Enhancement proposal for WLAN IEEE 802.11e: Desynchronization of its Working Procedure

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Abstract- **Up to the present, several studies have been performed in order to provide priorization of stations or classes of service for WLAN IEEE 802.11. The IEEE 802.11e draft specification aims to extend the original IEEE 802.11 MAC protocol to support QoS. One of the mechanisms for priorizing traffic is the assignment of different AIFS times to each priority level. Nevertheless, the AIFSs employed are separated by values that are multiples of the slot time. Therefore, due to the fact that the backoff time counter is slotted, the different priority levels can attempt for transmission simultaneously.**

In this paper, we evaluate the performance of the IEEE 802.11e when its working procedure is desynchronized: we avoid that stations belonging to different priority levels attempt for transmission at the same time. We assign AIFS times that are separated by values that are not multiples of the slot time, in order to avoid collisions between the different priority levels. We present a mathematical model and simulation results for analyzing the performance of the differentiation mechanism proposed. The results show that it solves the strangulation of low priority traffic, fact that occurs in IEEE 802.11e EDCA. Moreover, this proposal leads to a significant increase in the performance of the system as a whole.

Index Terms— **WLAN, IEEE 802.11e, MAC, differentiation, AIFS**

I. Introduction

There have been many developments since 1997, when the Institute of Electrical and Electronics Engineers (IEEE) defined the first standard, IEEE 802.11, for wireless local area networks. IEEE 802.11 worked at 2.4 GHz and at data rates of 1 and 2 Mbps. IEEE 802.11b, which at the same frequency achieved a data rate of 11 Mbps, appeared later. IEEE 802.11a was developed subsequently; it reached 54 Mbps and its working frequency was increased to 5 GHz. This change of frequency, however, decreased its interoperability with older equipment. In answer to this, the IEEE 802.11g was developed, which reaches 54 Mbps but works at 2.4 GHz. The working procedures are practically the same for all these standards; only the modulation, certain fields in the physical layer, the duration of the slot and the interframe space times (DIFS, SIFS and PIFS) change. Finally, in September 2003, a new working group began to develop IEEE 802.11n, which should reach data rates between 108 and 320 Mbps.

IEEE 802.11 can be considered a wireless version of Ethernet, in this way this standard offers a best-effort service and no service level guarantee exists for users and applications. Nowadays, a more increasing number of users, after experiencing the convenience of wireless connections through IEEE 802.11 standard, demands support of time-sensitive (voice and video) applications.

Up to now, several papers have been written on different aspects of IEEE 802.11 networks. Different mechanisms that priorize some stations over others have been evaluated. Moreover, the proposals of the IEEE 802.11e working group define procedures for managing network Quality of Service (QoS) using classes of service. The differentiation proposals studied consist in the modification of the backoff function calculation [1]–[3], in the assignment of different Inter-Frame Space (IFS) access times to the various priority levels [1], in the combination of both mechanisms [4], and in the employment of several packet lengths for the different priority levels [1].

The IEEE 802.11 task group "E" is currently working to enable QoS support within the original standard; it defines procedures for managing network QoS using classes of service. Moreover, the extensions introduced consider both access mechanisms: the distributed (DCF) and the point (PCF) coordination function. The new MAC protocol upcoming is called Hybrid Coordination Function (HCF). It combines a contention channel access mechanism, the Enhanced Distributed Channel Access (EDCA), and a polling-based channel access, the HCF Controlled Channel Access (HCCA). The IEEE 802.11e standard is still in draft version, and in the meantime, a large amount of studies has been carried out that claim that some important issues have still to be solved. Recent studies [5]-[7] have shown that under high loads of high-priority traffic, EDCA starves low-priority frames.

In this way, in this paper we propose a differentiation mechanism in order to avoid the strangulation of low priority traffic, as occurs in IEEE 802.11e EDCA. One of the mechanisms for priorizing traffic is the assignment of different Arbitration Inter-Frame Space (AIFS) access times to the various priority levels. Nevertheless, the AIFSs employed are separated by values that are multiples of the slot time. Due to the fact that the backoff time counter is slotted, the different priority levels work in a synchronized way: they can attempt for transmission simultaneously. We assign AIFS times that are separated by values that are not multiples of the slot time, in order to avoid collisions between the different priority levels. We present a mathematical model and simulation results for analyzing the performance of the differentiation mechanism proposed. Finally, we compare this behavior with the obtained with the assignment of the AIFS times employed in IEEE 802.11e.

The organization of the rest of the paper is as follows: section II exposes the IEEE 802.11 MAC protocol, section III presents the main topics of the IEEE 802.11e EDCA working procedure, section IV describes the simulation environment, section V presents the differentiation proposal and the mathematical model obtained, section VI exposes the system behavior working under the differentiation proposal, finally section VII concludes with the most relevant points of the article.

II. IEEE 802.11 MAC PROTOCOL

IEEE 802.11 has two operating modes: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The most common working mode is DCF that uses the medium access control (MAC) algorithm named CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance); it works as follows. Before initiating a transmission, a station senses the channel to determine whether it is busy. If the medium is sensed idle during a period of time named distributed interframe space (DIFS), the station is allowed to transmit. If the medium is sensed busy, the transmission is delayed until the channel is idle again. A slotted binary exponential backoff interval is uniformly chosen in [0, CW-1], where CW is the contention window. The backoff timer is decreased as long as the channel is sensed idle, stopped when a transmission is in progress, and reactivated when the channel is sensed idle again for more than DIFS. When the backoff timer expires, the station attempts for transmission. After each data frame successfully received, the receiver transmits an acknowledgement frame (ACK) after a short interframe space (SIFS) period. The value of CW is set to 32 in the first transmission attempt, and ascends integer powers of 2 at each retransmission, up to a pre-determined value (usually 1024).

III. IEEE 802.11e EDCA

The EDCA proposal enhances the current DCF access mechanism employed by the IEEE 802.11, in order to enable QoS support. The mechanism is designed to manage 8 different traffic priorities; each of them corresponds to a different QoS defined at higher layers. Packets belonging to the different traffic priorities are mapped into 4 access categories (ACs); each of them represents a different priority level. Each AC contends to the medium following the same rules as legacy DCF.

An AC uses AIFS[AC], CW_{min}[AC] and CW_{max}[AC] instead of DIFS, CW_{min} and CW_{max}. AIFS[AC] is determined by:

$$AIFS\,[AC] = SIFS + AIFSN[AC] \cdot SlotTime, \qquad (1)$$

where AIFSN[AC] is an integer greater than zero.

Fig. 1 shows the IEEE 802.11e MAC. Each AC belongs to an independent queue at the MAC layer and it behaves as a single DCF contending entity. When more than one AC at the same station finishes its backoff counter simultaneously, a virtual collision occurs among them. In this case, the highest priority frame is chosen and transmitted.

Finally, employing EDCA, the winner of a contention is allowed to transmit for a given period of time called transmission opportunity (TXOP). This multiple MPDU transmission is referred to as “Contention Free Burst” (CFB).

IV. SIMULATION ENVIRONMENT DESCRIPTION

In order to analyze the IEEE 802.11 performance, we use a simulation tool implemented at the Technical University of Catalonia (UPC). Our simulation program, written in C++ programming language, follows all the IEEE 802.11 protocol details. It permits the evaluation of different parameters: throughput (user data correctly transmitted by users without considering retransmissions and headers), average transmission delay, average queue delay, time fraction during which all network stations are in backoff state, probability of collision. The simulation tool has been verified comparing the results obtained with the information published in [8], under identical simulation conditions.

Simulation environment is composed of 12 stations, which are distributed in different priority levels.

The PHY layer of the IEEE 802.11g has been chosen to realize this study. We have taken into account that IEEE 802.11g uses different PHY layers, depending on the data rates employed:

- For 1, 2, 5.5 and 11 Mbps it uses the IEEE 802.11b PHY layer, either long or short PHY format. To compute the following results we have considered short format for 11 Mbps.
- For higher rates (6, 9, 12, 18, 24, 36, 48 and 54 Mbps) it uses ERP-OFDM PHY layer.

The stations transmit data packets with constant payload size, and the time between consecutive arrivals follows an exponential distribution function. All stations are under coverage area. Hidden terminal situation and transmission errors are not considered.

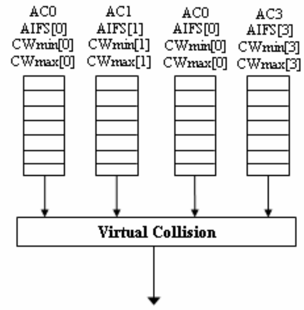

Figure 1. IEEE 802.11e MAC EDCA

The values of the remaining parameters used to obtain the numerical results are exposed in Table I.

V. Desynchronization proposal and Mathematical model

One of the existing methods that allow the priorization of stations or classes of service consists in the assignment of different AIFS access times to the various priority levels. The AIFS values defined in IEEE 802.11e are determined by equation (1). Due to the fact that the different AIFSs are separated by values that are multiples of the slot time, and that the backoff time counter is slotted, under heavy-load system conditions the different priority levels work in a synchronized way: they can attempt for transmission simultaneously. This situation produces collisions between the transmissions of high priority frames with backoff time and of lower level frames without backoff time. Consequently, in this paper we evaluate the performance of the IEEE 802.11e when we assign different access times that are separated by values that are not multiples of the slot time. In this way, we desynchronize the IEEE 802.11e working procedure: we avoid that different priority levels attempt for transmission at the same time. In this way, collisions between the different priority levels are avoided.

We consider a scenario composed of n stations. We distribute them in g groups; each of these groups belongs to a different priority level.

We denote the different priority groups as *group i* and each of them is composed of n_i stations and uses an access time called $AIFS_i$. For the evaluation of this differentiation proposal, we consider that the different priority groups employ the same backoff window size (CW_{min} and CW_{max}).

TABLE I

Main parameters used in the simulations

	802.11g (802.11b compatible)	802.11g (ERP-OFDM)
Transmission data rate (Mbps)	1, 2, 5.5, 11	6, 9, 12, 18, 24, 36, 48, 54
MAC header	34 bytes	
ACK	14 bytes	
Propagation time	1 μs	
Long PHY Preamble	144 μs	16 μs
Short PHY Preamble	72 μs	
Long PHY Header	48 μs	4 μs
Short PHY Header	24 μs	
Slot Time (σ)	20 μs	
SIFS	10 μs	
Min backoff window size (CW_{min})	32	
Max backoff window size (CW_{max})	1024	

If σ corresponds to the empty slot time size, we define a new $AIFS_i$ period for each priority group, following next equation:

$$AIFS_i = AIFS_{initial} + (i+1)\cdot\frac{\sigma}{g}, \quad where\ i = 0,...,g-1 \qquad (2)$$

and $AIFS_{initial}$ takes the value of the lowest AIFS access time employed in IEEE 802.11e; i.e. 30μs.

In this way, we have g independent backoff counters, without collisions between their correspondent transmissions. Therefore, we can model each group performance independently employing Bianchi's model [8]. Thus, following this model we can obtain τ_i: the probability that a station that belongs to *group i* transmits.

Bianchi's model concludes with the following expression for the saturation throughput S:

$$S = \frac{P_{tr} P_S E_p}{E_s}, \qquad (3)$$

where E_s is the average length of a slot time, E_p is the average payload length, P_{tr} is the probability that at least one station is transmitting and P_S is the probability that a transmission is successful.

Bianchi's model considers the different events that can occur within a generic slot time E_s. We compute the different average times needed, and to do so we distinguish $2g+1$ different types: the successful transmission time and the collision time for each priority group ($2g$ different times), and the empty slot time.

The stations of *group 0* belong to the highest priority level, and the ones of *group g-1* belong to the lowest priority class. Taking into account the differentiation mechanism proposal, a station of *group i* should transmit (after waiting its correspondent backoff interval) whenever none of the stations of *groups 0* until *i-1* is attempting a transmission. We take the clock of *group 0* as reference.

The successful transmission time for *group 0* is $T_{S0}=T_S$, where T_S corresponds to the time of a successful transmission presented in [8]. This event occurs with probability

$$P_{S0} = n_0 \cdot \tau_0 \cdot (1-\tau_0)^{n_0-1}. \qquad (4)$$

The successful transmission time for *group i,* where $i=1,..,g-1$, is $T_{Si}=T_S+i\cdot\sigma/g$. This event occurs with probability

$$P_{Si} = n_i \cdot \tau_i \cdot (1-\tau_i)^{n_i-1} \cdot \prod_{j=0}^{i-1} (1-\tau_j)^{n_j}. \qquad (5)$$

The collision time for *group 0* is $T_{C0}=T_C$, where T_C corresponds to the collision time presented in [8]. A station that belongs to *group 0* collides with probability

$$P_{C0} = \left(1-(1-\tau_0)^{n_0} - n_0 \cdot \tau_0 \cdot (1-\tau_0)^{n_0-1}\right). \qquad (6)$$

The collision time for *group i,* where $i=1,..,g-1$, is $T_{Ci}=T_C+i\cdot\sigma/g$. This event occurs with probability

$$P_{Ci} = \left(1 - \left(1 - \tau_i\right)^{n_i} - n_i \cdot \tau_i \cdot \left(1 - \tau_i\right)^{n_i - 1}\right) \cdot \prod_{j=0}^{i-1} \left(1 - \tau_j\right)^{n_j}. \quad (7)$$

Finally, the empty slot time has a length of σ and it occurs with probability

$$P_\sigma = \prod_{i=0}^{g-1} \left(1 - \tau_i\right)^{n_i}. \quad (8)$$

Considering the cases previously exposed, the average duration of a slot time follows the next equation:

$$E_S = P_\sigma \cdot \sigma + \sum_{i=0}^{g-1} \left(P_{Si} \cdot T_{Si} + P_{Ci} \cdot T_{Ci}\right). \quad (9)$$

Consequently, the system throughput is

$$S = \frac{E_p \sum_{i=0}^{g-1} P_{Si}}{E_S}. \quad (10)$$

Finally, the throughput for each *group i* follows the next equation:

$$S_i = \frac{E_p \cdot P_{Si}}{E_S}. \quad (11)$$

VI. Model validation and system behavior

To validate the model we have compared the mathematical results with that obtained with the simulation tool presented in a previous section. Following figures show that the analytical model is accurate: analytical results (lines) coincide with the simulation results (symbols). Note that the model applies only to systems composed of stations with access times that are separated by values that are not multiples of the slot time.

We evaluate the differentiation proposal for two different cases:

- Case 1: distribution of the stations in 2 priority levels; there are 6 stations per level
- Case 2: distribution of the stations in 4 priority levels; there are 3 stations per level

Taking into account the first case, we compare the system performance obtained employing the differentiation mechanism proposed with the results observed when no priorization scheme is used, and with the behavior obtained with the assignment of the AIFS times used in IEEE 802.11e.

Fig. 2 presents the throughput performance per station belonging to the group with the highest priority (*group 0*), for transmission rates of 11 and 54 Mbps. We can observe that, for the different PHY layers employed, using the differentiation mechanism proposed (the case with $AIFS_0$=40µs and $AIFS_1$=50µs) the stations belonging to *group 0* achieve an important throughput performance increase, in comparison with the case without priorization (the case with $AIFS_0$ = $AIFS_1$ = 50µs). This increase takes a value of 23% when the transmission rate is 11 Mbps and 29% when 54 Mbps are used. Moreover, the desynchronization of the transmission of stations that belong to different priority levels deals with a slightly lower differentiation level than the one obtained with the assignment of the AIFS times employed in IEEE 802.11e (the case with $AIFS_0$=30µs and $AIFS_1$=50µs). The differentiation proposal decreases the throughput performance of the highest priority stations with regard to the obtained with the IEEE 802.11e AIFS choice. This decrease takes a value of 6.6% when the transmission rate is 11 Mbps, and 5.5% for 54 Mbps.

Fig. 3 presents the throughput performance per station belonging to the group with the lowest priority (*group 1*), for transmission rates of 11 and 54 Mbps. Employing the differentiation mechanism proposed, these stations obtain a higher throughput performance in comparison with the behavior observed with the IEEE 802.11e AIFS choice. In this way, our differentiation proposal avoids the strangulation of low priority traffic; the stations belonging to the lowest priority group obtain only a slightly throughput decrease in relation to the case without priorization. This decrease takes a value of 4.4% when the transmission rate is 11 Mbps, and 1.6% for 54 Mbps. On the other hand, the IEEE 802.11e choice achieves a decrease of 26.6% for 11 Mbps and of 25.3% for 54 Mbps.

Fig. 4 presents the total system throughput performance. By using the differentiation mechanism proposed, the system throughput performance increases in comparison with the case without priorization. This increase takes a value of 9.3% when the transmission rate is 11 Mbps, and 14.6% when 54 Mbps are used. On the other hand, the IEEE 802.11e choice achieves a rise of 2.5% for 11 Mbps and of 5.6% for 54 Mbps. Thus, the differentiation proposal achieves a higher total system throughput performance in relation to the obtained with the IEEE 802.11e AIFS choice. With the mechanism described in this paper, we achieve desynchronization between the transmissions of the stations that belong to different priority levels. Consequently, we avoid the collisions between the different priority levels, and the collision probability for the different stations is reduced considerably. Thereby, the system reduces the time during which the channel is sensed busy because of a packet collision, which thus yields a higher throughput performance.

Subsequently, we evaluate the system performance when we distribute the stations in 4 priority classes, and we compare the performance obtained with the one observed when no priorization scheme is used.

Fig. 5 and 6 present the throughput performance per station belonging to the different priority groups (*group 0 – group 3*), and for transmission rates of 11 and 54 Mbps. Using the differentiation mechanism proposed (the case with $AIFS_0$=35µs, $AIFS_1$=40µs, $AIFS_2$=45µs and $AIFS_3$=50µs), we observe that the stations belonging to *group 0* obtain an increase of 47% when the system is working with 11 Mbps. This rise is of 58.5% for 54 Mbps. Finally, the stations of *group 3* decrease their throughput an 11%, when 11 Mbps are used. This decrease is of 4.6% for 54 Mbps.

Fig. 7 - 10 compare the throughput performance per station

belonging to the different priority groups, employing the differentiation mechanism proposed and the assignment of the AIFS times used in IEEE 802.11e (the case with $AIFS_0$=30µs, $AIFS_1$=50µs, $AIFS_2$=70µs and $AIFS_3$=90µs), for transmission rates of 11 and 54 Mbps. The differentiation proposal decreases the throughput performance of the stations belonging to *group 0*, with regard to the obtained with the IEEE 802.11e AIFS choice. This decrease takes a value of 21.7% when the transmission rate is 11 Mbps, and 16.1% for 54 Mbps. Furthermore, stations of *group 1* increase their performance, in comparison with the IEEE 802.11e choice, by 3.9% for 11Mbps and 10.7% for 54 Mbps. The stations of *group 2* achieve a rise of 64.3% for 11 Mbps and 77.6% for 54 Mbps. Finally, the stations of *group 3* increase their throughput by a factor of 2.3 for 11 Mbps and of 2.8 for 54 Mbps.

Fig. 11 presents the total system throughput performance. By using the differentiation mechanism proposed, the system throughput performance increases a value of 16.4% in comparison with the case without priorization, when the system is working with a transmission rate of 11 Mbps, and a value of 25.3% for 54 Mbps. On the other hand, the IEEE 802.11e choice achieves only a rise of 3.1% for 11 Mbps and of 3.2% for 54 Mbps.

When the stations are distributed in a higher number of priority groups, the collision probability for the different stations is reduced. In this way, the total system throughput performance increases and the throughput of the stations belonging to the highest priority class rises. On the other hand, the stations of the lowest priority group decrease slightly its performance.

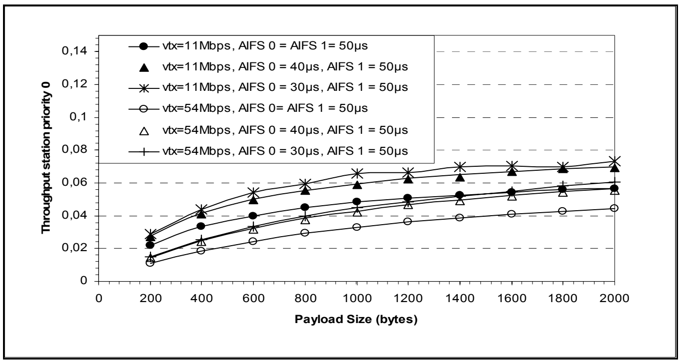

Figure 2. Throughput per station belonging to priority 0 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

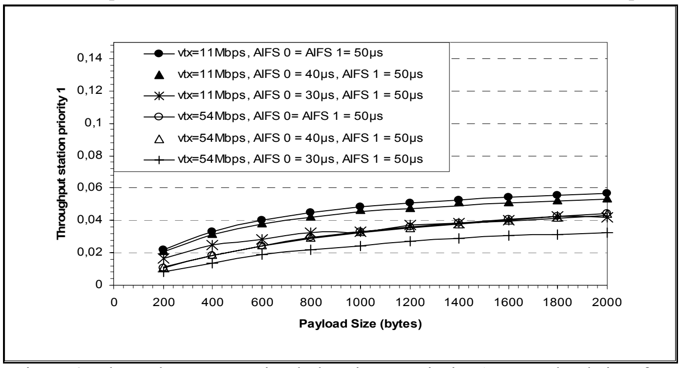

Figure 3. Throughput per station belonging to priority 1 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

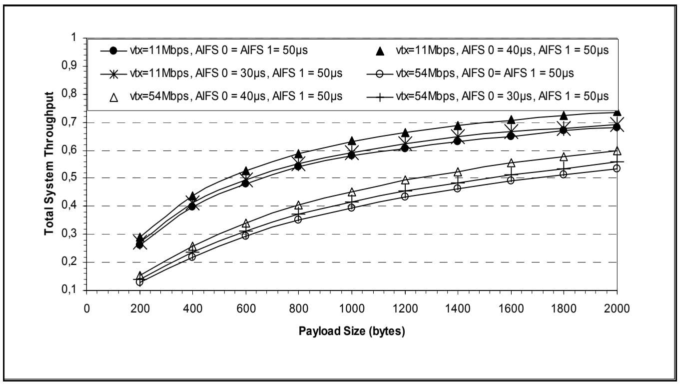

Figure 4. Total system throughput performance vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

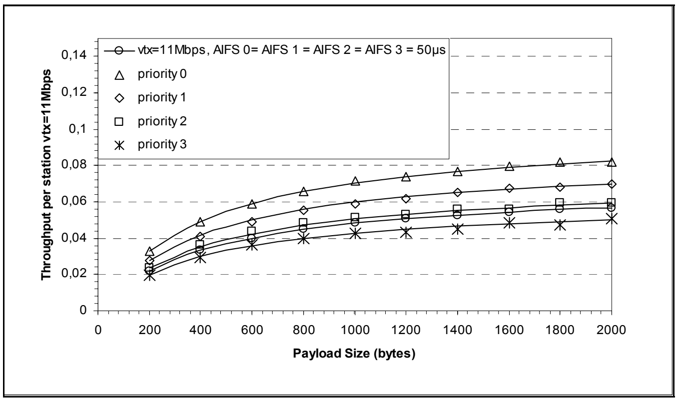

Figure 5. Throughput per station vs. payload size, for different priority levels and transmission rate of 11 Mbps

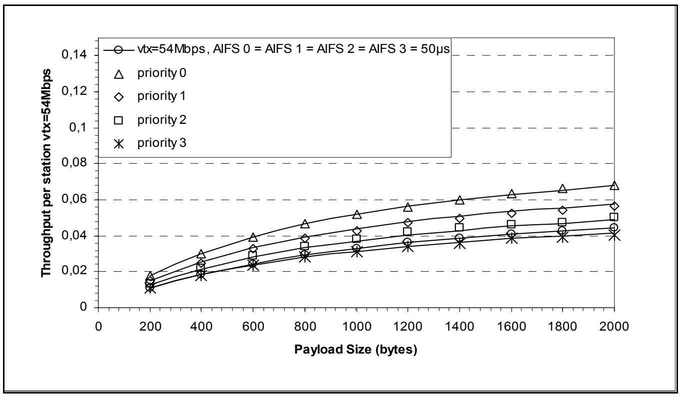

Figure 6. Throughput per station vs. payload size, for different priority levels and transmission rate of 54 Mbps

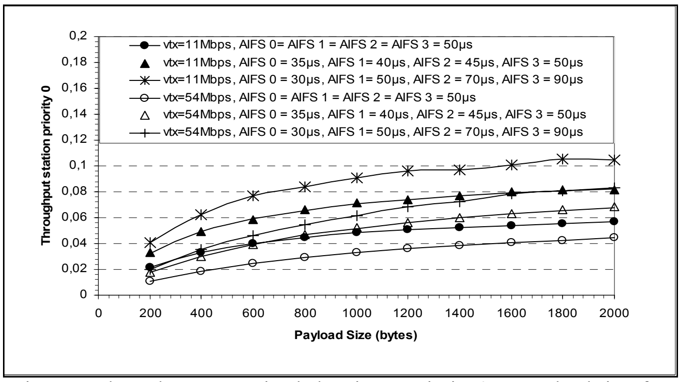

Figure 7. Throughput per station belonging to priority 0 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

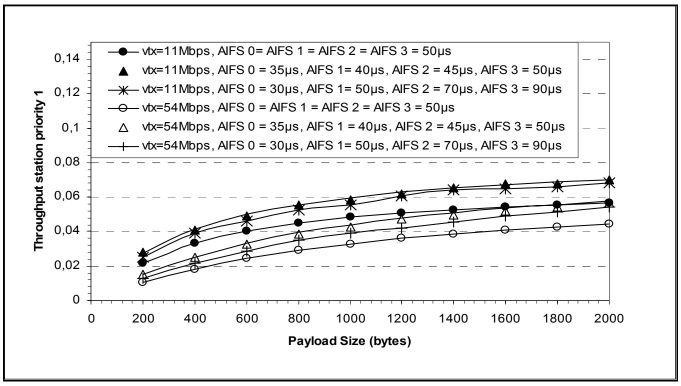

Figure 8. Throughput per station belonging to priority 1 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

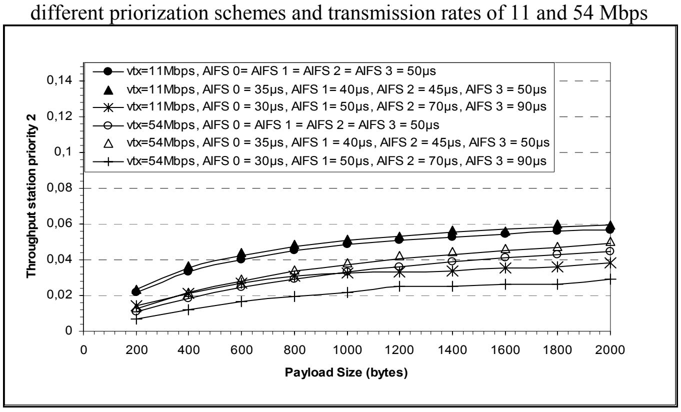

Figure 9. Throughput per station belonging to priority 2 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

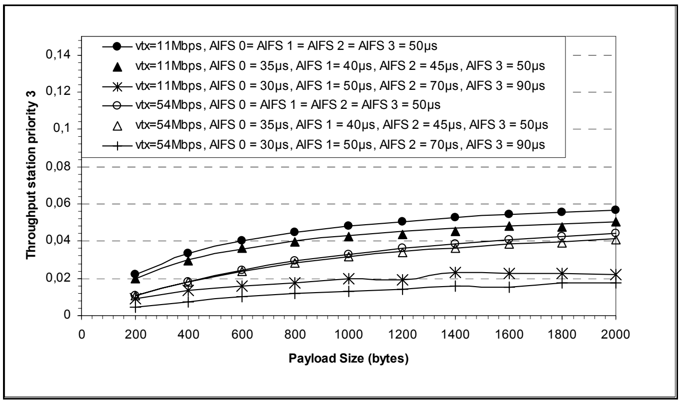

Figure 10. Throughput per station belonging to priority 3 vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

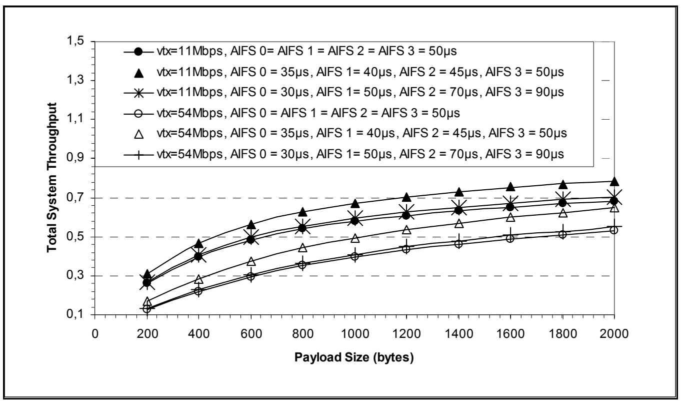

Figure 11. Total system throughput performance vs. payload size, for different priorization schemes and transmission rates of 11 and 54 Mbps

VII. Conclusions

Up to the present, several papers have been written on different aspects of IEEE 802.11 networks. Different mechanisms that provide priorization of stations or classes of service have been evaluated. Nevertheless, the studies performed on the assignment of the AIFS times defined in IEEE 802.11e reveal that different priority levels work in a synchronized way. This situation produces collisions between the transmissions of high priority frames with backoff time and of lower level frames without backoff time. Moreover, recent studies have shown that under high loads of high-priority traffic, EDCA starves low-priority frames.

We propose a mechanism based on the desynchronization of the IEEE 802.11e working procedure: it avoids that stations belonging to different priority classes attempt for transmission simultaneously. The results show that this proposal leads to a reduction in the total collision time, and, in this way, the mechanism described achieves a higher system throughput performance. Moreover, it avoids the strangulation of low priority traffic, fact that occurs when employing the IEEE 802.11e EDCA.

Nevertheless, a modification of the CCA (Clear Channel Assessment) algorithm is necessary, in order to implement the differentiation mechanism proposed in real hardware. This algorithm is the functional block to determine the channel status. In this way, a reduction of the CCA Time is needed, in order to allow the employment of the AIFS times used by our differentiation proposal.

Acknowledgments

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