

# A new MAC protocol with pseudo-TDMA behaviour for supporting Quality of Service in 802.11 Wireless LANs

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## Abstract

In this paper, a new Medium Access Control (MAC) protocol is proposed for Quality of Service (QoS) support in Wireless Local Area Networks (WLAN). The protocol is an alternative to the recent enhancement 802.11e. A new priority policy provides the system with better performance by simulating TDMA (Time Division Multiple Access) functionality. Collisions are reduced and starvation of low priority classes is prevented by a distributed admission control algorithm. The model performance is found analytically extending previous work on this matter. The results show that a better organization of resources is achieved through this scheme. Throughput analysis is verified with OPNET simulations.

Keywords: Wireless LAN, 802.11, EDCA, Saturation Throughput

## 1 Introduction

As wireless connectivity rapidly becomes a necessity, new protocols arise in order to cover certain flows of the old ones. In 1997, the first IEEE protocol, 802.11, proposed among other the Distributed Coordination Function (DCF), a means of organizing access in a common medium in a distributed manner. Eight years later, the need for Quality of Service support is guiding the creation of an improved version called Enhanced Distributed Coordination Function (EDCF) under the 802.11e protocol, which was later called EDCA (Enhanced Distributed Channel Access). In this protocol, high priority applications access the channel with greater probability. [1] and [2] contain thorough description of how this is achieved. However, [3] and [4] showed that in heavy load cases, mobile stations have extremely low probability to transmit low priority traffic when using EDCA, an effect called starvation of low priority applications. The quality of high priority classes is guaranteed in exchange of total surrender of low class quality.

Knowledge of 802.11 and 802.11e is assumed in this paper [5], [6]. Detailed overviews of this matter are

found in [1] and [7]. The 802.11 protocol utilizes a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique. In the Standards, two schemes are defined, Point Coordination Function (PCF) is controlled by a central point called Access Point, whereas in Distributed Coordination Function (DCF) the management is distributed in every node of the network. PCF, despite providing better quality, can only be used in infrastructure-based networks and due to the need for synchronization, has proved to be unreliable in some cases [8]. On the other hand, DCF has become the preferred MAC function due to versatility. Great effort has been put into improving the performance of DCF as regards throughput [9], [10], delay, [11], and Quality of Service, [12] and [13]. Most of the proposed schemes and algorithms are focused on two settings namely the Arbitrary InterFrame Spacing (*AIFS*) and the Contention Window (*CW*). These settings are used by the Mobile Station in order to differentiate from the rest of the contenders and access the common channel.

Multimedia applications have been proved prone to end-to-end and jitter delay, a usual deficiency of packet switched networks. On the other hand, circuit-switched networks offer great quality support for multimedia services but they are abandoned due to their inferiority to packet-switched networks in providing data applications. Research in wireless ATM networks, [14] and [15], have shown that multimedia applications quality can be well-supported in packet switched networks by means of TDMA schemes where an occasional access is guaranteed in one slot of every frame. The proposed model is designed to create a virtual TDMA environment in a system with variable packet length. The virtual timeslots are used in order to offer guaranteed service for high quality classes and a reserved bandwidth for low priority classes by means of an admission algorithm. The model is designed to be backward compatible with the other 802.11 protocols.

The rest of the paper is organized as follows. In section 2 and 3 the proposed model is described and evaluated respectively. In section 4, results are presented and

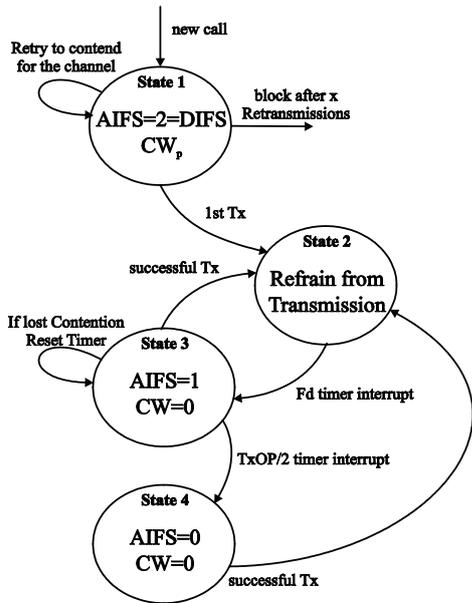


Figure 1: State diagram for priority class AC3.

in the final section, the conclusion is discussed.

## 2 System Model

The proposed model is a compatible enhancement to 802.11e protocol for Quality of Service using three already defined access classes (AC0, AC1 and AC2) and alternating priority access class (AC3). The design goal is to offer priority access to AC3, to prevent unfairness problem from occurring and guarantee low delay. The model is based on the functionality of a local timer. A virtual frame duration  $Fd$  is decided before the operation of the network.  $Fd$  can be decided separately for each Physical (PHY) Layer Protocol and statistically defines the duration of a virtual timeslot.  $Fd$  should match the application requirements for the delay between successive packets. Since the duration of a virtual timeslot is bound by the Transmit Opportunity ( $TxOP$ ) property of 802.11e, and the bandwidth and delay requirements of multimedia applications are known by the RTP protocol, the calculation of  $Fd$  is relatively easy. For a VoIP example with a codec  $20msec$ ,  $Fd$  should be  $20msec$  as well.

Using this local timer, every mobile station that transmits priority class information can self-organize the manner in which it transmits. Specifically, for priority classes only, figure 1 depicts a state diagram of the MAC functionality. Each state contains different values of  $AIFS$  and  $CW$  that the station uses to access the channel for this application. It is evident, that during state 1 the application request is in admission condition where it contends with all other requests. After the admission, the station occupies two basic states. In state 2, it refrains from transmission for as long as a  $Fd$  counter runs. An interrupt from the timer leads to state 3 where low  $AIFS$  and  $CW$  guarantee channel access. Certain issues remain to be discussed; the possible collisions of

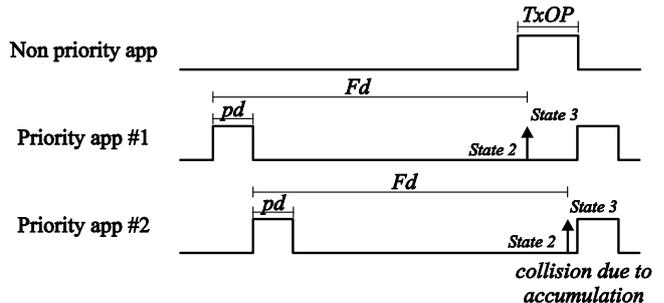


Figure 2: Collision between two high priority applications when state 4 is not used.

priority class, and the admission and blocking issue.

Collision between low priority calls is normally dealt as in DCF. Thus the point of interest is a possible collision of a high priority request. Specifically, this is divided in two cases; a collision between two ongoing high priority calls and a collision between high and low priority calls.

### 2.1 Collision of two high priority requests

Assume *Application1* successfully transmits at zero time and *Application2* immediately follows after packet duration  $pd$ . When the timer of *Application1* expires at  $Fd$ , *Application1* will try to transmit the next frame. As shown in figure 2, there is a chance that a low priority application may have just started to transmit a full  $TxOP$  long packet transmission. Collision between high priority applications can only occur in the case of accumulation of expired timers as in this case. This happens because  $pd$  will probably be smaller than  $TxOP$  and both *Application1* and *Application2* will be ready for transmission at  $Fd + TxOP(sec)$ . To avoid such a misfortunate occasion, we define a fourth state (state 4) in which the priority application hops to when it has already waited in state 3 for  $TxOP/2(sec)$ . This extra state ensures an order between high priority applications and enables a First-In First-Out (FIFO) functionality of the high priority contention queue. This ensures collision-free behaviour assuming that all transmissions of high priority class are longer than  $TxOP/2(sec)$  and no transmission is greater than  $TxOP(sec)$ .

Although collisions due to MAC protocol are avoided, there is always a chance that the packet is not accepted correctly due to unpredictable behaviour of Wireless environment. In case a packet is lost, it is not retransmitted. This UDP-like behaviour is in accordance with the TDMA-like nature of the proposed protocol.

### 2.2 Collision between a high priority and a low priority class

Low  $AIFS$  and  $CW$  values ensure that no collision can occur between a high priority and a low priority class when they contend simultaneously for the channel after a busy period. However, many consecutive idle slots

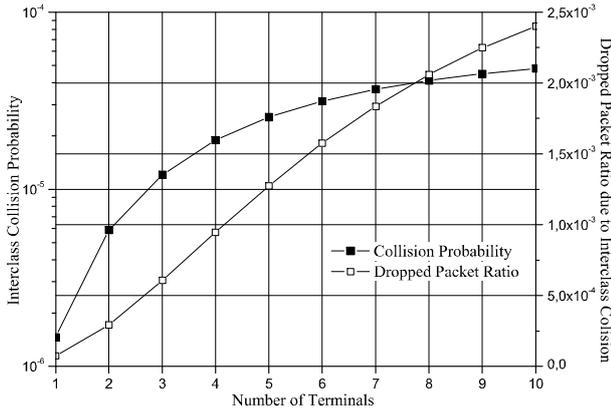


Figure 3: Probability of collision between high priority and low priority applications.

can allow a low priority call to collide with a high priority one. For this to happen, one low priority terminal should transmit in a slot which follows  $AIFS[w]$  idle slots together with a high terminal. The high terminal transmission slots are very few in a  $Fd$  frame and in case of high priority traffic conditions, there is a tendency for high priority transmissions to appear in groups (thus there is no room for consecutive idle slots). The high bound of the probability of collision between high priority and low priority classes is then calculated by assuming three independent events, the probability of high priority transmission in a slot, the probability of  $AIFS[w]$  consecutive idle slots and the probability of low priority transmission in the same slot.

$$p_c^{3,w} = \sum_{w=0}^2 \frac{N_3 \cdot Slot\_Time}{Fd} \cdot (P_i)^{AIFS[w]} \cdot N_w \cdot p_{T_w} \quad (1)$$

Where,  $p_c^{3,w}$  is the probability of interclass collision,  $N_3$  the number of terminals demanding high priority applications,  $Slot\_Time$  the duration of a single slot  $P_i$  the probability of the channel to be idle in a single slot,  $w \in \{0, 1, 2\}$  the number of the low priority access class (AC),  $AIFS[w]$  the respective arbitrary IFS,  $N_w$  the number of terminals demanding such traffic and  $p_{T_w}$  the probability that a terminal is accessing the channel in a specific slot for a packet of the specific AC. All these should be more clear after the following section.

The probability  $p_c^{3,w}$  is shown in figure 3 for the case of  $N \in [1, 10]$  simultaneously transmitting terminals with all four possible applications, AC0, AC1 and AC2 from 802.11e and the AC3 modified according to the proposed scheme. For the case of 10 simultaneously transmitting terminals, a ratio of 1 collision per 160sec and 1 lost packet per 40sec can be estimated. These values show that the collision between low priority classes and high priority classes is kept very small and cannot deteriorate the functionality of the proposed model.

## 2.3 Admission and Blocking

The  $Fd$  counter implies a fixed virtual frame length. This fixed length is very important for the quality of ongoing transmissions since an increase in the frame would cause a deterministic amount of delay in the system. This also implies that an admission strategy is necessary for preventing the system from overloading. Low priority applications are somewhat led through an admission procedure when contending for access with backoff counters. For high priority applications, a statistical admission is used. The call to be admitted senses the channel and makes  $x$  attempts to transmit. After  $x$  collisions the application becomes blocked. Blocking may also occur from the connection delay before the  $x$  re-transmissions take place.  $AIFS$  setting is set equal to non priority case and  $CWp$  is set smaller. The result is that high priority classes are easily admitted when the load is small. As the load increases the blocking probability increases as well. If the remaining virtual slots are few, the connection probability will be very small due to high connection delay. Blocking probability and fairness for high priority class, are governed by  $x$ ,  $CWp$  of State 1 and the number of non priority and priority contending mobiles. Figures 4 and 5 show some results on this matter.

As the number of mobile terminals increases connection delay and blocking probability both increase. This increase depends on two separate effects; the available bandwidth and the number of contending mobiles. This is clearly shown in the case of connection delay. Since 14 is the maximum number of possible high priority applications for 1Mbps selected transmission rate [20], from that point and after, connection delay depends only on backoff contention. The analytic approach for blocking probability and connection delay is found in the next section. The values  $CWp = 8$  and  $x = 4$  are chosen in the rest of the analysis. Small  $CWp$  gives priority and smaller connection delay, but results in channel monopoly by the priority class. A large  $x$  reduces blocking probability, but it also causes greater connection delay and monopolization of channel. Smaller connection delay can be achieved by using smaller  $AIFS$  values as well.

## 3 Mathematical Analysis

### 3.1 Analysis for non-priority classes

Low priority classes (AC0, AC1 and AC2) are treated separately from high priority since they follow different state transitions. The analysis found in [16], is the basis of the one to be used here. In, [17], Ziouva proposed a modified analysis considering freezing backoff counters, while in [18] the previous is applied on 802.11e. In our analysis we incorporate the recent findings of [19].

The Markov chain to be used, can be found in the figure 2 of [19]. For the solution of the Markov chain we assume that priority application admission procedure has a negligible influence on non priority access. The backoff procedure is normally analyzed and the bandwidth re-

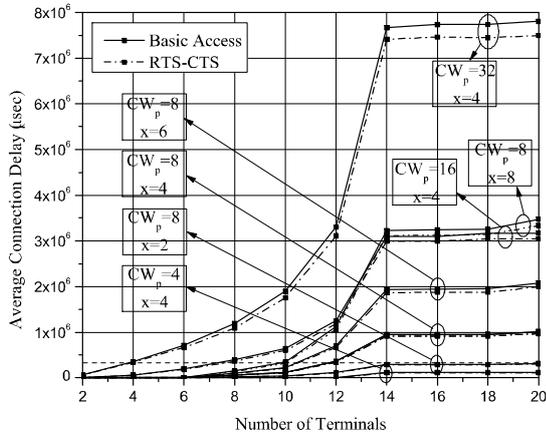


Figure 4: Connection Delay for high priority class,  $CW_p = [4, 8, 16, 32]$  and  $x = [2, 4, 6, 8]$ . Transmission rate is 1Mbps.

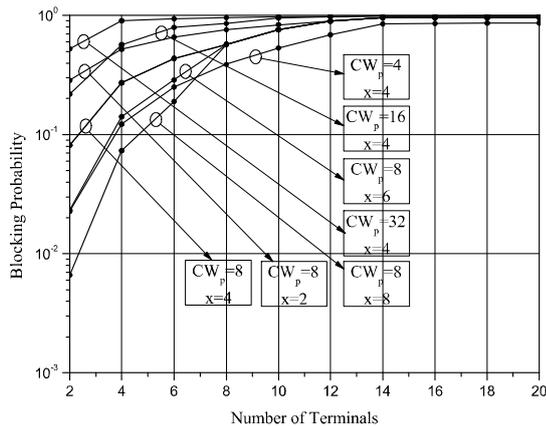


Figure 5: Blocking Probability for high priority class,  $CW_p = [4, 8, 16, 32]$  and  $x = [2, 4, 6, 8]$ . Transmission rate is 1Mbps.

duction due to priority transmissions is only taken into account in throughput and delay analysis. If  $b_{i,j,k}$  is the stationary probability of backoff state  $i, j, k$ , we can solve the system of equations for  $b_{1,0,0}$ . The system of equations can be found in [19], as well.

We define the probabilities of accessing the channel after a busy period  $\tau_{b,w}$  and after an idle period  $\tau_{i,w}$  and the probabilities of an idle (busy) slot after a busy period  $q_0$  ( $p_{0,w}$ ) and after an idle period  $q_1$  ( $p_{1,w}$ ). Probabilities  $\tau_{b,w}$ ,  $\tau_{i,w}$ ,  $p_{0,w}$  and  $p_{1,w}$  are dependent on each specific class while  $q_0$  and  $q_1$  are the same for all low priority classes, as in [18].

The probability of idle channel  $P_i$ , of each class successful transmission  $P_{s,w}$  and of collision  $P_c$ , are all defined in a free from priority contention slot and found in [19] as well. These probabilities are valid only for the proportion of bandwidth left free from high priority access called  $1 - BWp$ .  $BWp$  is the percentage of resources occupied by priority applications. A simple approach to  $BWp$  is:

$$BWp = N_\alpha \frac{pd}{Fd} \quad (2)$$

$N_\alpha$  is the number of successfully accepted calls to the system and  $pd$  is the total duration of a high priority application transmitted packet. Normalized throughput for non priority application  $w$  will be:

$$S_w = P_{s,w} E\{P\} (1 - BWp) / \left\{ (P_i \cdot Slot\_Time + \sum_{w=0}^2 P_{s,w} T_s + P_c T_c) \times (1 - BWp) + BWp \cdot pd \right\} \quad (3)$$

Where  $E\{P\}$  is the expected length of a non-priority class packet,  $T_s$  is the time that a successful transmission of a packet takes and  $T_c$  for a collided packet respectively, all found in [16].

The average delay for the class  $w$  will be:

$$E\{D\}_w = E\{N\}_w (E\{B\}_w + T_c + T_T) + E\{B\}_w + T_s \quad (4)$$

Where  $E\{N\}_w$  is the average number of retransmissions,  $E\{B\}_w$  is the average delay between each transmission due to backoff and freezing,  $T_T$  is the timeout duration after a collision,  $E\{X\}_w$  is the delay of backoff slots,  $E\{N_F\}_w$  is the average number of backoff freezing for each transmission and  $BD_w$  is the average number of backoff counters to be reduced until the transmission. Equation (4) can be solved using (5)-(10).

$$E\{N\}_w = \frac{1}{P_{s,w}} - 1 \quad (5)$$

$$E\{B\}_w = E\{X\}_w + E\{N\}_w \times \left( (1 - BWp) \left( \sum_{w=0}^2 P_{s,w} T_s + P_c T_c \right) + BWp \cdot pd \right) \quad (6)$$

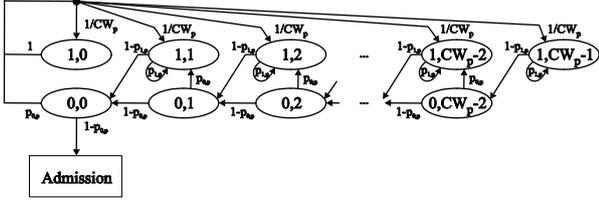


Figure 6: Backoff state diagram for high priority traffic at admission time.

$$E\{X\}_w = BD_w \times Slot\_Time \quad (7)$$

$$E\{N_F\}_w = \frac{BD_w}{\max(ConIdleSlots, 1)} \quad (8)$$

Where  $ConIdleSlots$  is the number of consecutive idle slots between each backoff freezing, defined as:

$$ConIdleSlots = \frac{P_i(1 - BW_p)}{1 - P_i(1 - BW_p)} \quad (9)$$

$$\begin{aligned} BD_w &= \sum_{j=0}^m \sum_{k=0}^{W_j-1} k \cdot b_{0,j,k} = \\ &= b_{1,0,0} \sum_{j=0}^m \psi_j \frac{W_j(W_j-1)(W_j-2)}{3} \end{aligned} \quad (10)$$

Where  $W_j = 2^j W_0$  and  $\psi_j$  is multivalued function defined in [19] and  $m$  is equal to  $\log_2(CW_{max}/CW_{min}) - 1$ .  $m$  and  $W_0$  depend on the class specifications.

The average durations of several cases frames  $T_s$  and  $T_c$  for basic and RTS-CTS access are found in [16] and [20].

### 3.2 Analysis for priority class

The throughput and delay analysis for priority class is much simpler than for non priority class as long as it is assumed that no hidden terminal effect exists. Throughput is given by:

$$S_3 = N_a \frac{E\{P\}_p}{Fd + TxOP/R} \quad (11)$$

Where  $E\{P\}_p$  is the expected packet length in bits per frame and  $R$  is the channel rate. The average delay will be:

$$E\{D\}_3 = (F_{PA} - 1)Fd + \frac{TxOP}{2} \quad (12)$$

Where  $F_{PA}$  is the packet accumulation factor indicating how many high priority packets are needed to be accumulated in a large packet that is longer than  $TxOP/2$ . The first part of the expected delay is a deterministic delay imposed by the packet accumulation. The second part is the expected value of a uniform random variable of how long a priority call may wait in states 3 and 4. Expected delay is independent of the load of the system.

Connection delay can be found with an analysis similar to EDCA as in [18]. The Markov chain for high priority admission will be a simple chain with  $CW_p$  different backoff stages with equal probability of selection and the stages for freezing of backoff counter (figure 6). The stationary probabilities are:

$$\begin{cases} b_{0,j} = (CW_p - 1 - j) b_{1,0}, \text{ for } j \in [1, CW_p - 2] \\ b_{1,j} = \frac{1 + p_{0,p}(CW_p - 1 - j)}{1 - p_{1,p}} b_{1,0}, \text{ for } j \in [1, CW_p - 1] \\ b_{0,0} = b_{1,0} \frac{CW_p - 1}{p_{0,p}} \end{cases} \quad (13)$$

Using  $b_{0,0} + \sum_{j=1}^{CW_p-2} b_{0,j} + \sum_{j=1}^{CW_p-1} b_{1,j} + b_{1,0} = 1$ , the stationary probabilities can be calculated:

$$\begin{aligned} b_{1,0} &= \left[ 1 + \frac{(1 - p_{0,p})(CW_p - 1)}{p_{0,p}} + \frac{CW_p(CW_p - 1)}{2} + \right. \\ &\quad \left. + \frac{CW_p - 1 + p_{0,p} \frac{(CW_p - 1)(CW_p - 2)}{2}}{1 - p_{1,p}} \right]^{-1} \end{aligned} \quad (14)$$

Where  $p$  indicates that AC3 class is in admission state. The probabilities of channel access for priority admission are:

$$\tau_{i,p} = \frac{b_{0,0}}{\left( \frac{q_{1,p}}{1 - q_{0,p} + q_{1,p}} \right)} \quad (15)$$

$$\tau_{b,p} = \frac{b_{1,0}}{\left( 1 - \frac{q_{1,p}}{1 - q_{0,p} + q_{1,p}} \right)} \quad (16)$$

Where:

$$q_{0,p} = \prod_{w=0}^2 (1 - \tau_{i,w})^{N_w} (1 - \tau_{i,p}) \simeq q_{0,w} \quad (17)$$

$$q_{1,p} = \prod_{w=0}^2 (1 - \tau_{b,w})^{N_w} (1 - \tau_{b,p}) \simeq q_{1,w} \quad (18)$$

$$p_{0,p} = 1 - q_{0,w} \quad (19)$$

$$p_{1,p} = 1 - q_{1,w} \quad (20)$$

Equations (17)-(20) show that the behaviour of admission is very much depended upon low priority access conditions, which in cases of heavy loaded channels prevents the phenomenon of resource starvation of low priority class.

Further on, the average number of backoff slots for every connection attempt can be found:

$$BD_p = \sum_{j=0}^{CW_p-2} j \cdot b_{0,j} = \frac{b_{1,0}}{6} (CW_p - 1)(CW_p - 2)(2CW_p - 3) \quad (21)$$

The average delay for every attempt to connect will be:

$$E\{CD\}_1 = BD_p \cdot Slot\_Time + \left(\frac{BD_p}{P_i} - 1\right) \times \left[ (1 - BW_p) \times \left(\sum_{w=0}^2 P_{s,w} T_s + P_c T_c\right) + BW_p \cdot pd \right] \quad (22)$$

The probability to successfully access the channel is:

$$P_{a,p} = (P_i q_{0,w} \tau_{i,p} + (1 - P_i) q_{1,w} \tau_{b,p}) (1 - BW_p) \quad (23)$$

The average connection delay, disregarding the calls that will drop due to extensive delay, is:

$$E\{CD\} = P_{a,p} E\{CD\}_1 \sum_{l=1}^{\infty} l (1 - P_{a,p})^{l-1} \quad (24)$$

Defining a threshold of acceptable connection delay  $Thr_{CD}$ , the fact that a priority demand will be blocked due to unacceptable delay will cause less number of re-trials ( $\bar{x}$ ) and greater Blocking Probability. We calculate Blocking Probability as:

$$P_B = (1 - P_{a,p})^{\min\{x, [\max(\bar{x}) | CD \leq Thr_{CD}]\}} \quad (25)$$

## 4 Results

In this section we calculate the behaviour of the proposed model in comparison with EDCA. The performance of the MAC protocols is tested for variable number of contending stations, basic and handshaking access and the several access classes. Every terminal is assumed to demand all four classes of access. In case of saturation analysis, it is assumed that a packet is always available for transmission. For AC3 of the proposed protocol, admission control is utilized to prevent the system from overloading. Since the demand is great, the throughput is found to be saturated. On the other hand, we present results where AC3 demand is not saturated. Every terminal initiates a VoIP call and saturated traffic for the rest of the classes. These results are shown in figures 9 and 10.

Voice over IP (VoIP) applications use the G.711 codec [21]. 160B of payload are transmitted every 20ms. The  $Fd$  timer could be set to 20ms for this case. However, the packet length (in Bytes) need to be greater than  $TxOP/2$ . Thus, a 4 packet accumulation is proposed before transmission, which yields a maximum of 60ms buffer delay. This deficiency is necessitated by the priority class collision avoidance mechanism proposed in section 2.1.  $Fd$  is, then, chosen to be 80ms and the packet payload would be 640B.

The analytical approach is compared with simulations with the OPNET<sup>TM</sup> simulator. The simulation values are described in table I.

Figures 7 and 8 show the results for Saturation Throughput in case of basic and RTS-CTS access respectively. A clear advantage of the proposed model is

802.11e values		$CW_{\min}$	$CW_{\max}$	$AIFS$
	AC3	3	7	2
	AC2	7	15	2
	AC1	15	1023	3
	AC0	15	1023	7
Saturation Traffic				
	packet length	1024B		
	interarrival time	0.01sec		
VoIP Traffic				
	packet length	$4 \times 160B$		
	interarrival time	0.08sec		

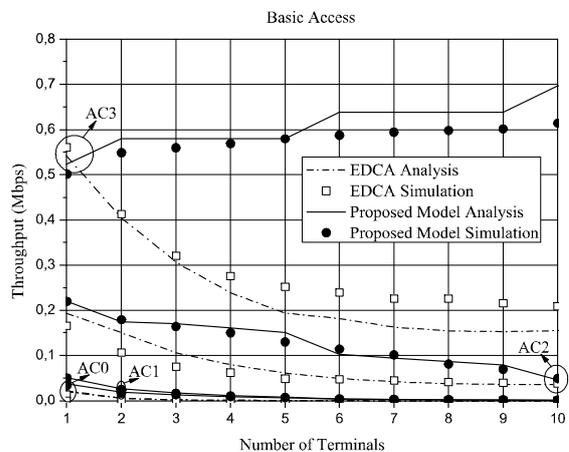


Figure 7: Saturation Throughput for 1Mbps channel rate and basic access.

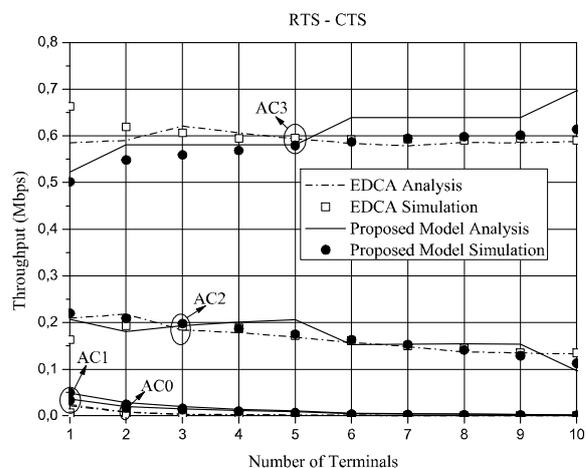


Figure 8: Saturation Throughput for 1Mbps channel rate and RTS-CTS access.

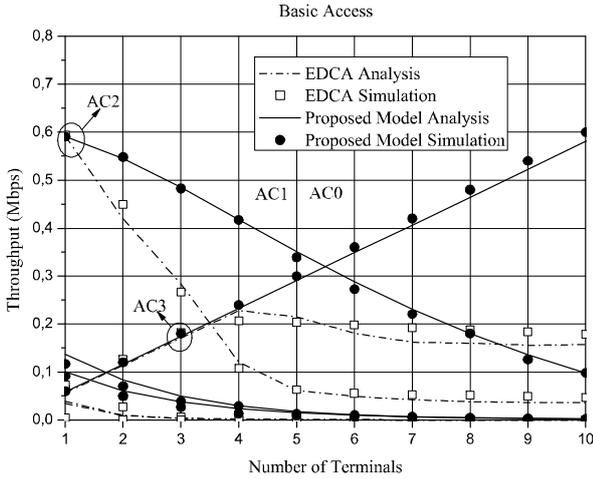


Figure 9: Throughput for non-saturated AC3 traffic, 1Mbps channel rate and basic access.

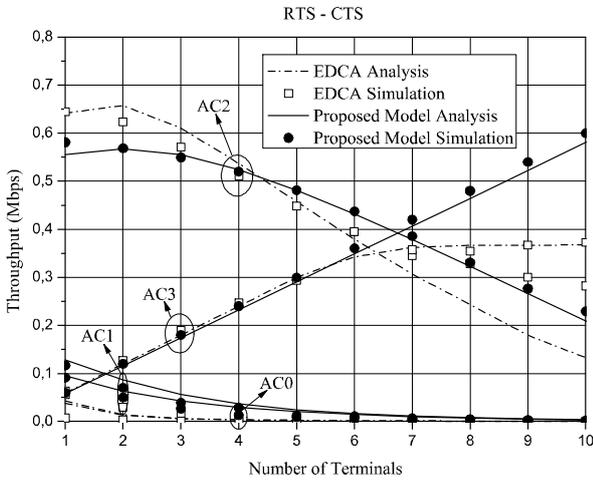


Figure 10: Throughput for non-saturated AC3 traffic, 1Mbps channel rate and RTS-CTS access.

obvious in case of basic access. However, this gain is compromised by the use of RTS-CTS, which indicates that EDCA results in more collisions. A small gain in throughput remains, which is expected from the fact that the proposed model uses the TDMA scheme.

In terms of simulation and analysis comparison, the proposed model throughput is found to be a little worse in simulations which is partially explained by the inter-class collisions and the way admission control is used in analysis. In figure 7, an unexpected difference between analysis and simulation for AC3 is shown.

Figures 9 and 10 show throughput for the case that AC3 traffic is not saturated. Specifically, one one-way VoIP application is considered to be generated by each of the terminals. The rest of the traffic sources are considered saturated. These conditions showcase the performance of the two protocols in realistic conditions. The proposed model is found to be superior in terms of throughput at the most of the times. AC3 for EDCA is saturated earlier than expected due to the smaller

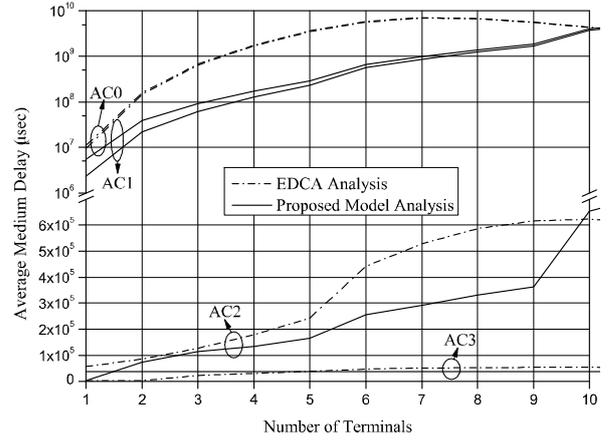


Figure 11: Average Medium Delay for 1Mbps channel rate.

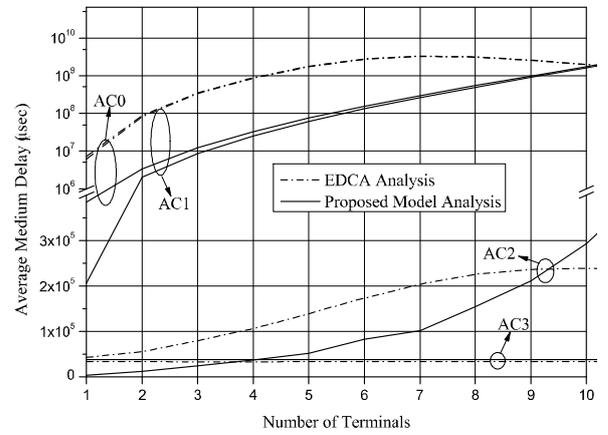


Figure 12: Average Medium Delay for 1Mbps channel rate and non-saturated AC3 traffic.

packet length used. It can be seen, that the proposed protocol performance for high priority class is unaffected by the packet length as long as it remains larger than  $TxOP/2$ .

A deviation between AC2 analysis and simulation is found in this case. For better comparison, packet accumulation is used for EDCA and the throughput is kept high having a negative effect on delay (figure 12). Admission control is not activated in this case.

Average Medium delay is shown in figures 11 and 12 for the case of saturated and non-saturated AC3 traffic respectively. A small gain is found in terms of delay for the proposed protocol high priority traffic. However, an important characteristic is that the proposed protocol yields very small jitter delay. This is analogous to the TDMA performance.

Low priority delay, on the other hand, can be very high when the high priority applications occupy the greater portion of the available bandwidth. If an improvement is required on this matter,  $CWp$  can be modified to perform a tighter admission control for high priority calls, nevertheless leading to higher blocking probability.

## 5 Conclusion

A new MAC protocol is proposed to be a backward compatible advancement to the wide-known 802.11e protocol. A timer called *Fd* timer is used in a distributed manner from each wireless terminal to create a virtual TDMA-like frame. Each terminal uses another timer to prevent collisions with other high priority applications. A tradeoff between high priority admission characteristics (connection delay and blocking probability) and low priority performance can be used in Quality of Service optimization procedure. The results show a small improvement in throughput due to the decrease in the backoff delay. The average delay for priority class is independent of load conditions, as expected by the TDMA nature of the proposed protocol, thus making the proposed protocol ideal for VoIP communications. Other advantages of the proposed protocol are the small jitter delay and the independence of throughput from the packet length.

## References

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