Analysis of priority mechanisms based on differentiated Inter Frame Spacing in CSMA-CA

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***Abstract*— A number of service differentiation mechanisms have been proposed for, in general, CSMA-CA systems, and, in particular, the 802.11 Enhanced Distributed Coordination Function. An effective way to provide prioritized service support is to use different Inter Frame Spaces (IFS) for stations belonging to different priority classes. This paper proposes a novel analytical approach to evaluate throughput and delay performance of IFS based priority mechanisms.**

I. Introduction

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol is an old Medium Access Control (MAC) mechanism, which has recently received significant research attention due to its application in the IEEE 802.11 MAC protocol for wireless local area networks [1]. A challenging issue is to provide differentiated levels of service support on top of a CSMA-CA based MAC protocol, in order to meet different quality of service requirements for different carried traffic. Part of the activities carried out in the 802.11 Task Group "e" concern the proposal of priority mechanisms for the 802.11 Distributed Coordination Function (DCF), aimed at the definition of an Extended DCF with mechanisms for differentiated service support [2].

A number of independent priority mechanisms have been considered throughout the evolution of the (still ongoing) EDCF specifications. An analytical model able to account for different values of the minimum/maximum contention windows, as well as different persistence factors, has been proposed in [3]. In this work we focus on priority mechanisms for CSMA-CA based on different Inter Frame Spacing (in what follows referred to as IFS-based priority mechanisms). The performance evaluation of IFS-based mechanisms, when applied to the IEEE 802.11 DCF, has been mainly carried out by means of simulation [4], [5]. A first attempt to analytically model these mechanisms appears in [6]: the proposed model is very simple and appealing, though the memoryless assumption does not allow to account for exponential backoff details. A more complex tridimensional Markov chain model has been proposed in [7]. This work extends our previous work [8] by adding a further state to the Markov chain to model different IFS for different prority classes. However, it also inherits from [8] the simplificative assumption of a constant probability to access the channel in a given time slot. When applied to IFS-based mechanisms, such a simplificative assumption does not allow to obtain results consistently accurate for all the possible scenarios (for an extreme example, the model fails when the difference between the IFS of two classes is greater than the minimum contention window).

In this work, we propose a new analytical approach to model IFS-based priority mechanisms applied to CSMA-CA with exponential backoff. The proposed model significantly differs from any other model appeared in the literature, including our own model [8]. The rest of this paper is organized as follows. Section II describes the IFS-based priority mechanism considered. The system model and the model time scales that enable our analysis are introduced in Section III. Section IV presents the details of the analytical derivation. Numerical results are presented in Section V. Finally, concluding remarks are given in Section VI.

II. IFS-based priority mechanisms

Prioritized channel access based on different Inter Frame Spaces (IFS) is a key component[1] of the Enhanced Distributed Coordination Function (EDCF), currently under standardization in the IEEE 802.11 task group e [2]. The idea of IFS-based priority schemes is to differentiate priority classes on the basis of their channel monitoring parameters.

We recall that, in CSMA-CA, no form of centralized channel access coordination is provided. A station with a packet to transmit monitors the channel activity until an idle period equal to a distributed inter-frame space (DIFS) is detected. To avoid transmission synchronization after busy periods, a further slotted delay (backoff) is randomly chosen in the range [0, $W-1$] slot-times, where W is called contention window. The backoff counter is decremented at every idle slot-time occurring on the channel. If the channel is sensed busy during a slot-time, the backoff counter is frozen until the medium is sensed idle again for a DIFS period. When the backoff counter reaches zero, the station is allowed to access the channel and transmit its packet. If successful reception occurs, the destination station responds, after a short inter-frame space (SIFS), with an acknowledgement packet. Since SIFS $<$ DIFS, no other stations will be able to access the channel between the data and the ACK packets.

IFS-based priority mechanisms rely on the above described channel access mechanism, but adopt, instead of a common DIFS for all competing stations, different Inter Frame Space values. More into details, and following the notation used in [2], competing stations are divided into Traffic Categories. Within each traffic category TC, a station may access the channel (with the usual backoff rules) only if the channel is sensed idle for a period equal to an Arbitration InterFrame Space, different for each considered traffic category (AIFS[TC]). To maintain slot-time synchronization, it is convenient to differentiate AIFS settings for different traffic categories of an integer number of slot-times. For example, a possible setting is AIFS[TC] = DIFS + TC $\cdot\sigma$, where σ is the slot-time duration (a thorough and wider discussion on timing relationships can be found in [2]). This implies that, in the first slot-time after a DIFS, only stations with TC=0 may access the channel; in the second slot-time both stations with TC=0 and TC=1 may access the channel and so on.

Although, at a first superficial analysis, the described operation might appear as a weak way to provide priorities (especially if the contention window is large), this is indeed not the case. In fact, when the number of competing stations is large, the average number of slot-times between two consecutive packet transmissions gets small, and thus stations with lower TC value will have an increased probability of accessing the channel versus stations with an high TC value. Clearly, note that IFS-based priority does not give absolute guarantees on throughput/delay performance, but only relative differentiation among service classes.

[1] other priority mechanisms considered in EDCF are the adoption of different backoff parameters for different traffic categories (specifically, different settings of CW_{min}, CW_{max}, and CW updating exponential factor - this last parameter being also called persistence factor pf has been abandoned in newer versions of the EDCF draft standard).

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III. System Model and Time Scales

As evident from [8], a key factor enabling the thorough analytical modeling of CSMA-CA is the proper definition of a discrete time scale. In the case of IFS-based priority mechanisms, this is even more true. We here propose to use different discrete time scales, not only for each different priority class, but also for each different memory process (backoff counter, backoff stage) involved in the model.

A. Backoff Parameters

To avoid formal complications in the presentation, in the following we consider only two different service classes, identified as class 1 and class 2 (the generalization to multiple service classes being straightforward). Each priority class $q \in (1, 2)$ is characterized by a different set of MAC parameters

- w_q = minimum contention window for priority class q;
- pf_q = persistence factor (exponential updating rule) for the contention window for priority class q (the parameter pf allows to trivially generalize the analysis to the case of non binary exponential backoff);
- m_q = maximum backoff stage for priority class q.

These parameters are used as follows. In the assumption of saturation conditions [8], each transmission attempt is subject to the backoff rules. At the first transmission attempt, a station in class q chooses an integer random value b in the range $[0, w_q - 1]$. This value is referred to in what follows as "backoff counter", and decrements according to the rules explained in the next subsection. When the backoff counter decrements to 0, the station is allowed to transmit. If the transmission is unsuccessful, the station extracts a new backoff counter in the range $[0, pf_q \cdot w_q - 1]$. We refer to the station as being in "backoff stage" 1. In general, a station in backoff stage s extracts the new backoff counter in the range $[0, W_q(s) - 1]$, where $W_q(s) = w_q * pf_q^s$. The backoff stage is incremented up to m_q after each transmission failure and it is reset to 0 after a successful transmission. Once the station reaches the maximum backoff stage, after each subsequent collision the backoff counter is extracted in the range $[0, W_q - 1]$, being $W_q = w_q \cdot pf_q^{m_q}$ the maximum contention window for the class q. For convenience, we do not consider in this paper an explicit frame retry limit - though its inclusion in the model is straightforward, see [9] and the following footnote 3.

In addition, each priority class is characterized by a different Arbitration Inter Frame Space, $AIFS_q$. Let σ be the slot-time duration. We recall that, for each Traffic Category TC, $AIFS[TC] = DIFS + \sigma \cdot TC$. With specific reference to the two priority classes considered in the paper, in what follows, we make the non-restrictive assumption $AIFS_1 \leq AIFS_2$, and we define Δ to be the integer number of slot-times σ (eventually zero) between the $AIFS_2$ and $AIFS_1$ sizes.

B. Backoff Timing

Let us now discuss the backoff timing adopted in this paper. In the derivation of the model, following [10], and unlike [8], we consider that whenever a station finds a busy slot, it does not decrement the backoff counter.

More into details, assume that a station of class q has a backoff counter equal to b at the beginning of a slot-time. If the current slot-time is idle, at the end of the slot-time the backoff counter is decremented, and the station will start the next slot-time with backoff value $b - 1$. If the current slot-time is busy (because another station is transmitting), the station freezes the backoff counter to the value b. As soon as the channel transmission ends, the considered station waits for a $AIFS_q$ time, after which de-freezes the backoff counter.

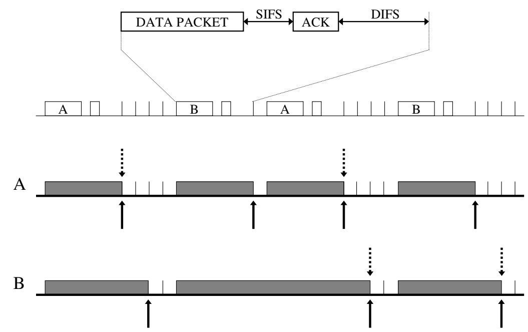

Fig. 1. Discrete time scale for backoff counter and backoff stage processes

The station will thus start the slot-time immediately following the $AIFS_q$ with the same value b for the backoff counter, and this value will be decremented only at the end of the slot-time, if idle.

This described model for the backoff modeling requires some supplementary comments. Different interpretation of backoff freezing have lead in the past to different analytical and simulation models of CSMA-CA appeared in the literature. A first possible interpretation is that the backoff counter is decremented at the *beginning* of a slot-time, but a transmission may occur only in the next slot-time. This implies that, during a busy slot, the backoff counter is decremented. We have relied on such an interpretation in our previous work [8]. The same interpretation has been explicitely clarified and considered in the latest version of the 802.11e draft standard [2]. A second interpretation, more conforming to the 802.11 DCF standard is the one described above, i.e. that of a discrete-time counter, decremented only at the end of a slot-time detected idle, and not decremented during a busy slot-time. This backoff timing model was first assumed in [10], and will be also adopted throughout this paper *regardless of the AIFS value*[2].

C. Time Scales

References [8], [10], [3] model the memory of the 802.11 backoff mechanism by using a bidimensional state space: the backoff counter and the backoff stage. The adoption of different IFS values introduces a further memory effect, which may be accounted for by adding a further dimension to the state space [7]. The model presented in this paper properly defines the time scales so that each memory effect (backoff counter, backoff stage, IFS value) can be independently accounted for.

Let us focus on a specific stantion. For this station, we model the backoff counter $b(t)$ as a discrete-time embedded Markov chain, sampled at the instants of time t representing the the beginning of the slot-time immediately following a generic busy slot. Instead, we model the backoff stage $s(T)$ for the considered station as a discrete-time embedded Markov chain sampled at the instants of time T representing the beginning of the slot-time immediately following a packet transmission from the considered station.

Figure 1 represents the resulting discrete time scale for two stations A and B which share the channel. Station B is assumed to have

[2]We remark that a model closer to the current EDCF specification should distinguish the case of AIFS=DIFS, for which the backoff counter is decremented at the end of the slot, from the case AIFS>DIFS, for which the opposite interpretation applies. We have decided to rely on a single homogeneous backoff timing model to avoid confusion and avoid additional complexity in the presentation

an AIFS time equal to a DIFS plus two time-slots, while station A is assumed to have AIFS=DIFS. The dashed arrows on the top of each plot indicate the time instants in which the backoff stage process evolves, while the solid arrows on the bottom indicate the time instants in which the backoff counter process evolves. Note that for each station, the evolution times are completely independent. Also, note that the proposed time scale depends on the AIFS value considered for the station. For example, the instant of time in which station B may start decrementing its backoff counter process $b(t)$ is two channel slots apart from the corresponding instant of time for station A. Also, the figure shows that one time step, for station B, may include several transmission events.

IV. Analytical Model

Let n_1 and n_2 be the number of stations belonging to, respectively, class 1 and 2. Let $n_1, n_2 \neq 0$. Assume that all competing stations are in saturation conditions [8], meaning that they always have a packet available in the transmission buffer.

Let us first focus on a specific class 1 station (tagged station). Let $B_1(i)$, $i \in (0, W_1 - 1)$, be the steady-state probability that, at a random time instant t, defined as in section III-C, the backoff counter is found in state i, and let $S_1(j)$, $j \in (0, m_1)$, be the steady-state probability that, at a random time T (also according to the definition provided in section III-C), the backoff stage is found in state j. For convenience of notation, let $\beta_q(i) = \sum_{j=0}^{i} B_q(j)$ be the cumulative distribution of the steady-state backoff distribution for class q.

Given that, at time t, the tagged station is in backoff state $b > 0$, the probability that the next busy slot will be used by the tagged station itself for transmission is given by the probability that no other station transmits in any intermediate slot. If $b > \Delta$, this event occurs if all the other stations of class 1 have a backoff counter greater or equal to b, and all the other stations of class 2 have a backoff counter greater or equal to $b - \Delta$:

$$Q_1(b) = [1 - \beta_1(b-1)]^{n1-1} \cdot [1 - \beta_2(b-1-\Delta)]^{n_2} \quad (1)$$

If $0 < b \leq \Delta$, stations belonging to class 2 cannot access the channel before the occurrence of the tagged station transmission. Hence, the probability that the tagged stations transmits in the next busy slot is:

$$Q_1(b) = [1 - \beta_1(b-1)]^{n1-1} \quad (2)$$

Finally, if $b = 0$, the tagged station transmits in the next slot with probability $Q_1(0)$ equal to 1. Hence, the unconditional probability that the tagged station transmits in a generic busy slot is obtained as:

$$\tau_1 = \sum_{i=0}^{W_1-1} B_1(i) Q_1(i) \quad (3)$$

Let us define with $Pr_1\{i\}$ the probability that, at steady state, the tagged station extracts a backoff value i after a *generic* transmission. This probability distribution in turns depends on the (still unknown) steady state probability $S_1(j)$ to find the tagged station in backoff stage j, with $j \in (0, \cdots, m_1)$. Specifically,

$$Pr_1\{i\} = \sum_{j=\lceil log_{pf_1}(\lceil (i+1)/w_1 \rceil) \rceil}^{m_1} \frac{S_1(j)}{w_1 \cdot pf_1^j} \quad (4)$$

where this equation simply accounts for the fact that a station with backoff stage j extracts a backoff counter i, with $i < w_1 \cdot pf_1^j$, with probability $1/(w_1 \cdot pf_1^j)$, and that backoff counters greater or equal than $w_1 \cdot pf_1^j$ can be extracted only if the backoff stage is greater than j (for an extreme example, the maximum backoff counter value $W_1 - 1$ can be extracted only if the backoff stage is equal to m_1, while the minimum backoff counter value 0 can be extracted from each backoff stage).

Let us now consider a tagged station found, at time t (defined according to section III-C), in backoff state $b > 0$. This can occur either because, during the previous busy slot, the station has transmitted and a backoff value b has extracted (this occurs with probability $\tau_1 \cdot Pr_1\{b\}$), or because the tagged station at the previous instant of time was in state $b + i$, and exactly i idle slot-times have elapsed. Thus, at steady state, the following probability flow balancing equations hold ($b > 0$):

$$B_1(b) = \tau_1 Pr_1\{b\} + \sum_{i=0}^{W_1-1-b} B_1(b+i) \cdot [Q_1(i) - Q_1(i+1)] \quad (5)$$

The case $b = 0$ can occur only if, during the last busy slot, the station has transmitted and it has selected a new backoff value equal to 0. In fact, if the backoff reaches 0 because the backoff timer expires, the station transmits its packet and a new backoff value must be selected. Thus:

$$B_1(0) = \tau_1 Pr_1\{0\}$$

The previous equations can be triangularized as follows:

$$\begin{cases} B_1(W_1-1) = \frac{\tau_1 Pr_1\{W_1-1\}}{Q_1(1)} \\ B_1(W_1-2) = \frac{\tau_1 Pr_1\{W_1-2\}}{Q_1(1)} + B_1(W_1-1)T_1(1) \\ \cdots \\ B_1(1) = \frac{\tau_1 Pr_1\{1\}}{Q_1(1)} + B_1(2)T_1(1) + ..B_1(W_1-1)T_1(W_1-2) \\ B_1(0) = \tau_1 Pr_1\{0\} \\ \sum_{i=0}^{W_1-1} B_1(i) = 1 \end{cases} \quad (6)$$

where $T_1(i) = Q_1(i) - Q_1(i+1)$ is the probability that the next transmission occurs exactly after i idle slots. Note that the τ_1 definition given in (3) corresponds to the normalization condition for the $B_1(b)$ probabilities.

To complete the system, it remains to find the steady-state distribution of the backoff stage process. Let p_1 be the probability that a collision occurs upon packet transmission (i.e. the conditional collision probability defined in [8]). Since the (unconditional) probability that the tagged station transmits in the next slot and the packet collides is easily expressed as:

$$PC_1 = \sum_{i=0}^{W_1-1} B_1(i) T_1(i) \quad (7)$$

then, p_1 can be obtained as $\frac{PC_1}{\tau_1}$. By considering the specific backoff rules adopted in the paper[3], we can express $S_1(i)$ as:

$$S_1(i) = \begin{cases} (1-p_1)p_1^i & 0 \leq i < m_1 \\ p_1^{m_1} & i = m_1 \end{cases} \quad (8)$$

Finally, similar relations can be obtained by considering a tagged station of class 2. Clearly, the embedding times of the specific markov chain for a class 2 station will be defined as the times immediately following a busy slot plus Δ idle slot-times. The only difference from the previous equations is the computation of the $Q_2(b)$ probabilities. In fact, we have to take into account that backoff evolution for class 2 occurs after Δ idle time-slots from the last time instant of class 1 backoff updating. Then, $Q_2(b)$ is the probability that all the other class 2 stations have backoff counter greater or equal to b and all class 1 stations have backoff counter greater or equal to $b + \Delta$, given that

[3] Note that, in order to extend the proposed approach to different backoff rules (e.g. finite retry limits, different backoff models, etc), it is just sufficient to modify the following equation 8.

such backoff counters are greater or equal to Δ. Assuming $\beta_1(-1)$ equal to zero to include the case $\Delta = 0$, for $b > 0$ we have:

$$Q_2(b) = [1-\beta_2(b-1)]^{n2-1} \cdot [1 - \frac{\beta_1(b-1+\Delta) - \beta_1(\Delta-1)}{1-\beta_1(\Delta-1)}]^{n_1} \quad (9)$$

Also in this case, the probability $Q_2(0)$ is equal to 1.

On the basis of the $Q_2(.)$ distribution, equations (6), (4), (7), and (8) can be rewritten for class 2 stations. If we consider a common system for the B_1, Q_1, Pr_1, S_1, and B_2, Q_2, Pr_2, S_2 distributions together with normalization conditions and PC_q definitions, we obtain a system of $2(W_1 + m_1 + W_2 + m_2 + 2)$ non linear equations in the same number of unknown parameters, which can be numerically solved. Throughput/delay performance figures are then readily computed as shown in the next section. Extension to further priority classes is straightforward, though at the price of a slight increase of the computational complexity (considering that $W_q \gg m_q$, the computational complexity depends on the sum of the W_q).

A. Throughput and Delay

Let Thr_q be the total normalized throughput for stations belonging to class q. To compute Thr_q, let us analyze what happens in each time step corresponding to class 1 temporization (we recall that $AIFS_1 \leq AIFS_2$). According to our time scale choice, in each time step at least a packet transmission occurs. Before the transmission, the channel is silent for a given number ψ of backoff time-slots. The packet transmissions can be originated either by class 1 and by class 2 stations (if ψ is greater than Δ). In particular, the transmission frequency of a class 1 station is τ_1, while the transmission frequency of a class 2 station (referred to the common class 1 temporization) is $\tau_2 \cdot [1-\beta_1(\Delta-1)]^{n_1}$. It follows that the fraction of transmissions originated by class 1 stations is:

$$P_{tr1} = \frac{n_1\tau_1}{n_1\tau_1 + n_2\tau_2 \cdot [1-\beta_1(\Delta-1)]^{n_1}}$$

while the fraction P_{tr2} of transmissions originated by class 2 stations is obviously $1 - P_{tr1}$. For service class 1, the frequency of a successful transmission is:

$$P_{s1} = n_1 \sum_{b=0}^{W-1} B_1(b)Q_i(b+1) = n_1(\tau_1 - PC_1)$$

For service class 2, the same relation must be conditioned by the event of no transmission by class 1 during Δ time-slots:

$$P_{s2} = n_2(\tau_2 - PC_2)[1-\beta_1(\Delta-1)]^{n_1}$$

The success conditional probability P_{sc_q} (i.e. the probability to have a success given that a transmission occurs) is simply P_{s_q}/P_{tr_q}. On the basis of P_{sc_q} and P_{tr_q}, it is possible to express Thr_q as the ratio:

$$Thr_q = \frac{E\{payload\,information\;by\;class\;q\;in\;a\;time\;step\}}{E\{time\;step\}} \quad (10)$$

In fact, being $E[P]$ the average packet payload size, the average amount of payload information successfully transmitted in a time step is $P_{tr_q}P_{sc_q}E[P]$ for each service class. The average time step duration is given by:

$$\begin{aligned} E[time\;step] = E[\psi]\sigma + [P_{tr1}P_{sc1} + P_{tr2}P_{sc2}]T_s + \\ +[P_{tr1}(1-P_{sc1}) + P_{tr2}(1-P_{sc2})]T_c \end{aligned} \quad (11)$$

where T_s is the average time the channel is busy because of a successful transmission, T_c is the average time the channel is busy during a collision, and σ is the duration of backoff slot-time. T_s and T_c expression in function of MAC parameters and packet payload length for both basic access and RTS/CTS access are given in [8]. To complete the throughput evaluation, we have to compute the average ψ value. Note that in each slot, ψ can assume values in the range $[0, min(W_1-1, W_2-1+\Delta)]$. Its probability distribution can be easily expressed as a function of the $Q_1(b)$ probabilities (considering $\beta_1(-1) = 0$):

$$Pr\{\psi = b\} = [1-\beta_1(b-1)]Q_1(b) - [1-\beta_1(b)]Q_1(b+1) \quad (12)$$

The previous equation represents the probability that no station transmits in the first $b-1$ slots minus the probability that no station transmits in the first b, i.e. the probability that next transmission exactly occurs after b idle slots. For $b > min(W_1-1, W_2-1+\Delta)$, $Pr\{\psi = b\}$ is equal to zero because at least one station has expired its backoff counter with probability 1 within $min(W_1-1, W_2-1+\Delta)$ slots.

The average access delay performance, i.e. the average time T_q elapsing between the instant of time the packet is put in the head-of-line position of the transmission buffer of a class q station, and the instant of time the packet is successfully transmitted, is trivially computed, owing to the Little's Result, as:

$$T_q = \frac{E[time\;step]}{P_{sc_q}P_{tr_q}} \cdot n_q \quad (13)$$

V. Model validation

In this section we provide a comparison between analysis and simulation results. To this purpose, we developed a C++ event-driven simulator which implements all the details of the DCF access mechanism with heterogenoues MAC parameter settings. For each service class q, it is possibile to specify different W_q, m_q, pf_q, and $AIFS_q$ values. To enlight the effects of the only IFS differentiation, we considered uniform settings for the other MAC parameters, namely: $W_1 = W_2 = 32$, $m_1 = m_2 = 5$, $pf_1 = pf_2 = 2$. System performance are expressed in terms of saturation throughput and service delay. As we saw in the previous section, these figures are derived from the backoff counter distribution and from the idle slots ψ distribution. Figure 2 shows an example of backoff counter distibution. The example refers to a scenario in which 5 High Priority (HP) stations share the channel with 10 Low Priority (LP) stations. HP stations adopt an IFS time equal to a DIFS, while LP stations adopt an IFS time equal to a DIFS + 3 time slots ($\Delta = 3$). The figure plots two distributions related to a target HP station and to a target LP station. Lines represent analytical results, while points represent

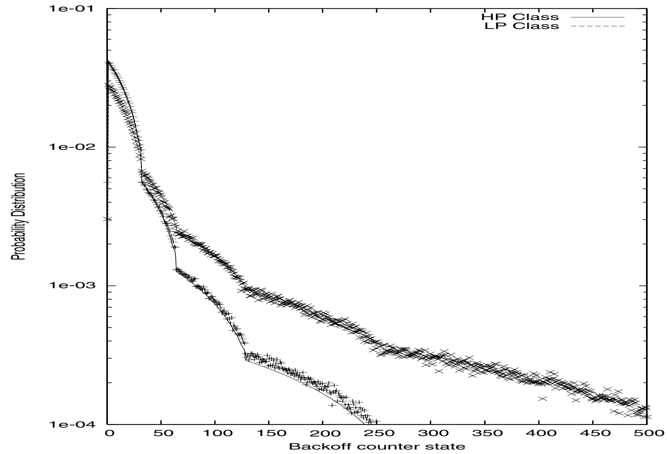

Fig. 2. Analysis vs. Simulation: backoff counter distribution

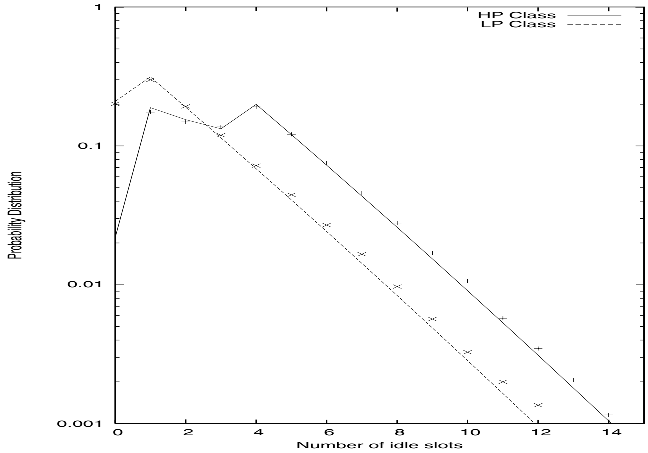

Fig. 3. Analysis vs. Simulation: observed channel silence

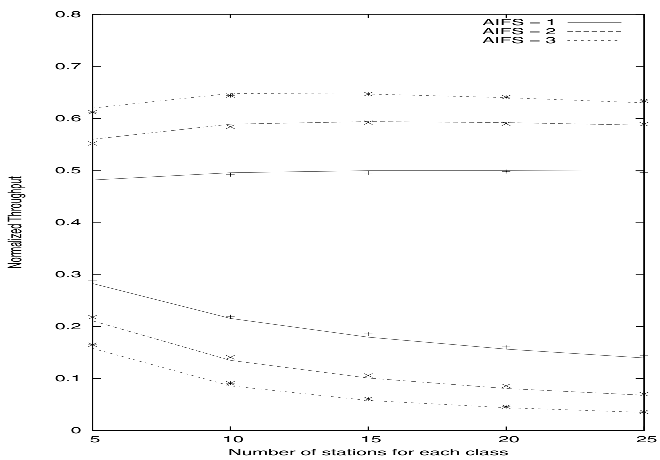

Fig. 4. Analysis vs. Simulation: saturation throughput differentiation

simulation ones. Analysis/simulation agreement is remarkable. Note that, for each class, backoff counter distributions are made up of linear tracts with different slopes. Slope variations occurs for every backoff value which implies a contention window increment with respect to the previous one (i.e. for $B_q = 32, 64, 128..$). For the same scenario, figure 3 plots the idle slots ψ distribution observed by a target HP and a target LP station. For $\psi > \Delta$, LP and HP stations see the same channel conditions, but the number of counted idle slots differ exactly of Δ. We see that LP distribution is parallel to HP ditribution segment starting from $\psi = 3$. For $\psi < 3$, HP distribution segment depends on the only HP stations. Since the distributions obtained via simulations are quite close to the ones obtained via analysis, we aspect that also performance figures agree. We run some simulations considering an equal number of LP and HP stations in the network. Figure 4 plots the total saturation throughput obtained for each service class in the case of basic access. The curves on the top represent HP throughput, while the curves on the bottom represent LP throughput. Curves of the same type refer to the same simulation, in which Δ is indicated in the legend. As shown in previous works [8], the number of stations in the network is a very critical parameter for system performance. However, we see that, as the number of stations increases, IFS time differentiation allows to attribute performance degradations mostly to LP stations. The same considerations are valid for the access delays illustrated in figure 5.

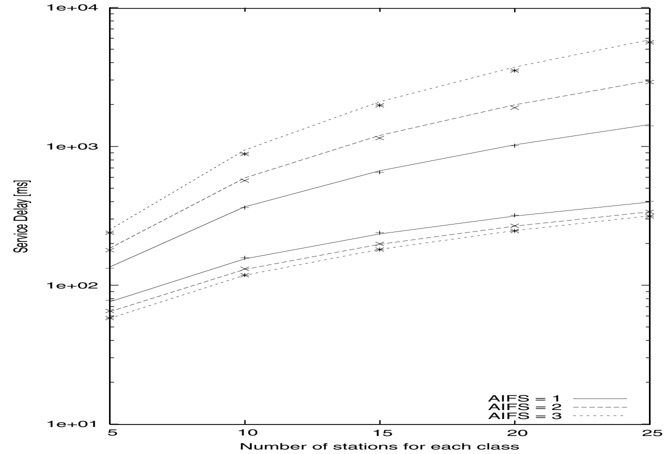

Fig. 5. Analysis vs. Simulation: delay differentiation

VI. Conclusions

We have proposed a novel mathematical model to evaluate the throughput/delay performance of CSMA-CA with IFS-based priorities. Unlike all the previous work in the field, the model does not rely on multi-dimensional Markov chains. In addition, the model is extremely accurate, regardless of the system parameters. As a side effect, if applied to legacy DCF, it can be considered as a significant modeling improvement with respect to our previous work.

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