Adaptive Approach for QoS Support in IEEE 802.11e Wireless LAN

Joe Naoum-Sawaya, Bissan Ghaddar, Sami Khawam, Haidar Safa, Hassan Artail, and Zaher Dawy

Abstract—**The IEEE 802.11e standard has been introduced recently for providing Quality of Service (QoS) capabilities in the emerging wireless local area networks. This standard introduces a contention window based Enhanced Distributed Channel Access (EDCA) technique that provides a prioritized traffic to guarantee the minimum bandwidth needed for time critical applications. However, the EDCA technique resets statically the contention window of the mobile station after each successful transmission. This static behavior does not adapt to the network state hence reduces the network usage and results in bad performance and poor link utilization whenever the demand for link utilization increases. This paper proposes a new adaptive differentiation technique for IEEE 802.11e wireless local area networks that takes into account the network state before resetting the contention window. The performance of the proposed technique is evaluated compared to the original differentiation techniques of the IEEE 802.11a and IEEE 802.11e standards. Preliminary results show that the proposed adaptive technique enhances the channel utilization and increases throughput.**

Index Terms—**A Enhanced Distributed Channel Access, IEEE 802.11e, Quality of Service, Wireless LAN.**

I. Introduction

The emerging IEEE 802.11 family of wireless technologies has shown tremendous growth and acceptance as a last hop wireless solution in Local Area networks (LANs). Simultaneously with the growth of wireless LANs, multimedia applications over IP were widely developed hence the demand for Quality of Service (QoS) has been increased. The use of such applications is now a reality in corporate networks and promises to expand to the global Internet. The original IEEE 802.11 networks are best effort networks and do not support QoS for time critical applications [1]. A new IEEE 802.11 Standard (IEEE 802.11e) has been introduced to replace the best effort services by more sophisticated services that guarantee QoS attributes such as bandwidth, delay, and jitter [2]. This standard focuses on replacing the conventional Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF) of the Medium Access Control (MAC) layer by a Hybrid Coordination Function (HCF). The HCF defines two medium access mechanisms: a contention-based channel access referred to as Enhanced Distributed Channel Access (EDCA), and controlled channel access referred to as HCF Controlled Channel Access (HCCA). In this work we focus on the EDCA only. The EDCA is a Contention Window (CW) based channel access function that is based on priority allocation for different kinds of traffics to guarantee the minimum bandwidth needed for high priority applications and thus improving the network performance [2]-[5]. Similarly to the traditional DCF technique, the EDCA technique of IEEE 802.11e employs a static reset to the CW. This static behavior is a drawback since it does not offer any room for adaptation to the network state [2]. It also reduces the network usage and results in bad performance and poor QoS whenever the demand for medium utilization increases [3].

We believe that optimizing CW values leads to enhancing the network performance. In this context, this paper introduces a new Adaptive EDCA technique that adapts CW to channel conditions and adjusts it depending on the network utilization and performance.

This paper is organized as follows. Section II gives a brief review of the DCF and EDCA of the IEEE 802.11 and 802.11e standards. Section III introduces the proposed Adaptive EDCA (AEDCA) scheme. Section IV evaluates and discusses the performance of the proposed technique compared to IEEE 802.11 and 802.11e standards. Conclusion and future work are drawn in Section V.

II. Overview of the MAC layer

In this section, we review the DCF and EDCA techniques of the IEEE 802.11 and 802.11e MAC layer

A. IEEE 802.11 MAC Layer

The DCF technique of the IEEE 802.11 MAC layer employs a contention based channel access function and uses CSMA/CA mechanism [1]. Under DCF a station that intends to transmit monitors the channel until it is idle, and then waits for a time period of a Distributed Inter-Frame Space (DIFS) length. After sensing an idle channel for a DIFS period, the mobile station randomly selects a backoff timer (time slot) within a backoff window. The backoff timer is decreased only

J. Naoum-Sawaya, B. Ghaddar, S. Khawam, H. Artail, and Z. Dawy are with the Department of Electrical and Computer Engineering, American University of Beirut, Beirut, Lebanon (email: {jfn00, btg00, sgk05, hartail, zaher.dawy}@aub.edu.lb).

H. Safa is with the Department of Computer Science, American University of Beirut, Beirut, Lebanon (email: haidar.safa@aub.edu.lb) and with the Mobile Computing and Networking Research Laboratory (LARIM), Ecole Polytechnique de Montreal, Montreal, Canada H3T1J4 (email: haidar.safa@polymtl.ca).

when the medium is idle; it is frozen when another station is transmitting. Each time the medium becomes idle, the station waits for a DIFS and continuously decrements the backoff timer. As soon as the backoff timer expires, the station is authorized to access the medium and transmit. The backoff timer is derived from a uniform distribution over the interval [0, $CW – 1$], where CW is a value between [CW_{min}, CW_{max}].

At the very first transmission attempt, CW value is equal to the initial backoff window size CW_{min}. For every unsuccessful transmission the value of CW is doubled until CW_{max} is reached. After transmitting a frame, the station expects to receive an acknowledgment (ACK) from the destination station following a Short Inter-Frame Space (SIFS) time. If the acknowledgment is not received, the sender assumes that the transmitted frame was subject to a collision, so it schedules a retransmission and enters the backoff process again. After every successful transmission the CW is reset to CW_{min}.

DCF can only support best-effort services, hence QoS is not guaranteed [4]–[6]. Typically, time-bounded services such as voice over IP, or audio/video conferencing require specified bandwidth, delay and jitter, but can tolerate some losses. However, in DCF mode, stations compete for channel resources. This mode provides no differentiation mechanism to guarantee bandwidth, packet delay or jitter for high-priority traffic or multimedia flows [3].

B. IEEE 802.11 MAC Layer

As mentioned earlier, the new IEEE 802.11e standard introduces a Hybrid Coordination Function (HCF) [2] comprised of two medium access mechanisms: a contention-based channel access referred to as Enhanced Distributed Channel Access (EDCA), and controlled channel access referred to as HCF Controlled Channel Access (HCCA). This work focuses on the EDCA only. In EDCA, QoS is realized with the introduction of Access Categories (ACs) and multiple independent backoff entities. Frames are delivered by parallel backoff entities within one 802.11e station. EDCA provides differentiated distributed channel access for eight traffic priorities that are mapped into four queues (ACs) as shown in Table I; thus four backoff entities exist in every 802.11e station. Each AC queue works as an independent DCF station and uses its own contention parameters such as Arbitration Inter-Frame Space (AIFS), CW_{min}, and CW_{max}. Similar to a DCF station, each AC starts a backoff timer after detecting an idle channel for a time interval equal to an AFIS length. The backoff value is chosen to be a random number between [1, CW+1], where initially CW is set to CW_{min} and increases whenever collision occurs up to CW_{max}. The value of CW increases as

$$CW_{new}[AC]= ((CW_{current} [AC] + 1) * PF[AC]) – 1 \qquad (1)$$

where PF is the persistence factor that decreases as priority increases [2].

In case of successful transmission, the CW value of the AC queue is reset to CW_{min}. As shown in Table II, in EDCA high priority traffic has a smaller $AIFS$, CW_{max}, and CW_{min} than low priority traffic. Thus, high priority traffic will enter the contention period and access the wireless medium earlier than low priority traffic.

In IEEE 802.11e, whenever a station seizes the channel, it will be able to transmit one or more frames for a Transmission Opportunity time interval (TXOP). A TXOP is an interval of time during which a given station has the right to transmit frames. A TXOP is defined by its starting time and duration. The duration of *TXOP* is limited by a parameter referred to as *TXOPlimit* Please refer to [2] for more details about EDCA.

The main problem of this EDCA ad-hoc mode is that the values of CW_{min}, CW_{max}, and the backoff function of each queue are static and do not take into account wireless channel conditions.

TABLE I
USER TRAFFIC PRIORITIES MAPPED TO ACCESS CATEGORIES

User Priority	Designation	Access Category
1	BK (Background)	AC_BK
2	BK (Background)	AC_BK
0	BE (Best-effort)	AC_BE
3	EE (Video/Excellent-effort)	AC_BE
4	CL (Video/Controlled Load)	AC_VI
5	VI (Video)	AC_VI
6	VO (Voice)	AC_VO
7	NC (Network Control)	AC_VO

III. ADAPTIVE EDCA TECHNIQUE

As described in the previous section, EDCA offers differentiation depending on the traffic access category. Each category is given a priority depending on resource requirements of each application. Access category values are shown in Table II. This differentiation technique offers adaptation depending on traffic category and does not take into account network state or network contention level since EDCA technique resets the CW of each station after each successful transmission to CW_{min}.

TABLE II
ACCESS CATEGORIES

Access Category	AC_VO	AC_VI	AC_BE	AC_BK
AIFS	2	2	3	7
CW_{min}	7	15	31	31
CW_{max}	15	31	1023	1023
TXOPlimit	0.003008	0.006016	0	0

In case of highly congested channels there is a high probability of collisions. These collisions entail CW into acquiring higher values. Consequently it is more favorable that CW values are accustomed to the channel state therefore getting values distant from CW_{min} whenever the channel is congested and values close to CW_{min} whenever the channel is free. Besides, this adaptation scheme should also be relative to CW_{max} therefore CW should acquire values close to CW_{max} whenever the channel is congested and values distant from

CW_{max} whenever the channel is free.

We believe that enhancing the EDCA technique to adapt CW values to the channel state has many advantages over the original EDCA technique of IEEE 802.11e. Such enhancement will avoid the waste of time (backoff time) since the original EDCA keeps increasing CW to a value that would allow transmission. Instead the proposed adaptive approach would set CW directly to a value close to the required one for transmission therefore eliminating the time spent for the try, fail, and wait of transmissions.

The proposed approach is based on adapting the values of CW depending on the channel congestion level. We observe that in IEEE 802.11e the value of CW is incremented whenever a station fails to transmit due to a collision. This would imply that when the channel is highly congested CW would acquire values distant from CW_{min} and close to CW_{max}. Similarly, when the channel is free, CW values would be close to CW_{min} and distant from CW_{max}. Hence, it is feasible to estimate the channel congestion level by taking into consideration the current value of CW. We use a very simple approach to estimate this level. In this approach, we start from the fact that CW value ranges in the interval $[CW_{min}, CW_{max}]$, then we compute its relative distance ($CW_{current}$ - CW_{min}) compared to the maximum distance ($CW_{max} - CW_{min}$) as an indication for channel congestion level. It follows that the estimated link congestion *ratio* in the proposed Adaptive scheme can be written as:

$$ratio = \frac{CW_{current} - CW_{min}}{CW_{max} - CW_{min}} \qquad (2)$$

To optimize further this *ratio*, we use a *weight* that reflects the certainty of the channel estimation. This certainty is decreased as time elapses between consecutive transmissions. Hence our current estimation of the channel has a greater value if the time difference between successive transmissions is negligible. In the proposed scheme, the ratio is weighted as follows:

$$ratio = weight \times \frac{CW_{current} - CW_{min}}{CW_{max} - CW_{min}} \qquad (3)$$

For instance, the *weight* of the ratio would be very small if current channel estimate is used in a transmission that occurred several minutes ago. However the *ratio* would be highly weighted if the difference in time between estimation and transmission is of the order of milliseconds. To obtain some preliminary simulation results, the *weight* was fixed in this paper to a value of 0.9. Indeed, the weight converged to this value after several tests. This is due to fact that video streaming is characterized by transmission occurring at very small time intervals.

The CW value of the proposed adaptive scheme, CW_{new} can be given then as follows:

$$\begin{aligned} CW_{new} &= ratio \times (CW_{current} - CW_{\min}) + CW_{\min} \\ &= weight \times \frac{(CW_{currrent} - CW_{\min})^2}{CW_{\max} - CW_{\min}} + CW_{\min} \end{aligned} \qquad (4)$$

The *ratio* is a normalized value ranging from 0 to 1 that reflects the weighted degree of channel contention. This ratio would take a value close to 0 whenever the channel is free. Therefore $CW_{current}$ would have a value close to CW_{min} and distant from CW_{max}. The value of this *ratio* would be close to 1 whenever the channel is congested. Therefore $CW_{current}$ would have a value distant from CW_{min} and close to CW_{max}. Multiplying this ratio by the factor ($CW_{current} - CW_{min}$) and adding the result to CW_{min} would result in a value bounded by $[CW_{min}, CW_{max}]$. This value of CW_{new} would be a good representation of the backoff timer value needed for transmission for the current traffic priority taking into account the current network conditions.

IV. Performance Evaluation

Two simulation scenarios evaluate the performance of DCF in IEEE 802.11 standard, EDCA in IEEE 802.11e scheme, and the proposed Adaptive EDCA. These simulations were implemented using NS-2 [7].

A. Scenario 1

The first simulation scenario reveals the performance of the DCF and the EDCA in terms of the following three parameters: bit rate, end-to-end packet delay, and packet drop rate. The simulation topology of this scenario is simple. It consists of 8 mobile nodes: 4 source nodes and 4 destination nodes. Each node is transmitting with a different priority. *Node 1* is given a higher priority than *Node 2*, which is given also a higher priority than *Node 3*. *Node 3*, in its turn, is given a higher priority than *Node 4*. Each source is a *Constant Bit Rate* source over UDP (User Datagram Protocol). The size of a transmitted packet is 512 bytes. Transmission rate of a node is 600Kbps. We assumed that the nodes are in transmission range at a constant distance of 195 m. The simulation time lasted for 80 sec.

Fig. 1, Fig. 2 and Fig. 3 show the performance of the DCF of the IEEE 802.11a MAC layer. Fig. 1 shows the bit rate achieved at the destination nodes. Fig. 2 shows the packet drop rate. Fig. 3 shows the delay of packet transmission. In Fig. 1, *Node 1* starts transmitting at time T = 1.4 sec while *Node 2* starts transmitting at time T = 10 sec. During the period of time [1.4 sec, 10 sec] *Node 1* is the only transmitting node using the entire available bandwidth. This justifies the high performance of *Node 1* during the specified interval of time. At time T = 10 sec, *Node 2* starts transmission hence sharing channel resources with *Node 1*. This explains the heavy reduction of bit rate. In addition, the bit rate plot experiences heavier oscillations and reduction as the number of transmitting nodes increases. Oscillations are reflected in heavy disorders in network performance.

A similar dramatic behavior is also reflected in Fig. 2, which shows a high packet drop rate whenever the number of nodes sharing network resources increases. We notice that the packet drop rate in the interval [1.4 sec, 10 sec] is 0. This can be easily justified since only one node is using the network during this time interval. However this high-quality performance is deteriorated as more nodes start sharing the network resources. Fig. 3 illustrates the end-to-end delay for delivering a packet. When the number of nodes that are sharing the network resources increases, the delay significantly increases and readjusting *CW* of each node takes longer time.

These results reveal the bad behavior of IEEE 802.11a networks when many nodes are transmitting offering no protection for streaming traffic. QoS is not guaranteed in IEEE 802.11a MAC layer.

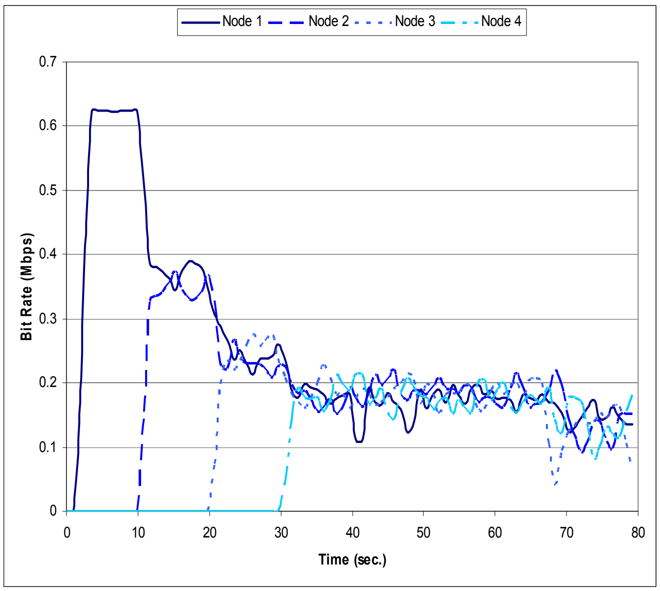

Fig. 1. Bit Rate in IEEE 802.11a

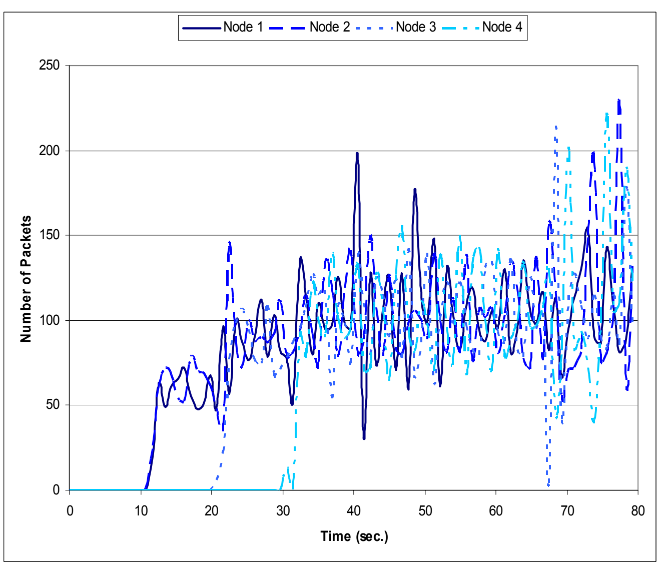

Fig. 2. Packet Drop Rate in IEEE 802.11a

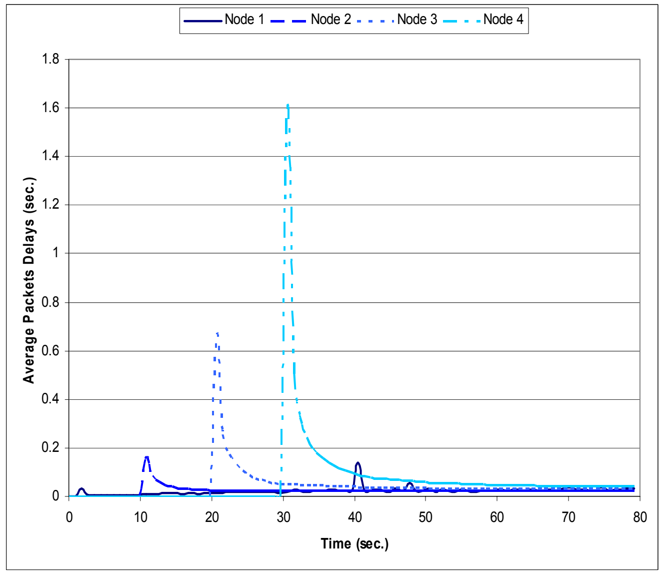

Fig. 3. Average Packets End to End Delay in IEEE 802.11a

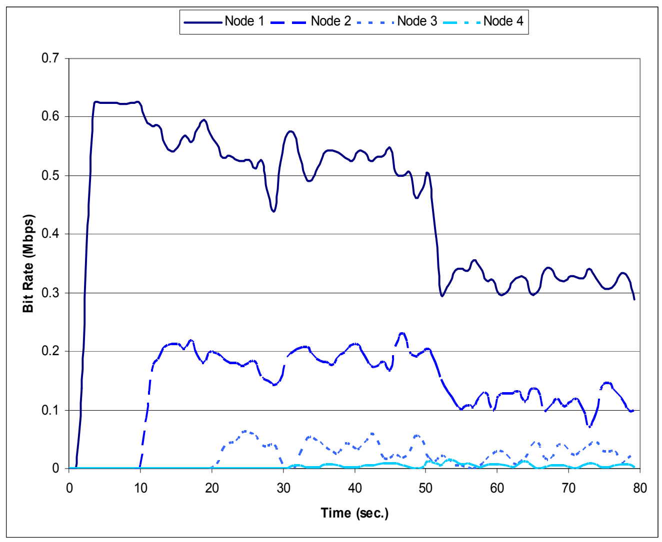

Fig. 4. Bit Rate in IEEE 802.11e.

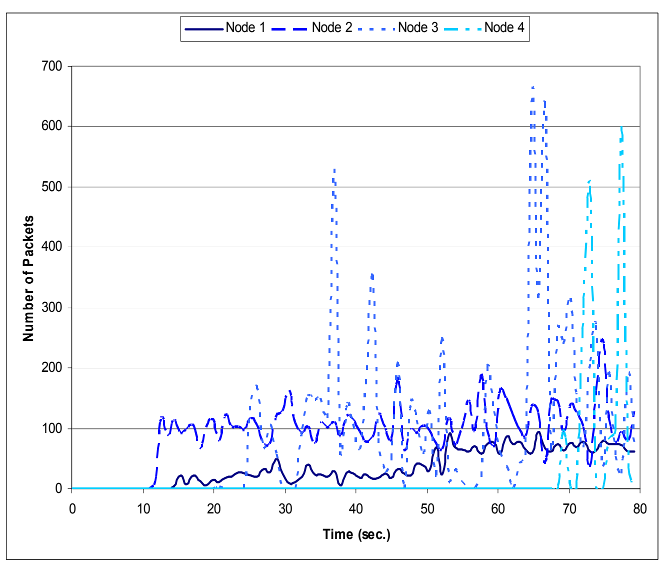

Fig. 5. Packet Drop Rate in IEEE 802.11e.

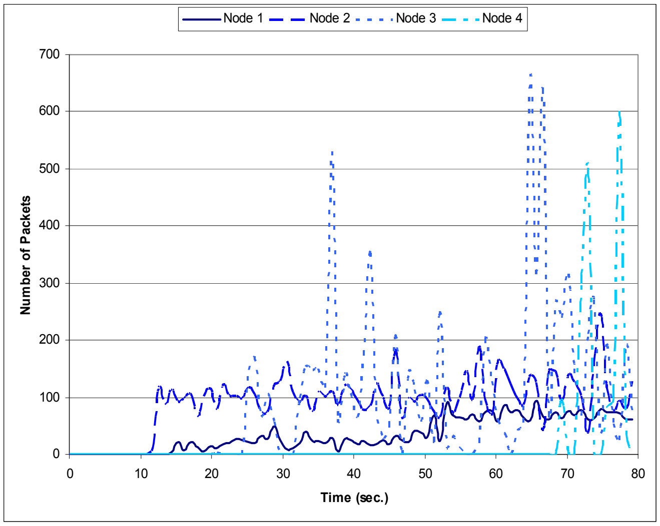

Fig. 6. Average Packets End to End Delay in IEEE 802.11e.

In Fig. 4, Fig. 5, and Fig. 6 the same topology described above is used in order to show the performance of the EDCA technique in IEEE 802.11e MAC layer. The bit rate in Fig. 4 shows a more stable system that does not experience heavy oscillations whenever network resources are shared. Additionally, bit rate is guaranteed depending on priorities. *Node 1*, having the highest priority, is guaranteed a minimum performance. This outperforms the IEEE 802.11a system simulated in Figures 1, 2, and 3. In EDCA, channel resources are divided relative to priorities. Each node is guaranteed a minimum value of throughput; therefore streams with higher priorities are protected against those of lower priorities. Fig. 5 illustrates the packet drop rate for each node. These plots show that the drop rate decreases as priority increases. *Node 1* having the highest priority experiences the least number of drops. We observe that *Node 1* in IEEE 802.11e experiences constant low drop rate. However, in IEEE 802.11a the drop rate heavily oscillates, as shown in Fig. 2, which highly affects performance of time critical applications. Figure 6 illustrates the end-to-end delay for IEEE 802.11e. In this figure, packets with high priorities do not experience any delay compared to IEEE 802.11a

In general, this simulation scenario shows the poor performance of IEEE 802.11a in heavily loaded networks. It also reveals how priorities, in IEEE 802.11e, can guarantee a relatively constant and reliable behavior even in heavily congested channel conditions

We evaluate the performance of the proposed Adaptive EDCA compared to the EDCA of the IEEE 802.11e standard using the same topology of scenario 1. Fig. 7, Fig. 8, and Fig. 9 show the performance obtained by employing the proposed adaptive technique. Fig. 7 demonstrates higher achievable bit rate especially when the channel is highly congested (Time > 50s) leading to better usage of network resources. Fig. 7 shows that the proposed technique outperforms the original one in all network conditions. Besides, the proposed Adaptive EDCA technique approximately doubles the bit rate achieved by the original EDCA especially in congested network conditions. The latter was subject to a deep fade when time *T* > 50s due to heavy channel congestions. Furthermore, this increase in performance is reflected over all priorities. Fig. 8 shows comparable results between the proposed adaptive EDCA and the original EDCA. Fig. 9 shows a decrease in packet end-to-end delay leading to a better network performance and utilization. The severe delay of Node 4 (lowest priority) is decreased when using the new adaptive scheme. This can be explained as follows. Because of the high bit rate achieved with the proposed technique, nodes can now transmit faster.

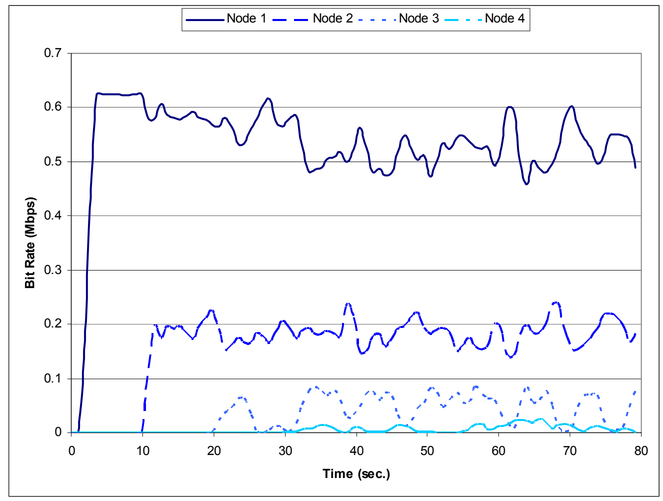

Fig. 7. Bit Rate in Adaptive EDCA.

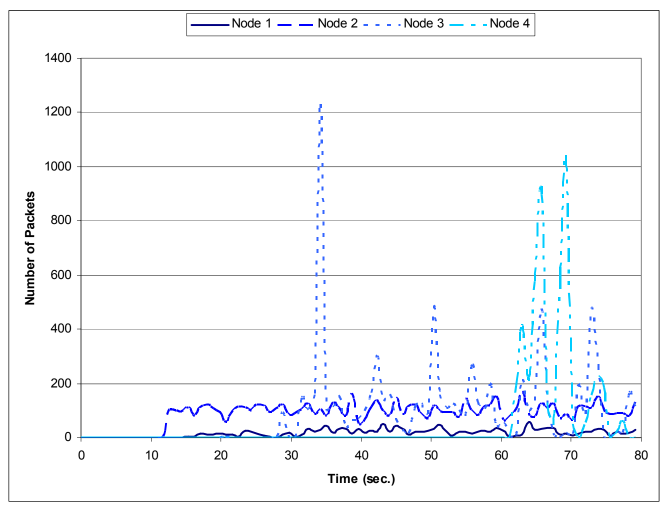

Fig. 8. Packet Drop Rate in Adaptive EDCA.

Table III presents the average bit rate gain obtained by using the proposed adaptive EDCA scheme over the EDCA scheme in IEEE 802.11e. The gains are presented for each access category. For example, the average gain is 28% over *Node 1* with priority 0 whereas the average gain is 16% over *Node 2* with priority 1. These variations are reflected in the gain which increases with the increase of network congestion. The gain is highest when all four nodes are transmitting simultaneously over the channel. We notice that by employing the original IEEE 802.11e scheme, lower priority applications suffer heavily hence applications transmitting at this priority are subject to starvation. The introduced adaptive scheme offers better protection for lower priority traffic. This is reflected in a 59% gain on *Node 3* (priority 2) and a 56% gain over *Node 4* (lowest priority). By employing the Adaptive scheme lower priority nodes are less likely to suffer from starvation.

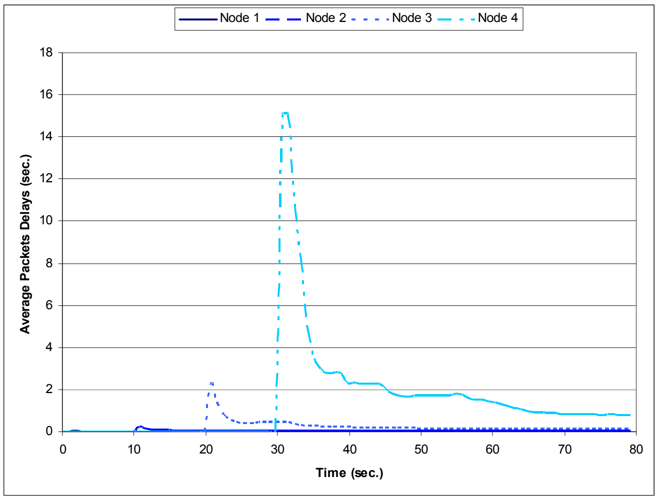

Fig. 9. Packet Average Packets End to End delay in Adaptive EDCA.

TABLE III
BIT RATE AVERAGE GAIN

Access Category	AC_VO	AC_VI	AC_BE	AC_BK
Average Gain	28%	16%	59%	56%

Generally speaking, this simulation scenario shows that when additional nodes start transmitting in the medium, the IEEE 802.11a DCF is subject to a severe decrease in performance. This performance decreases further as more nodes start transmitting. However highly prioritized traffic transmitted with the EDCA of IEEE 802.11e is protected from severe fades whenever new channels access the medium. Nevertheless, this scheme does not achieve a high performance under all network conditions. IEEE 802.11e undergoes heavy decrease in performance when the channel gets more and more congested. The new proposed adaptive scheme demonstrates static behavior over all channel conditions. The simulation clearly shows that under same network conditions, the proposed adaptive technique outperforms the other two techniques.

B. *Scenario 2*

In this scenario we investigate the performance of the IEEE 802.11a DCF, the IEEE 802.11e EDCA, and the proposed adaptive EDCA for real time applications. For this purpose we have used EVALVID tool [8] to transmit MPEG-4 video sequence and used a topology similar to the one in the previous scenario. However, this scenario simulates a severe congested network. The simulated topology consists of 20 nodes separated by a distance of 195m. All nodes are assumed to be in transmission range. *Node 1* is transmitting MPEG-4 sequence of 400 frames. Each frame is fragmented into packets of 1000 bytes. The frame rate is 30 frames/sec. The sequence is received at *Node 2*. We evaluate the performance of the network by inspecting the received video sequence at *Node 2*.

Applications on the other 18 nodes are generating Constant Bit Rate traffic over UDP. They are transmitting packets of size 1000 bytes each. The used bit rate in this simulation is 500Kbps. Applications are transmitting traffic with priority 4. Such high priority applications running on 18 nodes generate a heavily congested channel and represent a great challenge for the support of QoS.

Samples of the received video sequences are shown in Fig. 10. The figure shows that IEEE 802.11a experiences heavy congestion. This is reflected in a very poor video quality at the receiving node. Even though the main purpose of IEEE 802.11e is to provide QoS, we observe a reduced quality in the received video frames. However, we notice a remarkable QoS for the video sequence transmitted using the proposed Adaptive EDCA. Results confirm the ability of the proposed technique in protecting real time applications with high priority in heavily congested networks.

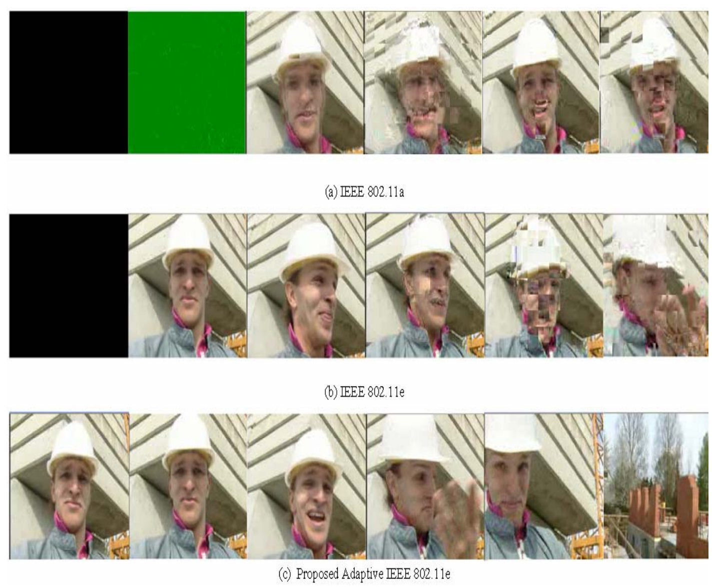

Fig. 10. Performance of the Three Schemes using MPEG-4 Video Streaming.

V. CONCLUSION

In this paper, we have evaluated the performance of the IEEE 802.11a and IEEE 802.11e standards. We have also proposed a new adaptive differentiation technique for resetting the value of the contention window after each successful transmission. The proposed adaptive technique takes into account the current level of link utilization when resetting such value. We have performed several simulation scenarios, using NS-2, to evaluate the proposed technique compared to IEEE 802.11a and IEEE 802.11e. During the evaluation, we have focused on three parameters: bit rate, end-to-end packet delay, and packet drop rate. In addition, we evaluated the proposed approach, under heavy loads, using EVALVID tool to generate and transmit MPEG-4 video sequences. Results have shown the effectiveness of the proposed technique compared to other techniques.

REFERENCES

[1] IEEE Std 802.11. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification," 1999 edition.

[2] IEEE Std 802.11e/D4.3. Draft Supplement to IEEE standard for Telecommunication and Information exchange between systems – LANMAN specific requirements. Part 11: wireless LAN Medium Access Control (MAC) and Physical Layer (Phy), May 2003.

[3] Q. Ni, L. Romdhani and T. Turletti, "A survey of QoS enhancements for IEEE 802.11 wireless LAN," *Wireless Communications and Mobile Computing* 4, pp. 547–566, 2004.

[4] S. Mangold, S. Choi, P. May, O. Klein, G. Hiertz, and L. Stibor, "IEEE 802.11e wireless LAN for quality of service," *Proceedings of European Wireless (EW2002)*, Florence, Italy, February 2002.

[5] D. Gu and J. Zhang, "QoS Enhancement in IEEE 802.11 Wireless Area Networks," *IEEE Commun. Mag*., vol. 41, no. 6, June 2003, pp. 120-24.

[6] I. Aad and C. Castelluccia, "Differentiation mechanisms for IEEE 802.11", Proceedings *of IEEE Infocom 2001*, Anchorage, Alaska, USA, April 2001; 1: 209–218.

[7] NS-2 simulator. http://www.isi.edu/nsnam/ns/ [April 2002].

[8] Evalvid simulation tool home page - http://hpds.ee.ncku.edu.tw/~smallko/ns2/Evalvid_in_NS2.htm