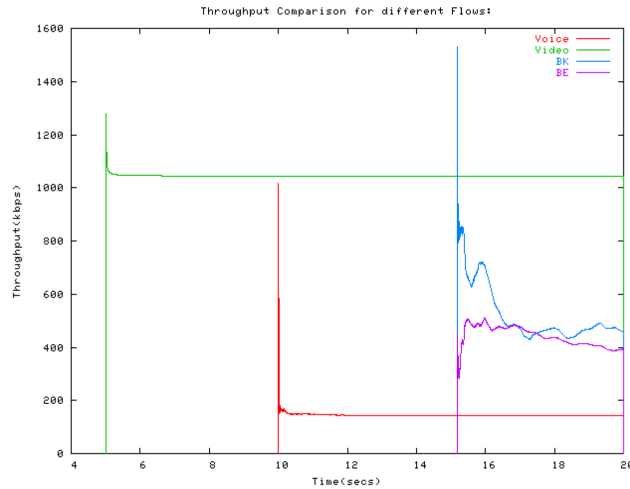

Fig. 7 (c) Throughput for scenario 3

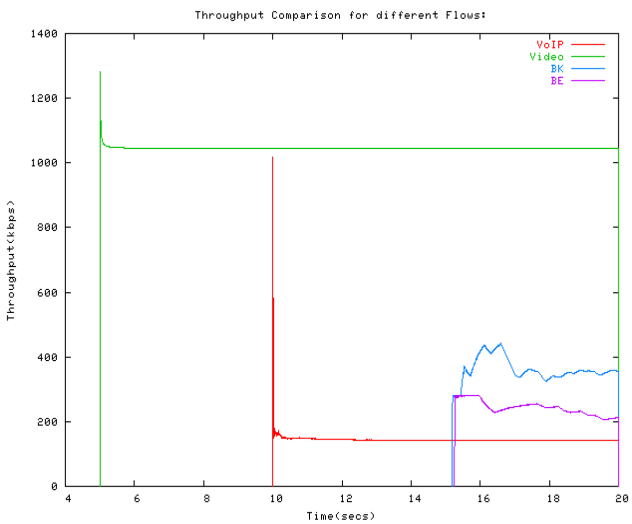

Fig. 7 (a) Throughput for scenario 1

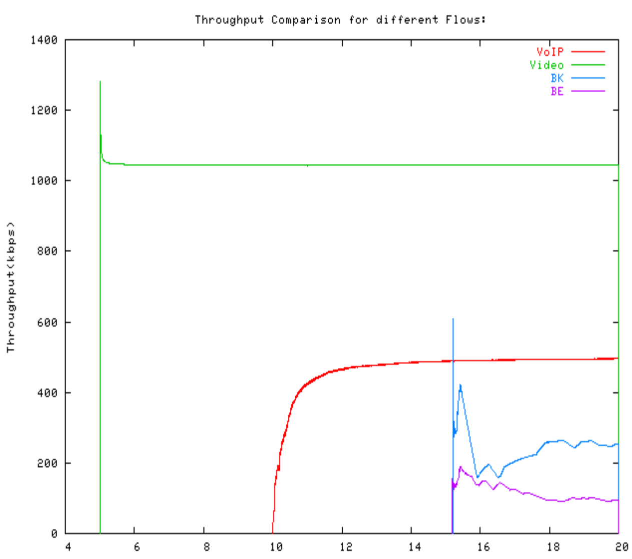

Fig. 7 (b) Throughput for scenario 2

IV. Conclusion

In this paper, we have evaluated the performance of EDCA mechanism for QoS support in IEEE 802.11e WLAN. Through our simulations, we compared the legacy 802.11 DCF and the 802.11e EDCA to show that EDCA provides differentiated channel access for different traffic types and is better equipped than DCF to handle real time applications with stringent QoS requirements. We find that with heavily loaded traffic connections under non-negligible background traffic, the EDCA mechanism is not able to provide QoS guarantee.

Better results can be obtained if we can adapt the EDCA parameters during the run-time depending on the network load and supported applications.

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