Adaptive Transmission Opportunity with Admission Control for IEEE 802.11e Networks

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ABSTRACT
The increase of IEEE 802.11's bandwidth led to a deployment of many multimedia applications over wireless networks. Nevertheless, these applications impose stringent constraints in QoS. In this context, a lot of works have been proposed in order to enhance the QoS-capable IEEE 802.11e MAC protocol. However, they settle for maintaining only an inter-QoS differentiation between the traffic classes, and neglect the intra-Qos differentiation. In fact, the flows belonging to the same service class are assigned the same MAC parameters regardless of their data rate, which leads to throughput fairness rather than perceived QoS fairness. On the other hand, the proposed schemes exhibit performance degradation when the number of flows increases. In this paper, we propose a new MAC protocol based on the reservation of the wireless channel through the use of transmission Opportunity (TXOPlimit) parameter. Each traffic class monitors the MAC queue and computes at runtime the TXOPlimit's value. Thus based on the class' priority and flow's data rate, we can ensure both intra and inter QoS differentiation. Additionally, we specify a distributed admission control mechanism that regulates the network load and protects the admitted flows from the new ones. Simulation results show that compared to the Enhanced Distributed Channel Access (EDCA) scheme of 802.11e, our protocol excels, in terms of network utilization and ability to maintain intra-QoS data rate differentiation. Further when introducing the admission control mechanism, we ensure high protection to the admitted flows, and maintain the network in steady state.

Categories and Subject Descriptors
C.2.1 [**Computer – Communication Networks**]: Network Architecture and Design – *Wireless communication.*

I.6.6 [**Simulation – Modeling**]: Simulation Output Analysis.

General Terms
Algorithm, Performance, Design.

Keywords
MAC protocol, IEEE 802.11e, CSMA/CA, QoS, Admission Control.

1. INTRODUCTION
Wireless local area networks are becoming ubiquitous and increasingly reliant on as IEEE 802.11[1] products that become successful in the market. One key market for the IEEE 802.11 products, public net access through hot spots at airports, hotels and coffee shops, is rapidly becoming common and high speed wireless Internet access is generating more growth projections. Meanwhile, new emerging applications that impose a stringent requirement in QoS are being widely adopted (Visio conferencing, VoIP and Video On demand). In this context, it is important to guarantee these requirements at IEEE 802.11 MAC-level, allowing continuity and interaction with higher layer QoS mechanisms (cross-layer QoS)[2]. To tackle the QoS issues at MAC level, the IEEE formed the 802.11 e task group to notably design a generic framework for supporting QoS mechanisms. The IEEE 802.11e draft standard[3] proposes the Hybrid Coordination Function (HCF) and specifies two access schemes: the Enhanced Distributed Channel Access (EDCA) and the HCF Controlled Channel Access (HCCA). Among these schemes, EDCA introduces priority-based CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance). The EDCA access mechanism supports relative priority service through the introduction of Access Categories (ACs). Instead of using a single queue and one channel access function as in the Distributed Coordination Funcion (DCF), each station implements multiple ACs. Each AC consists of an independent transmit queue and a channel access function with its own parameters, that include minimum and maximum Contention Windows (CWmin, CWmax), Arbitration Interframe Space (AIFS) and Transmission Opportunity (TXOP) duration. Substantial amount of works were carried out focusing on enhancing EDCA and developing differentiated services mechanisms. They proposed different priority schemes through differentiating the inter-frame spaces (IFS), minimum/maximum contention windows and even contention window increasing process. In AEDCF (Adaptive EDCF)[4], after each successful transmission, the authors propose to smoothly reset the CW values based on the actual average collision rate. The AF-EDCF (Adaptive Fair EDCF)[5] aims at reducing the effect of idle time slots through using a AC[i]-based adaptive backoff threshold taking into account the channel load. This consists in increasing the contention window during deferring periods when the channel is busy, and using an adaptive fast backoff decreasing mechanism when the channel is idle. Generally, the adaptive backoff-based

differentiation[4][5][6][7]provides priority medium access for multimedia streams by reducing the probability of collision between frames belonging to different access classes. These approaches however, are not sufficient to provide deterministic intra-AC QoS differentiation, given that they consider only inter-AC QoS differentiation. Indeed, if we consider two flows belonging to the same AC with two different data rate, it is obvious that the flows with higher data rate must access to the channel more frequently. Meanwhile, when the number of the contending flow increases, these mechanisms exhibit high network performances degradation.

Our main concern, in this paper, is to provide a QoS-capable mechanism that guarantees both inter-AC differentiation and intra-AC differentiation, while maintaining fairness between the AC[i]'s flows. At first, we propose a new scheme called Enhanced Transmission Opportunity (ETXOP), which uses the new feature proposed by 802.11e, namely TXOPlimit. In fact, Transmission Opportunity is the interval of time when a particular wireless station has the right to initiate transmission. The wireless station is allowed to transmit successive frame as long as the transmission time does not exceed the TXOPlimit. In[8], the authors show that using TXOPlimit as differentiation parameter in EDCA improves very significantly the overall performances. However, since EDCA uses the same TXOPlimit's value for all AC[i]'s flows, no intra-QoS differentiation is achieved. To solve this problem, we propose to use a dynamic TXOPlimit's value, which is computed at runtime and according to: *(i)* AC's priority (Inter-AC QoS differentiation); *(ii)* the amount of data to transmit (Intra–AC QoS differentiation). Afterwards, we extend ETXOP scheme with a distributed admission control, which protects the existing flows from the new ones. In fact, according to the network state information, each station is able to accept or reject the arriving flows. Within this method we attempt to control the network access dynamically and through a distributed way when the number of flows increases.

The remainder of this paper is organized as follows. The next section will provide background material on the 802.11 MAC, and QoS enhancements. Section 3 describes the design of the Enhanced Transmission Opportunity ETXOP protocol. Section 4 describes the admission control mechanism. In Section 5 we compare the performance between ETXOP and EDCA, and show the improvement introduced by the admission control algorithm. Finally, we draw conclusions from this work in Section 6.

2. BACKGROUND AND RELATED WORK

The IEEE 802.11 MAC defines two transmission modes for data packets: the Distributed Coordination Function (DCF) based on CSMA/CA and, the contention-free Point Coordination Function (PCF), where the Access Point (AP) controls all transmissions based on a polling mechanism. The popularity of the IEEE 802.11 wireless LAN (WLAN) is due mainly to the DCF, whereas the PCF is barely implemented in today's products due to its complexity and inefficiency for the normal data transmissions, even though it has some limited QoS support. In fact, the PCF may cause unpredictable beacon delays and unknown transmission durations of the polled stations. On the other hand, DCF is the basic mechanism for IEEE 802.11 employing CSMA/CA algorithm. Before sending a packet, a wireless station first senses the medium for the duration of the Distributed Inter-Frame Space (DIFS). If the medium is free for the duration, the wireless station starts sending the packet immediately. Otherwise, if the wireless station detects the medium as busy for the duration, the wireless station backs off for a multiple of time slots (1).

$$Backoff = Random\ (0,\ CW\text{-}1)\ *\ SlotTime \qquad (1)$$

If no other terminal starts transmitting before the intended slot is reached, the transmission is started. Collisions can only occur in the case where two terminals have selected the same slot. For each unsuccessful transmission the contention window is exponentially increased as follows:

$$CW_{new} = \left(CW_{\min} \times 2^{i}\right) \qquad (2)$$

where i is the number of unsucceful transmission attempts.

The need for better access mechanism supporting service differentiation has led task group e of IEEE 802.11 to propose an extension of the actual IEEE 802.11 standard. EDCA is a new channel access scheme, which enhances the DCF access mechanism by introducing service differentiation. This differentiation is achieved through varying the amount of time a station would sense the channel as idle and the length of the contention window during a backoff. EDCA supports four access categories: AC3 is for voice transmission; AC2 is for video transmission; AC1 is for background traffics and AC0 is for best effort data transmission. Each AC flow maintains AC-specific parameters such as Arbitration Inter-frame Space AIFS[i], contention window minimum CWmin[i], contention window maximum CWmax[i] and Transmission Opportunity TXOP[i]. AIFS is determined by:

$$AIFS[i] = SIFS + AIFSN[i] * SlotTime \qquad (3)$$

where SIFS : Short Interframe Space and $AIFSN[i] \geq 2$.

However, the probabilistic nature of the CSMA/CA protocol makes it difficult to maintain high channel utilization and fair channel usage. As the network becomes congested, backoff times must increase in order to keep the probability of collision relatively low. In this context it is more useful to take the channel state into account in order to maintain QoS between the ACs. In [4][5][9][10] the proposed schemes are based on the network load in the design of the MAC's parameters (AIFS, CWmin , CWmax and PFactor). In fact, by monitoring the network state, these schemes improve considerably the network performances. Nevertheless, all the proposed schemes provide only inter-AC QoS differentiation. Moreover, all of them show a network's performances degradation when the flows' number increases. To provide a good QoS-capable scheme, three important characteristics must be assured: *(i)* maintaining a strict inter-AC QoS differentiation; *(ii)* providing intra-AC QoS differentiation; *(iii)* limiting the number of flows in order to guarantee QoS to the admitted flows.

3. ENHANCED TXOP

3.1 Context

Most of existing works that addressed QoS issues in IEEE 802.11, guaranteed a strict differentiation between AC. Nevertheless, this is not sufficient, especially if we consider the case where different flows belonging to the same AC have different data rate. Indeed, through differentiating the inter-frame spaces (IFS) or minimum/maximum contention windows as well as the window increasing process, the differentiation is guarantee only between the AC. Hence, the flows belonging to the same AC have the same probability for transmission. To cope with this issue, we control the channel access through the use of the TXOPlimit parameter. Thus when a wireless station wins the contention, it is allowed to transmit a burst of packets until it reaches the TXOPlimit. In the design of ETXOP, we define for each Access Class *i* a TXOPlimit value. However, unlike EDCA that defines a static TXOPlimit's value, we provide for each station the mean to compute at runtime the TXOPlimit value. Further, according to AC's priority, the way to compute the TXOPlimit is different. Thus in case of AC2 and AC3 that represents the high priority ACs, the TXOPlimit is computed dynamically and in a way to maximize the perceived throughput and minimize the packet loss rate. On the other hand, for Background and Best effort traffic (AC0, AC1), we assign a static TXOPlimit. Thereby, we ensure that AC's stations send a limited burst of packets. Additionally, it is important to maintain an inter-AC QoS, so, we propose to use the AC's MAC parameter defined in[3].

3.2 ETXOP Procedure

Transmission Opportunity (TXOP) is a new feature proposed by the IEEE 802.11e draft. The TXOP is used in both EDCA and HCCA.

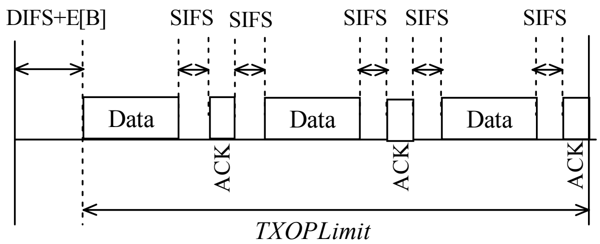

Figure 1. Medium access when enabling TXOPlimit

In EDCA, the TXOPlimit's value is constant and determined for each AC by the AP through the beacon frame. In HCCA, a simple scheduling algorithm is proposed to take the QoS requirement of traffics into account. Each Wireless Station (WS) sends a QoS request packet to the AP containing the mean data rate of the application. Based on this information, the AP computes the TXOPlimit appropriate for each WS. The TXOPlimit is computed based on equations (4), (5).

$$N_i = \frac{P_i \times SI}{M_i} \qquad (4)$$

$$TXOP[i] = N_i\left(\frac{M_i}{R} + 2 \times SIFS + ACK\right) \qquad (5)$$

where P_i represents the mean data rate, M_i the packet size ,Ri the channel data rate and *SI* is the service interval.

In other word, the WS is allowed to send all the arrival packets every *SI* period. Thus this scheduler ensures that each WS's queue is polled.

Our main idea in the design of ETXOP mechanism is rather than using a static TXOPlimit value, we use the concepts used in HCCA mechanism. In fact we propose a dynamic TXOPlimit's value based on application's data rate requirement. At this point, it is important to note that HCCA is a centralized mechanism and the ETXOP is a distributed one. To cope with this situation, we propose that each time a WS wins the channel contention; it monitors the MAC-level queue in order to note the queue length and the arrival packets. Thus, each WS's flow is able to deduce the N_i and M_i presents in the equation (5), and consequently computes at run time the TXOPlimit's value. Thereby, rather than using a centralized polling mechanism, each WS is able to compute periodically the TXOPlimit through a distributed mechanism.

Basically, the N_i value influences significantly the TXOPlimit value. In fact, it represents the number of packets to transmit in burst. The higher is this value, the higher is the TXOPlimit's value. Thus, we rely on the N_i to separate the AC3 and AC2 flows. Since AC3 represents the most sensitive traffics, therefore this class must perceive a constant QoS whatever the network load. Accordingly, we propose that, N_i represents the current AC3 Queue length. Here, we ensure that the totalities of WS's packets present in the queue are transmitted. In other word, the AC3 queue is emptied each time a WS wins the contention.

On the other hand, as AC2 carries video flows that are more sensitive to packet loss, it is important to achieve low loss rate for this class. In this context consider Figure 2 that represents a single MAC-level Queue.

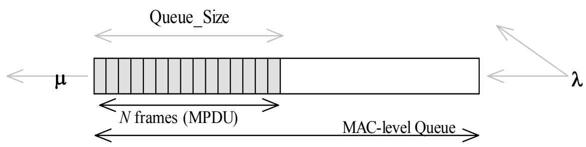

Figure 2.AC's queue instance

It is obvious that we can assimilate this queue to a Markov M/M/1/K model, with one single server and buffer size k. Further, we assume that channel service is exponential with parameter μ and inter-arrival times are exponential with parameter λ. Thereby a packet loss occurs whenever an arriving packet finds the queue full. We note p = λ / μ as the queue utilization. According to the Markov M/M/1/K queue model, the probability that a loss occurs is:

$$Loss = \frac{(1-\rho)\rho^k}{1-\rho^{k+1}} \cong \frac{\rho^k}{1+\rho+\rho^2+\ldots+\rho^k} \qquad (6)$$

Therefore this probability is around 1, if λ is much higher than μ. In the context of AC2, we propose to maintain a low packet loss rate by ensuring that $\lambda \le \mu$. Nevertheless, in order to simplify ETXOP we choose to ensure rather that $\lambda = \mu$. In other word, we will try to guarantee that the arriving packet rate is equal to the departure packet rate. This is possible by allowing WS to transmit all the arrival packets between the last successful transmission and the new transmission attempt, as soon as WS wins the contention. To do so we must find the N_i's value which satisfy that $\lambda = \mu$. Thus we note *t* as WS's waiting time before winning the contention (7).

$$t = E[B] + AIFS + \Delta t \qquad (7)$$

Here, Δt is equal to zero if the queue is not empty (always a packet to transmit). Otherwise it represents packet's inter-arrival time. Consequently, the packet arrival rate and the transmitted packet rate between the two transmissions are noted as follows:

$$A_r = \lambda \times t \qquad (8)$$

$$S_r = \mu \times t \quad (9)$$

It is worth mentioning when $S_r = N_i$, that $\lambda = \mu$ is equivalent to $N_i = A_r$. Accordingly, in case of AC2 flows, we propose to replace N_i by the number of arriving packets at the queue between the last successful transmission and the new transmission attempt.

3.3 Intra-AC QoS Differentiation

In order to assess the accuracy of our scheme in terms of achievable intra-AC QoS differentiation, consider equation (5). It is clearly seen that TXOPlimit is depending drastically on N_i's value because *(ACK + 2SIFS + M/R)* is constant. Now consider two flows *f1* and *f2* belonging to the same AC with two different data rate (λ1 and λ2 and λ1 > λ2). Under ETXOP these two flows will compute periodically the TXOPlimit's value. By considering Figure 1 that represents a burst of packet during AC's transmission attempt and assuming that no collision can occur, the station's throughput during this burst could be obtained as follows:

$$T_i = \frac{N_i \times M_i}{AIFS_i + E[B] + N_i\left(\frac{M_i}{R} + 2\times SIFS + ACK\right)} \quad (10)$$

Since the E[B] is practically constant when we consider flows belonging to the same AC, the higher the N_i's value, the higher is the perceived throughput. Because $\left((M_i / R) + 2\times SIFS + ACK)\right)$ is very negligible by report to M_i. Consequently, the *f1*'s throughput is higher than *f2*'s throughput. This is well proved for AC3 and AC2. On the one hand, in the case of A C3, as N_i represents the queue size, *f1* will filled up the queue more quickly than *f2*. So at any time, the *f1* queue's size is higher than *f2* queue's size. Hence, *f1*'s N_i is higher than *f2*'s N_i. Consequently, *f1*'s perceived throughput is higher than that obtained by *f2*.

On the other hand, when considering AC2, N_i represents the arrival packets at t intervals. By noting $N_i = \lambda * t$ ($N_i = A_r$), it is obvious that *f1*'s N_i is higher than *f2*'s N_i. Given that t is practically the same for all flows belonging to the same AC, therefore, *f1*'s throughput is higher than *f2*'s throughput.

Note that, in case of Variable Bit Rate (VBR) traffic one can say that M_i is a variable. In this context we propose to compute M_i as follows:

If ***Flow i belongs to*** *AC3 Then*

$$M_i = \frac{Queue\_size(Byte)}{Number\_packet\_queue}$$

If ***Flow i belongs to*** *AC2 Then*

$$M_i = \frac{\sum Size\_arrival\_packet}{Number\_arrival\_packet}$$

In other word, we take packets' mean size present in the queue, when the flow belongs to AC3. If the flow belongs to AC2, M_i is the mean of arrival packets' size during the period t. Here in case of Constant Bit Rate M_i is constant, given that all the packets have the same size.

4. ETXOP ADMISSION CONTROL

The main weakness of ETXOP is the possibility given to a high priority flow to send a burst which is depending on the number of packets presents in the queue. In fact, if the number of flows increases, automatically μ decreases. Thus performance degradation will result due to increasing AC2 and AC3's queue size. We argue this by the fact that packets' number N_i sent in AC2 and AC3's bursts will increase. Accordingly, each time an AC2 or AC3's flow wins the contention; it monopolizes the wireless channel for a long duration. In this context it is crucial to restrict the volume of traffic in order to maintain service quality of current serving traffic. In other word, provide ETXOP an admission control mechanism. The proposed admission control is based on both the network load and application data rate requirement. The main objective is to prevent channel overload and protect admitted flows. This is particularly important to inelastic multimedia traffics that are sensitive to bandwidth fluctuations.

Let now consider Figure 1 that represents a burst of packet during AC3 or AC2's transmission attempt. If we assume that no collision occurs, the time needed to transmit this burst could be obtained as follows:

$$T_{trans} = AIFS_i + E[B_i] + N_i\left(\frac{M_i}{R} + 2\times SIFS + ACK\right) \quad (11)$$

Indeed, each flow selects a random backoff interval (E[W]) that is more or less quickly decremented in respect to the number of observed busy time slots. Thus, the burst transmission deferring $E[B_i]$ depends on the selected backoff interval and the degree of the network load. According to[12], $E[B_i]$ can be expressed as follows:

$$E[B_i] = \left(E[W_i] + E[Fr_i]\times T_{busy}\right)\times \delta \quad (12)$$

E[Fr] is the average time where the station freezes the backoff before its counter reaches 0, T_{busy} is the observed busy slots during the T_{slot} period, E[W] is the mean contention window and δ is the slot duration.

Actually, the deferring time is proportional to the Busy Slot and the mean Contention window size. Further, the $E[W_i]$ is approximately equals to (CW_{min} [i]+ CW_{max} [i])/2. Therefore, in order to satisfy a flow requirement on data rate we must maintain $\sum \left(TXOP_{limit} + E[B]\right) \le T$, where T is the control period expressed on seconds. Nonetheless we can approximate this formula if we consider that the flow can send only one burst.

$$N_i\left(\frac{M_i}{R} + 2\times SIFS + ACK\right) + AIFS_i + E[B_i] \le T \quad (13)$$

Accordingly, N_i is obtained as follows:

$$N_i = \frac{T - \left[\left(E[W_i] + E[Fr_i]\times T_{busy}\right)\times \delta + AIFS_i\right]}{\left(\frac{M_i}{R} + 2SIFS + ACK\right)} \quad (14)$$

Clearly, the above formula may be used to accept new AC3 or AC2 flows at each WS. Indeed, formula (14) gives approximately how many packets a station can send based on the actual network state and the flow's AC. Therefore, as in ETXOP $N_i = \lambda$, the admission is achieved by computing N_i and comparing this value with the flow data rate. On one hand, if ($N_i \le \lambda$) the new flow is automatically rejected. In other words, the requested bandwidth cannot be fulfilled due the current network state. On the other hand, if ($N_i > \lambda$) the new flow is accepted.

For AC1 and AC0, we adopt the same procedure i.e compare the N_i with the bandwidth requested by the flow. However, the difference is in the computation of N_i value. In fact for AC1 and AC0 flows we can consider that instead of sending a burst these ACs send only one packet. Thus the formula (11) is rearranged as:

$$T_{trans} = N_i \times \left[AIFS_i + E[B_i] + \left(\frac{M_i}{R} + 2 \times SIFS + ACK \right) \right] \qquad (15)$$

Therefore, N_i is expressed as:

$$N_i = \frac{T}{\left(\frac{M_i}{R} + 2SIFS + ACK \right) + E[B_i] + AIFS_i} \qquad (16)$$

In other words, each WS is responsible of network monitoring through carrier sense and making admission decisions. Thus periodically, each active station keeps track of the busy and the average freezing time. Further, in order to remove short term fluctuations due to the wireless channel's characteristic, the network measured values (Busy slots and the average freezing time) are weighted in respect to past measures using EWMA (Exponential Weighted Mean Average).

$$T_{Busy} = \alpha \times T_{Busy\_t} + (1-\alpha) \times T_{Busy\_t-1} \qquad (17)$$

$$E[Fr] = \alpha \times E[Fr]_t + (1-\alpha) \times E[Fr]_{t-1} \qquad (18)$$

From these information, the admission controller at each station is able to predict the network state. Thus, when a new flow arrives, the station compares the requested bandwidth with N_i's value computed according to flow's AC. If the control algorithm determines that there is insufficient bandwidth to service flow (i.e $N_i \leq \lambda_i$), the flow is rejected, otherwise the flow is accepted. Further, it is commonly mentioned that in WLAN networks, it is difficult or practically impossible to use all the slot time. As shown in [14], the network utilization is not depending on the active station number, and it does not exceed the 85%. Thereby, we rearrange the admission control algorithm as follows:

For *Each Control Period(T)* **{**

If *Flow i* $\in$ *AC3 or AC2* **{**

$$N_i = \frac{(T \times 0.85) - \left[(E[W_i] + E[Fr_i] \times T_{busy}) \times \delta + AIFS_i \right]}{\left(\frac{Mi}{R} + 2SIFS + ACK \right)}$$

If *($N_i \leq \lambda_i$) or ($N_i < 0$)* ***{****Reject the new flow****}***

If *($N_i > \lambda_i$)* ***{****Accept the new flow****}***

} ***If*** *Flow i* $\in$ *AC1 or AC0* **{**

$$N_i = \frac{T \times 0.85}{\left(\frac{M_i}{R} + 2SIFS + ACK \right) + (E[W_i] + E[Fr_i] \times T_{busy}) \times \delta + AIFS_i}$$

If *($N_i \leq \lambda_i$) or (Ni < 0)* ***{****Reject the new flow****}***

If *($N_i > \lambda_i$)* ***{****Accept the new flow****}***

}}

5. SIMULATION AND RESULTS

In order to evaluate the advantages of the proposed scheme, we have constructed a simulation of the Enhanced Transmission Opportunity using ns-2 (Network Simulator)[13]. At first, ETXOP's performances are compared to EDCA (IEEE 802.11e - Draft 8.0) when TXOPlimit is disabled and enabled. Here, we note EDCA_CFB as EDCA when TXOP is enabled. Afterwards, we compare ETXOP with and without admission control. In our simulations we assume that stations are within the transmission range.

5.1 ETXOP Versus EDCA

The first series of simulations focus on the protocols' abilities to maintain the quality of service levels when the network's load is varying (see Table 1) and to differentiate between access class's flows.

Table 1. Network load

Station number	2	4	6	8	10
Load (%)	22	44	66	88	110

Table 2. MAC parameters

	EDCA				ETXOP			
	AIFS	CWmin	CWmax	TXOPlimit		AIFS	CWmin	CWmax
AC3	2	7	15	0.003	-	2	7	15
AC2	2	15	31	0.006	-	2	15	31
AC1	3	31	1023	0.003	0.003	3	31	1023

Table 3. Flow's characteristics

Traffic features	Packet size (Bytes)	Interval (sec)	Bit rate (Kbps)	Queue length
Background (AC1)	800	0.02	320	50
Video1 (AC2)	1300	0.02	520	50
Video2 (AC2)	1300	0.01	1040	50
Audio1 (AC3)	180	0.02	72	50
Audio2 (AC3)	180	0.01	144	50

In all cases, each station sends three flows belonging to AC3, AC2 and AC1 to a common receiver. Further, to evaluate the intra-QoS differentiation, we use two traffics with different data rate belonging to the same AC (see Table 3). The reasons CBR traffic is chosen in these simulations is because we can accurately evaluate the achievable throughput limit, and evaluate ETXOP's abilities to maintain fairness between the flows belonging to the same AC.

For instance, when the network load is 22%, the first WS sends an AC3's traffic with 144 Kbps, AC2's traffic with 520 Kbps and an AC1's traffic with 320 Kbps. On the other side, the second WS sends an AC3's traffic with 72Kbps, AC2's traffic with 1040Kbps and an AC1's traffic with 320 Kbps.

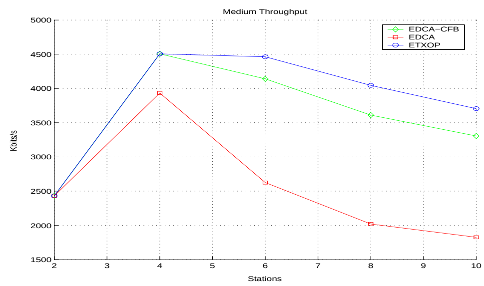

Figure 3. Overall network throughput

The overall network throughput is shown in Figure 3, in terms of the total achieved throughput during the simulation. Clearly, when the network is sufficiently relaxed (when the network load is low), there is a sufficient bandwidth available and both EDCA and ETXOP achieve similar throughputs, carrying the load as it is offered. However, when the number of station increases, the use of

TXOPlimit parameter in EDCA and ETXOP permits a significant advantage. This is due to the fact that the use of TXOPlimit allows the WS to send a burst of packets, while the other stations wait until the end of this burst. In fact the other stations freeze the Backoff timer until the end of this burst, which minimizes the collision probability. Consequently, this increases the overall network throughput naturally. Furthermore, when the network becomes heavy (from 66%), it is clearly seen that ETXOP outperforms EDCA with and without the use of TXOPlimit. This represents roughly 250 Kbps and 1.2 Mbps of the realized data rate gain compared to EDCA_CFB and EDCA, respectively. This gain by report to EDCA_CFB is principally due to the dynamic TXOPlimit's value used in ETXOP.

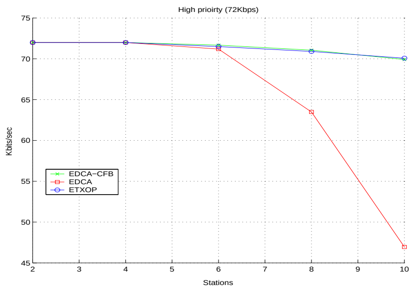

Figure 4. AC3's flow (72kbps) data rate

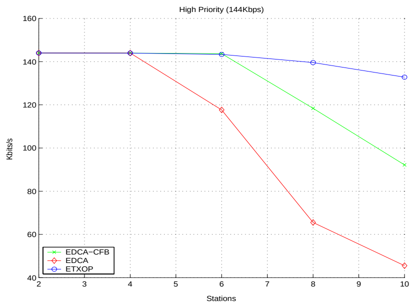

Figure 5. AC3's flow (144kbps) data rate

Figure 4 and Figure 5 illustrate the mean data rate achieved by AC3's flows (72kbps and 144kbps respectively) when using ETXOP, EDCA and EDCA_CFB. The ETXOP maintains consistent delivery bit rate throughout the simulation, regardless of the presence of both high network load, and application data rate. Furthermore, in case of flow1 (72kbps), both EDCA_CFB and ETXOP achieve the demanding data rate. However, as the network becomes heavy the data rate is severally dropped in EDCA. On the other hand, for flow2 (144kbps), only ETXOP satisfy the requested data rate. In contrast, EDCA and EDCA_CFB drop severally the data rate (45.5 kbps, 98.2 kbps). This gain is due to intra-AC differentiation achieved by ETXOP. Indeed, when using ETXOP, each AC3's flows send a burst of packets corresponding to its queue size. Thus the queue is emptied periodically, which leads to practically sending all the packets.

Figure 6 and Figure 7 show the mean data rate obtained by AC2's flows (520kbps and 1040kbps, respectively). It is clearly seen that using *TXOPlimit* enhances considerably the performances. Further, ETXOP outperforms the others schemes only for flow2 (520kbps). In contrast, for flow1 EDCA_CFB exceeds ETXOP scheme. However if we consider a fairness point of view of the two schemes, we found that under ETXOP the mean data rate for flow1 and flow2 is 381.285 kbps and 754.342 kbps respectively, which represents a ratio of 73% and 72% between the mean data rate and the requested data rate, respectively. On the other hand, under EDCA_CFB the ratio is 83% and 63% for flow1 and flow2, respectively. This shows that our scheme provides an intra-AC QoS differentiation, while maintaining a high fairness between flows of the same AC. Indeed this fairness is maintained by providing a constant ratio of throughput between the flows.

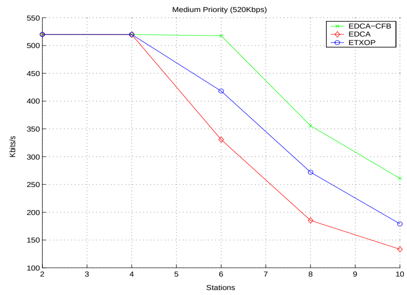

Figure 6. AC2's flow (520kbps) data rate

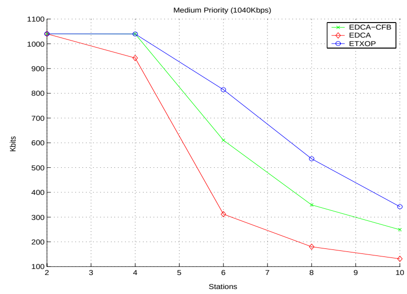

Figure 7. AC2's flow (1040kbps) data rate

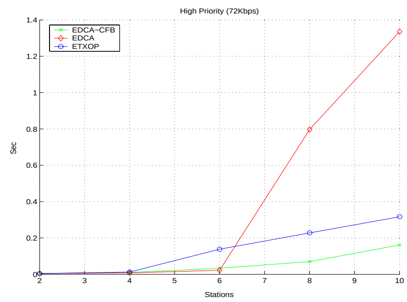

Figure 8. AC3's flow (72kbps) packet delays

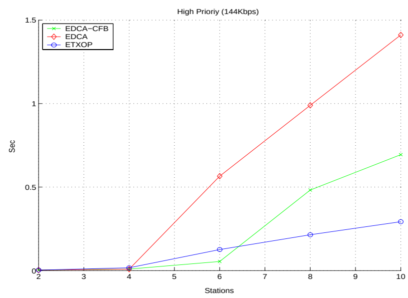

Figure 9. AC3's flow (144kbps) packet delays

Figure 8 and Figure 9 depict the delays experienced by AC3's flows. Unlike data rate, ETXOP outperforms the other scheme only for flow 2. For flow1, EDCA_CFB outperforms the other scheme. Nevertheless, ETXOP maintains practically the same mean delays for the two flows, 0.1398s and 0.1306s, respectively. In contrast, in EDCA_CFB the delays are different for the two flows, i.e 0.055s and 0.248s. This is mainly due to the fact that no intra-QoS differentiation is assured by EDCA_CFB.

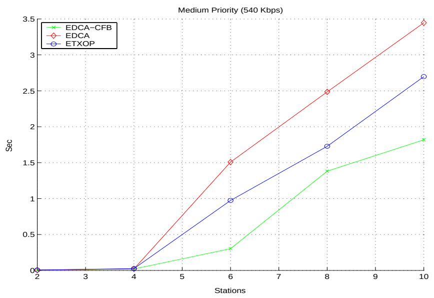

Figure 10. AC2's flow (520kbps) packet delays

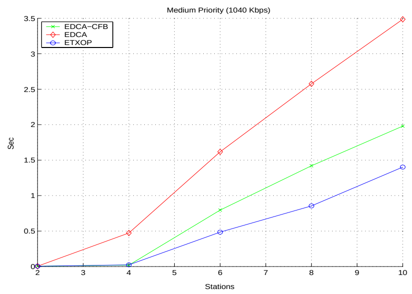

Figure 11. AC2's flow (1040kbps) packet delays

From Figure 10 and Figure 11 we plot the packet's delays of AC2's flows. Like for the throughput, ETXOP improves only flow2's performances, while EDCA_CFB gives the best performance for flow1. This is to be expected, as ETXOP gives the same ratio of throughput to the two flows, the delays are practically the same.

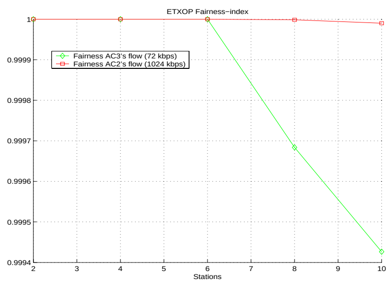

Figure 12. ETXOP fairness index

In order to evaluate ETXOP fairness between flows of the same priority with the same data rate, we use the fairness index formula (see 20) presented in [5]

$$FI = \frac{\left(\sum_{i=1}^{n} T_i\right)^2}{n \sum_{i=1}^{n} (T_i)^2} \qquad (19)$$

where n is the number of the same priority flows, and T_i is the throughput of flow i.

Thus, FI is equal to 1 if all T_i are equal, which corresponds to the highest degree of fairness between the different flows. Here $FI \leq 1$. As shown in Figure 12, the ETXOP measurements of flow's data rate, show the same fluctuation for each AC's flow. This means that traffic flows belonging to the same AC with the same data rate are affected equally.

5.2 ETXOP with Admission Control

We evaluate admission control in context of dedicated multimedia network. In other words, we only use audio and video flows. Each video and audio stream is 1.024Mbps and 64 Kbps, respectively. The MAC parameters are the same as used in Table 2. We adopt a value 0.8 for α and 0.5 second for the control period in our simulation. These two parameters control the variability of the estimated network state. We believe the value chosen provide a good balance between removing short term fluctuations and reflecting long term trend. The simulation time is 120 s. Every 2 second a new flow is added until 38 s. The arriving flows are alternatively audio and video.

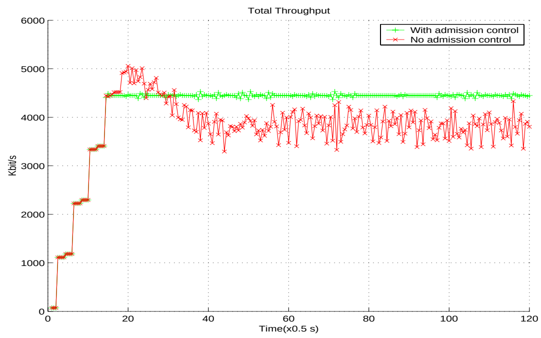

Figure 13. Overall Throughput

Figure 13 illustrates the overall throughput with and without admission control. From t= 16 s when using admission control all the arriving flows are rejected. This permits to maintain a constant throughput during the rest of the simulation. On the other hand, when no admission control is used, we notice that the saturation throughput is obtained at t= 20s. Nevertheless, as the number of flows increases the throughput decreases. This is due to the fact that arriving flows increases the collisions' number in the network. From t= 38s where the load is very heavy, we notice that the admission control improves considerably the throughput performance.

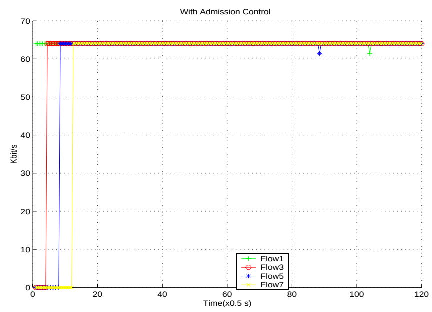

Figure. 14. Audio's data rate (with admission control)

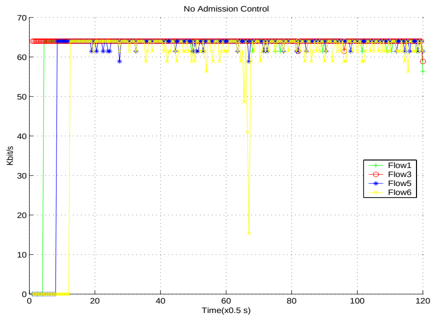

Figure. 15. Audio's data rate (no admission control)

Figure 15 and Figure 16 show the data rate of audio flows with and without admission control. We observe that without admission control, the data rate oscillate around 64 Kbps when the network is in relax state. However, after t= 38 s the data rate drops frequently under the 64 Kbps. Further, with admission control, we see that the data rate is protected and is constant (i.e 64 Kbps).

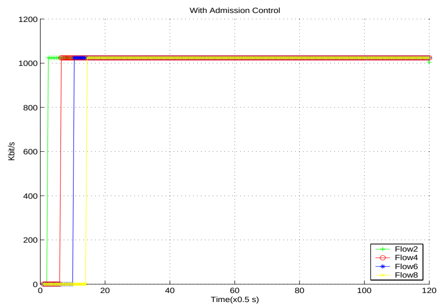

Figure. 16. Video's data rate (with admission control)

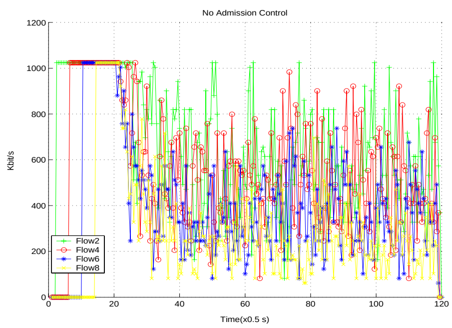

Figure. 17. Video's data rate (no admission control)

In Figure 17 and Figure 18, we show the video's data rate with and without using admission control. It is clearly seen that using admission control permits to protect considerably the video's data rate, which is constant and around 1 Mbps. On the other hand, without admission control, the video's data rate messed up and oscillates to as low as zero when traffic load is very heavy, and therefore video flows cannot be protected.

6. CONCLUSION

In this paper we presented a novel scheme for QoS enhancement for IEEE 802.11 wireless networks. The ETXOP scheme is based on the concept of Contention Free Burst. In fact, each time a wireless station wins the contention; it is allowed to send a burst of packets. The number of packets presents in this burst is computed dynamically and according to the flow's data rate and flow's priority. We control the access to the network through a distributed admission control mechanism, which is executed at each station. Simulations have shown that ETXOP scheme achieves numerous performance gains over EDCA. In addition to stronger inter-AC QoS differentiation, ETXOP improves throughput and reduces delay. It also achieves high intra-AC QoS differentiation based on flow's data rate. Furthermore, we have shown that admission mechanism can improve considerably the performances and that it is necessary to guarantee QoS to multimedia applications.

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