Adaptive Transmission Opportunity for QoS Enhancement in (EDCA) IEEE 802.11e WLANs

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Abstract

This paper focuses on performance enhancement of the contention based access mechanism called Enhanced Distributed Channel Access (EDCA) introduced in the upcoming IEEE 802.11e standard. The use of transmission opportunity received little attention in previous QoS enhancement studies and contention window size was used as the main differentiation mechanism. Our approach, called Adaptive Transmission Opportunity (ATXOP), is derived from the EDCA. It aims to share the transmission channel efficiently and reduce the overhead cost. Relative priorities are provisioned by adjusting the transmission opportunity duration of each traffic class taking into account both applications requirements and medium utilization. We evaluate through simulations the performance of ATXOP scheme and compare it with the basic EDCA. The results show that our new approach outperforms the basic EDCA, especially at high traffic load conditions. Indeed, ATXOP increases efficiently the medium utilization ratio and so, it can provide an overall goodput up to 25% higher than EDCA while achieving delay differentiation.

1 Introduction

IEEE 802.11 wireless LAN specification defines two different ways to configure a wireless network: ad-hoc and infrastructure mode. In infrastructure mode an Access Point (AP) is needed to connect wireless stations to a Distribution System (DS), whereas in ad-hoc mode all wireless stations are distributed without access coordinator. In this paper, we focus on ad-hoc networks since distributed random access control are often preferred to centrally coordinated access control. Distributed Coordination Function (DCF) is the basic medium access mechanism of 802.11 for both ad-hoc and infrastructure modes [2]. It uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol. In this mode, if the medium is found idle for longer than a DIFS (Distributed InterFrame Space) then the station can transmit a packet. Otherwise, a backoff process is started. More specifically, the station computes a random value called backoff time, in the range of 0 and CW (Contention Window) size. The backoff timer is periodically decremented by one for every time slot the medium remains idle after the channel has been detected idle for a period greater than DIFS. As soon as the backoff timer expires, the station can access the medium. If no acknowledgment is received, the station assumes that collision has occurred, and schedules a retransmission by reentering the backoff process [2].

Quality of Service (QoS) support is critical to wireless home networking, video on demand, audio on demand and real-time voice IP applications. Time-bounded services such as audio and video conference typically require some specified bandwidth, delay and jitter guarantee, but can tolerate some losses. However, in DCF all the stations in a Basic Service Set or all the flows from the same station compete the resources and channel with the same priority. There is not any differentiation mechanism to guarantee packet delay and jitter to stations or flows supporting time-bounded multimedia services. The performance evaluation results in [11] show that DCF suffers from significant throughput degradation and high delay at high load conditions, which are caused by the increasing time used for channel access negotiation. Many medium access schemes have been proposed for IEEE 802.11 WLAN to provide some QoS enhancements for real-time audio and video traffics. Previous research works mainly focus on the station-based DCF enhancement scheme [12, 13, 14, 15]. When two or more TCP senders share the same receiver, they all receive TCP-ACKs with the same priority (limited to the same receiver priority). This tends to reduce the service differentiation. Furthermore, if the shared receiver is slow, the observed relative priority will also be reduced [17, 16]. This motivates the use of queue-based differentiation where a shared node handles simultaneously several flows with different priorities. There are many recent works that focus on the queue-based enhancement schemes [5, 7, 9, 4, 1] since they perform more efficiently.

The IEEE working group is currently working on the support of QoS in a new standard, called IEEE 802.11e [1]. A new access method called Hybrid Coordination Function (HCF) is introduced, which combines functions from the Distributed Coordination Function (DCF) and Point Coordination Function (PCF) mechanisms. Enhanced Distributed Contention Access (EDCA) is a contention-based HCF channel access specified in IEEE 802.11e [1]. The goal of this scheme is to enhance the DCF access mechanism of IEEE 802.11 and to provide a distributed access approach that can support service differentiation. The proposed scheme provides capability for up to four types of traffic classes. It assigns a short $CWmin$, $CWmax$, and $AIFS$ to classes that should have higher priority in order to ensure that in most cases, higher-priority classes will be able to transmit before the lower-priority ones. To decrease delay, jitter, and achieve higher medium utilization, packet bursting is proposed in IEEE 802.11e standard. So, once a station has gained access to the medium, it can be allowed to send more than one frame without contending for the medium again. After getting access to the channel, the station is allowed to send as many frames it wishes as long as the total access time does not exceed a certain limit ($TXOPLimit$) and no collision occurs. Moreover, there is no need to use RTS/CTS frames for the transmitted packets. The benefits of the using transmission opportunity is to decrease the overhead cost for each packet transmission. The $TXOPLimit$ parameter is fixed and could not react on medium utilization and contention level. As we have observed in a previous simulation results, EDCA performs poorly when the medium is highly loaded [4, 3]. This is due to the high collision rate and wasted idle slots caused by backoffs in each contention cycle. Moreover, the EDCA adopts fixed$TXOP$ length for each access class which could not response to the application requirements. In the previous QoS enhancement studies, contention window size was used as the main differentiation mechanism. We believe that differentiation based on adaptive packet bursting can provide a good performance in a distributed network. To get benefits from the $TXOP$ duration efficiently, we propose adaptive transmission opportunity duration based on medium utilization fraction and the average packet size in the queue while providing service differentiation. The simulation results of our scheme show a good enhancement comparing to the basic access.

The remainder of this paper is organized as follows. In Section 2, we give the most important works that have been described to address cross layer architecture for MANET. The description of the proposed ATXOP scheme is given in Section 3. Simulation methodology and performance evaluation of our proposal are detailed in Section 4. Section 5 concludes the paper by summarizing results and outlining future works.

2 Related Works

Many works have been addressed to enhance EDCA scheme specially in high network load. 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 polling based channel access. EDCA mode can be regarded as a soft QoS assurance mechanism in the sense that a traffic class can statistically reduce its transmission delay by categorizing itself into a higher priority traffic class. In [5] Both the enhanced distributed channel access (EDCA) and the polling based channel access modes are evaluated for QoS in IEEE 802.11 WLAN in carrying QoS applications. Through our simulations, the authors show the performance under real time audio and video traffic. They find that EDCA provides satisfactory service differentiation among its four access categories. However, in the presence of heavy load traffic such as a high definition television (HDTV) signal transmission, it is more desirable to place such load under HCF polling mode to avoid the adverse impact of other traffic on this class of traffic. With a hybrid polling and EDCA protocol, network capacity is effectively increased to better support real-time audio and video transmissions in future home networks. Therefore, more centralized control at the AP is desired when heavy traffic load is expected in the network. However, if we consider a fully distributed network, at high load, EDCA cannot provide the minimum service guarantee for each class traffic.

In [6], the authors compare two approaches for Quality of Service support in WLAN-based ad hoc networks. The first approach is to use per-packet priorities, according to the IEEE 802.11e standard. The second approach is to allocate radio resources on the path between source and destination, according to the introduced protocol 'Distributed end-to-end Allocation of time slots for REal-time traffic' (DARE). For example, each node between source and destination allocates some dedicated time slots for this ow before the actual transmission starts. On the one hand, this removes uncertainties that come with a distributed random medium access. It thus has the potential to support applications demanding a non-varying end-to-end delay. On the other hand, such a reservation mechanism is typically much more complex than a priority mechanism. In particular, it adds signaling overhead to coordinate the nodes. All nodes between source and destination must agree in distributed manner on the reserved resources, the nonparticipating nodes must be informed so they abstain from transmission, and the reservation must be maintained and re-established when broken. Performance simulations show the following results: In case of low load, IEEE 802.11e has slightly lower end-to-end delay and higher packet loss rate, since it does not use any coordination among nodes for real-time packets. In case of medium load, DARE is superior in terms of jitter, delay, and packet loss. In case of high load, DARE clearly outperforms 802.11e. The results still hold if DARE has to repair the resource reservation path due to node failures.

In [8], the authors have presented an analytical model to analyze the performance of EDCA, the contention-based channel access mechanism in the forthcoming IEEE 802.11e protocol. All the important new features of the EDCA, viz., virtual collision, different AIFS, and CW have been taken into account. they also considered the difference of the count down procedure between the EDCA and the legacy DCF, as well as the retransmission limit. Based on the proposed model, the authors have studied the throughput performance for multi-class priority traffic and have proposed a recursive method to calculate the mean access delay. The model and results are validated via simulations. The effects of the CW and AIFS on the service differentiation ability of the protocol have been investigated. The results show that the number of ACs, or in other words, the traffic load, should be limited in order to provide a relatively satisfactory service level for both high priority and low-priority ACs. The model and analysis provide an in-depth understanding and insights into the EDCA mechanism. They also provide helpful and powerful tools for further study, such as parameterization for some types of traffic and development of call admission control schemes for further QoS improvement for WLANs. Any solution have been introduced to solve problem when the traffic load increases.

In [9], the authors expose results relative to the interaction of reactive routing protocols for MANETs and the IEEE 802.11e MAC layer technology. This work shows the importance of using EDCA to achieve service differentiation comparing to the basic access (DCF). The study focused on the performance improvements in terms of TCP and UDP traffic in a typical MANET environment when uniquely routing packets are assigned to the highest priority access category under IEEE 802.11e. The difference in behavior of two reactive routing protocols - AODV and DSR - relating the traffic throughput and routing overhead results to their internal mechanisms, are detailed. Results show that when routing packets benefit from the prioritizing mechanism of IEEE 802.11e the performance is improved drastically. We find that this improvement is due to an increase in the responsiveness of the different routing protocols. In terms of TCP throughput gain achieves an increase of up to 150% with DSR and up to 300% with AODV. Maximum UDP throughput is also increased substantially, up to 200% for both routing protocols. Relatively to normalized routing overhead, which is the reference metric used in simulations to measure the performance of the routing protocols, the IEEE 802.11e allows achieving better results. The difference becomes more noticeable as the level of saturation in the network is increased, since saturation causes the malfunction of routing protocol mechanisms. Overall, the authors consider that upgrading the MAC layer of MANET stations to IEEE 802.11e is very important not also for multimedia traffic support, but also to improve the efficiency of the routing mechanism used, especially if it is a reactive one.

To improve the performance under different load rates and to increase the service differentiation in EDCA-based networks, a new scheme called Adaptive EDCF (AEDCF) has been proposed in [4]. This scheme extends the basic EDCF by making it more adaptive taking into account network conditions. Indeed, AEDCF uses a dynamic procedure to change the contention window value of each priority class differently. In fact, each class updates its contention window based on the estimated collision rate computed during a constant period. For further differentiation, each traffic category multiplies this collision rate by a priority factor [4].This mechanism offers to high priority traffic a higher probability to generate smaller CW value than low priority traffic and so they can access the medium first. Moreover, this scheme achieves a high medium utilization and it is much more efficient at high load. Furthermore, it improves total goodput, delay and delay-jitter. The TXOP option is not consider in this proposal.

In [7], a detailed evaluation of the EDCA protocol with the Contention Free Burst (CFB) option to quantify its performance gain is performed. The impact of the MAC transmit buffer size is also incorporated. Accordingly, the authors propose a suitable approach to guide the configuration of the burst limit (TXOPLimit). They have shown that the bursting option can be used to improve performance. However, it is shown that for an optimized operation, the proper configuration of the TXOPLimit variable is crucial and could be associated with the MAC buffer size. The simulation results introduced in [7] show that, a limit proportional to at least 50% of buffer occupancy and not larger than 100% should be utilized. Moreover, the results prove that the bursting option can be used to improve performance. Indeed, it is shown that for an optimized operation, the proper configuration of the TXOPLimit variable is crucial and be closely associated with the MAC buffer size. However, this consideration couldn't be efficient if the packet loss is not considered. Indeed, the paper does not give any results about throughput performance and so the minimum service guarantees specially for low priority traffic that suffer from starvation at high load.

It is clearly demonstrated, in all related works, that the basic EDCA operation fails to scale well. The tuning of the $TXOP$ duration can provide a big benefits to enhance application performance. Hereafter, we adapt this parameter to network conditions and average packet size in each priority queue in order to achieve a good QoS support while providing some minimum service levels for each traffic category.

3 Adaptive Mac Layer transmission opportunity scheme

In order to efficiently support time-bounded multimedia applications, we use a dynamic procedure to change the $TXOP$ duration. We believe that this adaptation will enhance medium utilization and so increase the total goodput of the traffic which becomes limited when using the basic EDCA, mainly for high traffic load.

During the TXOP, the station can send a burst of DATA frames separated by SIFS. The TXOP ends when there are no more frames to be transmitted or when the TXOP maximum duration expires. In a fully distributed network, and where there is no QoS Access Point (QAP) that adapts the $TXOPLimit$ according to the traffic characteristics and the network conditions, the default TXOP maximum duration values could not be efficient when we have an heterogeneity of application characteristics. Indeed, we believe that the $TXOPLimit$ value for each priority queue depends mainly on the average packet size to be transmitted in that duration and so on the medium utilization fraction during a controlled period T while maintaining service differentiation. Indeed, different packet size yielding different transmission time duration. Moreover, in a high traffic load it is more better to avoid as possible as overhead costs as RTS/CTS packets, to efficiently use the medium for data transmission. To this end we propose to adapt the $TXOPLimit$ value as follow:

- ***$TXOPLimit$ calculation based on the average packet size in each queue:***

At the beginning of each control period T, we set each $TXOP$ duration according to the average packet size in each queue i and its priority level. We compute the average packet size in each queue i that we note ($avgpkt[i]$). Our target is to ensure that the number of packets of each class served in every period is proportionally of its priority. In other words, let's N be the total number of packets sent successfuly by a given station during the period T, our objective is then to get the number of packets of class i is $N_i = \left(\frac{n_i}{\Sigma n_j}\right) N$, where $n_i$is a differentiation factor that gives a weight to the total transmitted packets for each class comparing to the total transmitted packets at each node. We can also write $N_i = TXOPduration[i]\frac{rate}{avgpkt[i]}$. From the previous two equations we can write $TXOPduration[i] = \left(\frac{n_i}{\Sigma n_j}\right) N\frac{avgpkt[i]}{rate}$. Then, we can write $TXOPduration[i+1] = \frac{(n_{i+1})}{(n_i)}\frac{avgpkt[i+1]}{avgpkt[i]}TXOPduration[i]$. This relationship between each two successive priority classes ensure a tightly differentiation between them. Therefore, if we set the value of TXOP for the class number 0, we are able to compute those of other classes. We explain hereafter how TXOP of class 0 is adapted dynamically according to the medium utilization.

- ***Adaptive Transmission opportunity based on medium utilization:***

Assuming all ACs adopt different fixed TXOP durations according to their priority as described in the draft[1], they will have the same relative probability of obtaining a successful contention and so the same relative amount of throughput. However, this amount will decrease rapidly since the overhead cost will affect the effective throughput. Moreover, in saturation conditions, the success transmission probability is very low. So, it will be better to maximize the transmission opportunity duration of each AC while maintaining service differentiation.

At the end of each control period T, the station number s computes the TXOP of the highest queue as follows:

$$TXOP_{highest} = max(TXOP_{min}, f_s * TXOP_{max}) \qquad (1)$$

where $f_s = \frac{TotalBusTime}{T}$,is the medium utilization parameter,$TotalBusTime$ is the total busy time around the node during the control period $T, TXOP_{min}$is a minimum value that allows to avoid medium starvation, and $TXOP_{max}$is a parameter used to prevent the medium being monopolized by a given class. The medium utilization parameter is computed dynamically in each period T expressed in time-slots. This period called update period should not be too long in order to get good estimation and should not be too short in order to limit the complexity.

4 Performance evaluation

We have implemented ATXOP in the ns-2 simulator [?]. We have extended the EDCA scheme [1] to support our algorithm. We report in this section part of simulations we have done with different traffic load and source characteristics. We also provide a performance analysis of our proposal based on the obtained simulation results and we compare it with the original scheme.

4.1 Scenario description

Our simulations use different types of traffics to evaluate service differentiation. Three queues are used in each station. The highest priority queue in each station generates packets with packet size equal to 160 bytes and inter-packet interval of 20 ms, which corresponds to 8 Kbit/s audio flow. The medium traffic queue generates packets of size equal to 1280 bytes each 10 ms which corresponds to an overall sending rate of 128 Kbit/s (video flow). The low priority queue in each station generates packets with sending rate equal to 120 Kbit/s, using a 1500 bytes packet size. The physical data rate is set to 36 Mb/s. The nominal bit rate is 2 Mbps. For all the scenarios considered, we set the EDCA queue parameters based on the draft[1]. To increase the load of the system, we gradually increase the number of stations. We start simulations with two wireless stations, then we increase the load rate by increasing the number of stations by one every eight seconds. We increase the number of stations from 2 to 16 which corresponds to load rates from 9.5% to 100%.

For this purpose, we use the topology shown in Figure 1, which consists of n stations indexed from 1 to n . Each station generates the same traffic of three data streams, labeled with high, medium and low, according to their priorities. Station n sends packets to station number 1 . Station i sends to station $i + 1$ three flows belonging to the three classes of service: Audio (high priority), Video (medium priority), and Background Traffic (denoted by BT for low priority). We use CBR sources to simulate BT, video, and audio traffics.

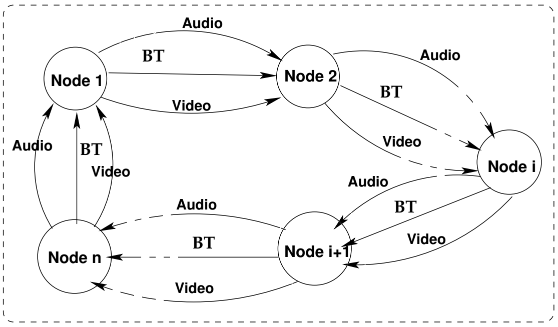

Figure 1: Simulation topology

In the following simulations, we assume that each wireless station operates at IEEE 802.11a PHY mode-6, see network parameters shown in Table 1.

Table 1: IEEE 802.11a PHY/MAC parameters used in simulation

SIFS	$16\mu s$
DIFS	$34\mu s$
ACK size	14 bytes
Data rate	36 Mbits/s
Slot_time	9 μs
CCA Time	$3\mu s$
MAC Header	28 bytes
Modulation	16-QAM
Preamble Length	$20\mu s$
RxTxTurnaround Time	$1\mu s$
PLCP header Length	$4\mu s$

Table 2 shows the network parameters selected for the three TCs.

4.2 Simulation metrics

We analyze several QoS metrics to evaluate the performance of our approach and we compare results with the basic EDCA mechanism protocol. The following metrics are defined:

- **Total goodput**: This metric computes the total amount of goodput delivered successfully by the MAC layer.

- **Mean delay**: It is the average delay of all the flows that have the same priority in the different stations. The average delay is used to evaluate how well the schemes can accommodate real-time flows. However, real-time flows require both low average delay and bounded delay jitter. So we will also use the following metrics of latency distribution and delay variation.

- **Latency distribution**: Latency distribution allows to trace the percentage of packets that have latency less than the maximum delay required by the applications.

4.3 Results Analysis

To evaluate the performance of ATXOP, we investigate in this section the effect of the traffic load and compare it with the basic EDCA scheme.

We analyze throughput, delay, and delay distribution metrics to evaluate the performance of our approach and we compare results with the basic EDCA scheme. Figures 2, 3, and 4 show the significant improvement obtained by ATXOP scheme comparing to the basic EDCA.

Figures 2 shows that ATXOP provides significantly more total throughput compared to the basic EDCA, mainly in high load situations (about 30% total goodput gain when the channel is fully loaded).

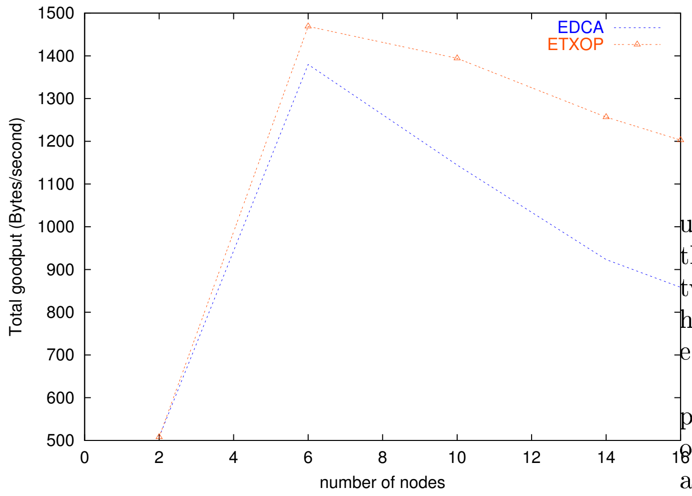

Figure 2: Mean goodput

Table 2: MAC parameters for the three TCs.

Parameters	**High**	**Medium**	**Low**
CW_{min}	7	31	31
CW_{max}	15	31	1023
AIFS(μs)	34	43	52
Packet Size($bytes$)	160	1280	200
Packet Interval(ms)	20	10	12.5
Sending rate($Kbit/s$)	64	1024	128
slot-time(us)	16	16	16
$TXOP_{max}(ms)$	0.003	0.006	0.003

Figure 3 shows the mean delay of all traffics. The ATXOP scheme is able to keep the delay lower than the basic EDCA even when the traffic load is very high. We can see that the mean delay for ATXOP is 41% smaller than that for the basic EDCA when the load rate is up to 100% (16 stations). Moreover, the mean delay our approach is still similar or smaller than that of the basic access scheme when the load rate is low.

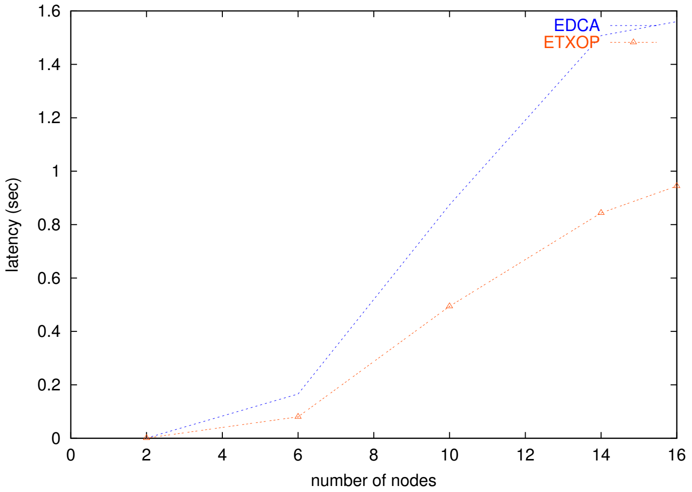

Figure 3: Mean delay

We show the latency distribution for video traffic in Figures 4, in which a fixed number of 16 stations is used to show the delay performance. There are considerable differences between them, i.e. more than 75% of video packets for ATXOP have delay less than 400ms, whereas only 17% of video packets for EDCA have delay less than 400ms.

All the obtained results show that ATXOP always outperforms EDCA. We believe that the adaptive transmission opportunity is very efficient to estimate the network status and reduce collisions while providing service differentiation support. Indeed, it enhances the medium utilization and so increase the total goodput of the traffic which becomes limited when using the basic EDCA, mainly for high traffic load. Indeed, in such conditions it is more better to avoid as possible as overhead costs as RTS/CTS packets, and backoff procedure for each transmission packet to efficiently use the medium for data transmission.

5 Conclusion and Future Works

This paper presented a new adaptive transmission opportunity scheme for Quality of Service enhancement for IEEE 802.11 WLANs. To this end, we propose to adapt the TXOPLimit value as follow: at the beginning of each control period T, the TXOP duration is set according to the average packet size in each queue i and its priority level. Then, we establish an analytic relationship between these values according to the medium utilization level while maintaining service

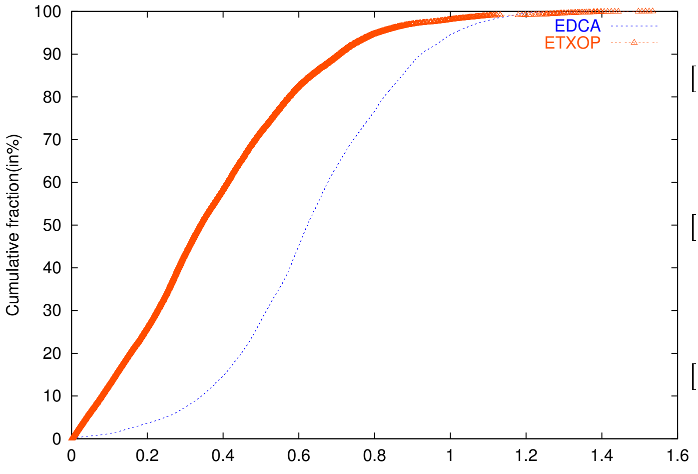

Figure 4: Latency distributions of video

differentiation. The goal is to enhance real-time applications and avoid starvation of low priority traffics.

We evaluate through simulations the performance of ATXOP scheme and compare it with the basic EDCA. The results show that our new approach outperforms the basic EDCA, especially at high traffic load conditions. Indeed, ATXOP increases efficiently the medium utilization ratio and it provides an overall goodput up to 25% higher than EDCA while achieving delay differentiation.

One of the important future work is to evaluate the performance of this proposal in multihop networks and provide interaction between MAC and routing protocols in order to tune the TXOP duration according to the network conditions that could be included in the routing packets. Doing real experimentations at least for static ad hoc networks is also will be considered.

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