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A Throughput and Delay Model for IEEE 802.11e EDCA Under Non Saturation

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Abstract. In this paper, we present a model to analyze the throughput and delay performance of the EDCA mechanism under non saturation conditions. The main strength of our model is that it can be used to analyze generic source models, as it neither makes any assumption on the source's arrival process nor requires all packets be of the same length. Simulation results confirm the accuracy of our model under a variety of realistic source models, including (i) typical arrival processes for voice, video, and data traffic, and (ii) packet length distributions derived from measurements.

Keywords: WLAN, 802.11e, EDCA, delay analysis, throughput analysis, non saturation

1. Introduction

In recent years, much interest has been devoted to the design of wireless local area networks (WLAN's) with Quality of Service (QoS) support. The Enhancements Task Group (TGe) was formed under the IEEE 802.11 Working Group to recommend an international WLAN standard with QoS support. This standard is called 802.11e and has been recently approved [1]. The standard defines two different access mechanisms: the *Enhanced Distributed Channel Access* (EDCA) and the *HCF Controlled Channel Access* (HCCA). Our focus here is on the former.

To date, there has been a remarkable amount of work to evaluate the throughput performance of 802.11e EDCA analytically. However, most of the existing analyses [2–8] are based on the unrealistic assumption that all stations always have packets ready for transmission. This is commonly referred to as *saturation conditions*. In this paper, we propose a novel model for EDCA that, unlike these analyses, does not assume saturation conditions but works for finite loads.

Although some previous analyses of non saturated WLANs have been proposed in the literature [9–13], these are typically valid only for Poisson arrivals and restricted to fixed length packets. In contrast to these previous papers, our analysis here does not make any assumption on the arrival process and allows for variable packet lengths. Indeed, our simulation results, which are based on different arrival models and variable packet lengths, show the validity and accuracy of our analysis under such conditions.

The rest of the paper is structured as follows. In Section 2, we briefly summarize the 802.11e EDCA mechanism. In Section 3, an analysis of the throughput and delay performance of EDCA under non saturation traffic conditions is presented. The accuracy of the presented analysis is validated by the simulations results presented in Section 4. Finally, the paper closes with some final remarks in Section 5.

2. 802.11e EDCA

This section briefly summarizes the EDCA mechanism as defined in the 802.11e standard. EDCA controls the access to the wireless channel on the basis of the Channel Access Functions (CAF's). To transmit its frames, each CAF executes an independent backoff process which is regulated by a number of configurable parameters. For the configuration of these parameters, the standard groups the CAF's by Access Categories (ACs) and assigns the same configuration to all the CAF's of an AC. In this paper, we assume for simplicity that each station runs only one CAF and use indistinctly the terms CAF and station.[1]

A station of an Access Category i (AC_i) with a new frame to transmit monitors the channel activity. If the channel is idle for a period of time equal to the arbitration interframe space parameter of this AC ($AIFS_i$), the station transmits. Otherwise, if the channel is sensed busy (either immediately or during the $AIFS_i$ period), the station continues to monitor the channel until it is measured idle for an $AIFS_i$ time, and, at this point, the backoff process starts. The $AIFS_i$ takes a value of the form $DIFS + n\sigma$, where DIFS and σ are constants dependent on the physical layer and n is a nonnegative integer.[2]

Upon starting the backoff process, the station computes a random value uniformly distributed in the range $(0, CW_i - 1)$, and initializes its backoff time counter with this value. The CW_i-value is called the contention window, and depends on the number of transmissions failed for the frame. At the first transmission attempt, CW_i is set equal to the minimum contention window parameter (CW_i^{min}). As long as the channel is sensed idle the backoff time counter is decremented once every time interval σ. When a transmission is detected on the channel, the backoff time counter is "frozen", and reactivated again after the channel is sensed idle for a certain period (equal to $AIFS_i$ if the transmission is received with a correct CRC, and equal to $EIFS - DIFS + AIFS_i$ otherwise).

As soon as the backoff time counter reaches zero, the station transmits its frame in the next slot time. A collision occurs when two or more stations start transmission simultaneously. An acknowledgement (Ack) frame is used to notify the transmitting station that the frame has been successfully received. If the Ack is not received within a given timeout, the station assumes that the frame was not received and reschedules the transmission by reentering the backoff process. After each unsuccessful transmission CW_i is doubled, up to a maximum value given by the CW_i^{max} parameter. If the number of failed attempts reaches a predetermined retry limit R, the frame is discarded. Once the backoff process is completed (either successfully or unsuccessfully), CW_i is set again to CW_i^{min}.

When the station gains access to the channel, it is allowed to retain the right to access it for a duration equal to the transmission opportunity limit parameter ($TXOP\_limit_i$). If this parameter is set to zero, a station is allowed to transmit only one packet upon accessing the

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[1] Note that, following the lines of [7], the analysis here could easily be extended to the case of multiple CAF's per station.

[2] According to the IEEE 802.11e standard terminology, $AIFS_i = SIFS + n\sigma$, where $DIFS = SIFS + 2\sigma$ and $n \geq 2$. Without loss of generality, in this paper we use the simplified notation $AIFS_i = DIFS + n\sigma$, with $n \geq 0$.

channel. In the rest of this paper, we assume this setting for the TXOP_limit$_i$ parameter, and concentrate on the analysis of the other three parameters ($\mathrm{CW}_i^{\min}$, $\mathrm{CW}_i^{\max}$ and AIFS_i).[3]

3. Throughput and Delay Analysis

In this section, we consider a WLAN operating under the EDCA mechanism and analyze the throughput and the delay of each AC in the WLAN. The input parameters to our analysis are:

- The number of AC's in the WLAN (which we denote by N).
- The number of stations of each AC (we denote by n_i the number of stations of AC i).
- The average sending rate of the stations of each AC (denoted by ρ_i).
- The configuration $\{\mathrm{CW}_i^{\min}, m_i, A_i\}$ of each AC, where m_i is defined such that $\mathrm{CW}_i^{\max} = 2^{m_i}\,\mathrm{CW}_i^{\min}$ and A_i such that $\mathrm{AIFS}_i = \mathrm{DIFS} + A_i\,\sigma$.

The key approximation upon which we base our analysis is centered on the notion of *saturation rate*. By the saturation rate of an AC we understand the rate that the stations of this AC would obtain if they always had a packet ready for transmission. Based on this, our assumptions are:[4]

- As long as the average sending rate of the stations of a given AC falls below the AC's saturation rate, we assume that the stations of this AC see all their packets served (i.e., their transmission queue never overflows). We refer to such an AC as a *non saturated* AC.
- On the other hand, if the average sending rate of the stations of the AC exceeds the saturation rate, we consider that the stations of this AC always have packets ready for transmission (i.e., their transmission queue never empties). We say that such an AC is *saturated*.

The key variable upon which we build our analysis is τ_i, defined as the probability that a station of AC i transmits upon a backoff counter decrement. In the following, we first analyze separately the τ_i of a saturated AC and the τ_i of a non saturated AC, respectively. Then, we combine both analyses in order to compute the τ_i-values of all the AC's in the WLAN. Finally, based on these values, we calculate the throughput and the delay of each AC.

3.1. Analysis of a Saturated AC

Let us start with the case of a saturated AC [8]. With the assumption of [14] that each transmission attempt collides with a constant and independent probability, we can model the behavior of this AC with the same Markov chain as Figure 5 of [14]. Then, the probability that a station

[3] Note that the impact of the TXOP_limit$_i$ parameter is typically small in realistic scenarios. In fact, for real-time traffic parameters are usually set such that the queue never grows to more than one packet, and therefore this parameter is not used, while for data traffic this parameter is set such that only one packet is transmitted upon accessing the channel, in order to avoid degrading the delay performance of real-time traffic.

[4] Note that, as these assumptions rely on no source property other than the *average sending rate*, our model can be applied to analyze generic source models. The only restriction imposed on the sources is that they be stationary, as otherwise their average sending rate could change over time. Even in that case, our model could be used to analyze each stationary time interval separately.

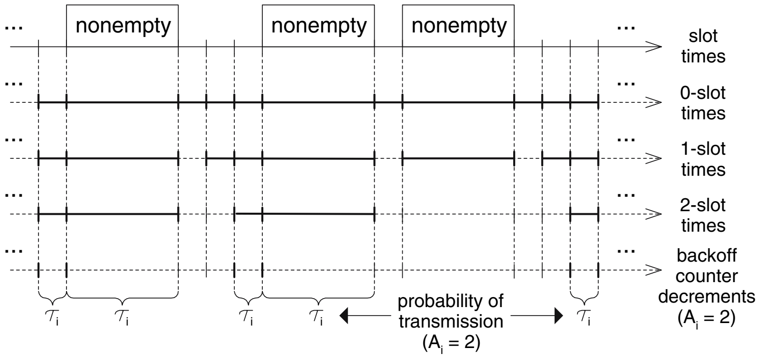

Figure 1. k-slot times and probability of transmission (example with $k = 2$).

of a saturated AC transmits upon a backoff counter decrement can be computed following the well known result of [14],

$$\tau_i^{\text{sat}} = \frac{2(1-2p_i)(1-p_i^{R+1})}{\text{CW}_i^{\min}(1-(2p_i)^{m_i+1})(1-p_i)+(1-2p_i)(1-p_i^{R+1})+\text{CW}_i^{\min}2^{m_i}p_i^{m_i+1}(1-2p_i)(1-p_i^{R-m_i})}, \tag{1}$$

where p_i is the probability that a transmission attempt of a station of AC i collides.

To compute p_i, we proceed as follows. We start by defining a *slot time* as the time interval between two consecutive backoff counter decrements of a station with minimal AIFS_i (i.e., DIFS). We say that a slot time is nonempty when it contains a collision or a successful transmission and that it is empty otherwise.

We further define a *k-slot time* as a slot time that is preceded by k or more empty slot times. Note that, since a station with $A_i = k$ starts decrementing its backoff counter only after k empty slot times following a nonempty slot time, we have that the backoff counter decrements of this station coincide with the boundaries of the *k-slot times*. Therefore, a station of AC i, with $A_i = k$, transmits in a *k-slot time* with probability τ_i, and does not transmit in any other slot time (see Figure 1).

Based on the above definitions, we compute p_i as a function of the probability of an empty *k-slot time* (denoted by $p(e_k)$) as follows. A *k-slot time* is empty as long as (i) the considered station does not transmit, and (ii) no other station transmits. The latter can be expressed as a function of p_i by noting that the probability of a collision corresponds to the case when some other station transmits. Thus,

$$p(e_k) = (1 - \tau_i)(1 - p_i), \tag{2}$$

which yields

$$p_i = 1 - \frac{p(e_k)}{1 - \tau_i}. \tag{3}$$

Now let us focus on the probability that a given *k-slot time* is empty. If the previous *k-slot time* was nonempty, in this *k-slot time* only the AC's with $A_i \leq k$ may transmit. If the previous *k-slot time* was empty, the given *k-slot time* is preceded by $k + 1$ or more empty slot times, which is exactly the definition of (k+1)-*slot time*, and therefore such a *k-slot time* is empty

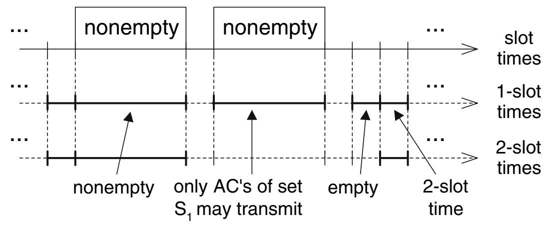

Figure 2. Probability of an empty *k-slot time* (example with $k = 1$).

with probability $p(e_{k+1})$. Applying this reasoning (see Figure 2), $p(e_k)$ can be written as

$$p(e_k) = (1 - p(e_k)) \prod_{j \in AC_k} (1 - \tau_j)^{n_j} + p(e_k) p(e_{k+1}), \tag{4}$$

where AC_k is the set of AC's with $A_i \leq k$.

Let Δ be the largest A_i in the WLAN. As (with this definition of Δ) in a Δ-*slot time* all stations may transmit, the following equation holds

$$p(e_\Delta) = \prod_{j \in AC_\Delta} (1 - \tau_j)^{n_j}. \tag{5}$$

Starting from τ_i $\forall i$, with Eq. (5) we can compute $p(e_\Delta)$. Then, with Eq. (4) for $k = \Delta - 1$, we can compute $p(e_{\Delta-1})$. Applying this recursively, we can compute $p(e_k)$ $\forall k$. Then, p_i can be computed via Eq. (3) and, finally, τ_i^{sat} can be obtained from Eq. (1). As result, we can express the τ_i of a saturated AC, τ_i^{sat}, as a function of all the τ_i's. This terminates the analysis for this case.

3.2. Analysis of a Non Saturated AC

We next focus on the analysis of a non saturated AC. According to our previous assumption, a station of a non saturated AC sees all the traffic it sends served, either because their packets are transmitted successfully or because they are discarded when reaching the retry limit. Hence, the following equation holds,

$$\rho_i (1 - p_i^{R+1}) = r_i, \tag{6}$$

where r_i is the throughput experienced by a station of AC i (i.e., the successful transmission rate), ρ_i is its average sending rate and p_i^{R+1} corresponds to the probability that a packet of this station is discarded upon reaching the retry limit.

The throughput r_i is computed as the average payload information transmitted in a slot time divided by the average duration of a slot time:

$$r_i = \frac{p(s_i) l_i}{p(s) T_s + p(c) T_c + p(e) \sigma}, \tag{7}$$

where l_i is the average packet length of a station of AC i, $p(s_i)$ is the probability that a randomly chosen slot time contains a successful transmission of a station of AC i, $p(s)$, $p(c)$, and $p(e)$ are the probabilities that a slot time contains a successful transmission, a collision or is empty, respectively, and T_s, T_c, and σ are the average slot time durations in each case.

The probability $p(e)$ is, by definition, $p(e_0)$, as all slot times are 0-*slot times*. This has already been computed in Section 3.1.

Let us define p_k as the probability that a slot time is a k-*slot time*. Since a slot time is a k-*slot time* if and only if the previous slot time is a $(k-1)$-*slot time* and it is empty, this probability can be expressed as

$$p_k = p_{k-1} p(e_{k-1}). \tag{8}$$

Starting from $p_0 = 1$ (which holds by definition), it follows

$$p_k = \prod_{j=0}^{k-1} p(e_j). \tag{9}$$

The probability that a random slot time contains a success of a given station of AC i can be computed as

$$p(s_i) = \sum_{k=A_i}^{\Delta} p(AC_k) p(s_i | AC_k), \tag{10}$$

where $p(AC_k)$ is the probability that a randomly chosen slot time is allowed for transmission to only the AC's of set AC_k, and $p(s_i|AC_k)$ is the probability that a slot time in which only the AC's of set AC_k may transmit contains a success of a given station of AC i.

A slot time is allowed for transmission to only the AC's of set AC_k (with $k < \Delta$) if the slot time is a k-*slot time* but not a $(k+1)$-*slot time*.[5] For $k = \Delta$, we have that in a Δ-*slot time* all AC's are allowed to transmit. Thus,

$$p(AC_k) = \begin{cases} p_k - p_{k+1}, & k < \Delta, \\ p_\Delta, & k = \Delta. \end{cases} \tag{11}$$

The probability $p(s_i|AC_k)$ corresponds to the case when the considered station transmits and no other station of set AC_k does:

$$p(s_i|AC_k) = \tau_i (1-\tau_i)^{n_i - 1} \prod_{j \in AC_k \backslash i} (1-\tau_j)^{n_j}. \tag{12}$$

The probability that a slot time contains a success can be computed as the sum of the individual success probabilities:

$$p(s) = \sum_{i \in AC_\Delta} n_i p(s_i). \tag{13}$$

The average duration of a success can be computed according to

$$T_s = \sum_{i \in AC_\Delta} \frac{n_i p(s_i)}{p(s)} T_s^i, \tag{14}$$

[5] Note that a slot time that is a k-*slot time* but not a $(k+1)$-*slot time* is preceded by exactly k empty slot times, and therefore only the AC's with $A_i \le k$ (i.e., the AC's of set AC_k) may transmit in such a slot time.

where T_s^i is the average duration of a success of a station of AC i, which is calculated according to

$$T_s^i = T_{PLCP} + \frac{H + l_i}{C} + SIFS + T_{PLCP} + \frac{ACK}{C} + DIFS, \tag{15}$$

where T_{PLCP} is the Physical Layer Convergence Protocol preamble and header transmission time, H the MAC overhead (header and Frame Check Sequence), ACK the size of the acknowledgement frame, and C is the channel bit rate.

The probability that a slot time contains a collision can be obtained from

$$p(c) = 1 - p(e) - p(s). \tag{16}$$

In order to compute the average duration of a collision, we note that this is given by the largest packet length involved in the collision. Thus,

$$T_c = \sum_{l \in L} \frac{p(c_l)}{p(c)} T_c^l, \tag{17}$$

where $p(c_l)$ is the probability that a slot time contains a collision in which the length of the longest packet involved is equal to l, T_c^l the duration of this collision, and L is the set of all possible packet lengths.

T_c^l is computed as

$$T_c^l = T_{PLCP} + \frac{H + l}{C} + EIFS \tag{18}$$

and $p(c_l)$ as

$$p(c_l) = \sum_{k=0}^{\Delta} p(AC_k) p(c_l | AC_k), \tag{19}$$

where $p(c_l|AC_k)$ is the probability that, given that only stations of set AC_k may transmit, a slot time contains a collision with the longest packet involved of length l.

To obtain $p(c_l|AC_k)$ we proceed as follows: we sweep along all the stations that may transmit and compute the probability that (i) the considered station transmits a packet of length l, (ii) some other station transmits, and (iii) no packet longer than l is transmitted. Let us define S_k as the set of stations of AC_k, τ_j as the probability that station j transmits and $p(t_j = l)$ as the probability that its transmission length is equal to l. Then,

$$p(c_l | AC_k) = \sum_{j \in S_k} \tau_j \, p(t_j = l) p(\text{no } tx > l) p(\text{some } tx), \tag{20}$$

where $p(\text{no } tx > l)$ is the probability that no station of set S_k other than j transmits a packet longer than l, and $p(\text{some } tx)$ is the probability that, given that no station transmits a packet longer than l, at least some other station transmits.

For the computation of $p(\text{no } tx > l)$, we index all the stations and refer with $S_{k,j}$ to the set of stations of S_k with index smaller than j. Then,[6]

$$p(\text{no } tx > l) = \prod_{m \in S_{k,j}} \big(1 - \tau_m p(t_m \geq l)\big) \prod_{m \in S_k \setminus S_{k,j} \cup j} \big(1 - \tau_m p(t_m > l)\big), \tag{21}$$

where $p(t_m > l)$ and $p(t_m \geq l)$ are the probabilities that a transmission of station m is longer than l and longer than or equal to l, respectively.

$p(\text{some } tx)$ is computed as

$$p(\text{some } tx) = 1 - \prod_{m \in S_{k,j}} \frac{1 - \tau_m}{1 - \tau_m p(t_m \geq l)} \prod_{m \in S_k \setminus S_{k,j} \cup j} \frac{1 - \tau_m}{1 - \tau_m p(t_m > l)}. \tag{22}$$

Finally, by combining Eqs. (7)–(22) with Eq. (6), we can express the τ_i of a non saturated AC as a function of all the τ_i's as follows:

$$\tau_i^{\text{nonsat}} = \frac{\rho_i (1 - p_i^{R+1}) \left(p(s)T_s + p(e)T_e + p(c)T_c\right)}{l_i (1 - \tau_i)^{n_i - 1} \sum_{k=A_i}^{\Delta} p(AC_k) \prod_{j \in AC_k \setminus i} (1 - \tau_j)^{n_j}}, \tag{23}$$

which terminates the analysis of a non saturated AC.

3.3. Mixed Saturated and Non Saturated AC's Analysis

We next combine the above analyses in order to obtain all the τ_i's in the WLAN under stationary conditions. Then, we calculate the throughput and delay of each AC based on the obtained τ_i values.

From the above two subsections we have a method to compute the τ_i of a saturated and of a non saturated AC, respectively; the remaining challenge lies in determining which AC's are saturated and which are not. For this, we proceed step by step as follows in order to classify all the AC's into two sets, one set with the saturated AC's and the other with the non saturated ones:

- In the first step, we consider that all AC's are saturated (i.e., they are all in the set of saturated AC's) and compute their saturation throughputs. Note that, from Section 3.1, we can express each τ_i of a saturated AC as a function of all the τ_i's. Therefore, we have a system of N nonlinear equations on the τ_i's that can be resolved using numerical techniques. Once the τ_i-values have been derived, we compute the throughput of all AC's by using Eqs. (7)–(22).[7]
- We next compare the throughputs resulting from the first step against the sending rates. If the throughput of an AC is larger than its sending rate, we consider from this step on that this AC is not saturated, and move it to the set of non saturated AC's. Indeed, such an AC cannot always have packets ready for transmission (and therefore cannot

[6] The distinction in Eq. (21) between the stations of indexes smaller and larger than j is done in order to avoid counting more than once the event when two or more stations transmit a packet of length l.

[7] In Section 3.2, we calculated the τ_i of a non saturated AC by setting the throughput of the AC such that Eq. (6) is satisfied. Note that the part of that section where the throughput is computed as a function of all τ_i's (Eqs. (7)–(22)) does not make any assumption about the status (saturated or not) of the AC, and therefore these equations can also be used to compute the throughput of a saturated AC as a function of all τ_i's.

be saturated), as otherwise it would be sending more packets than those generated by the station.
- In the second step, we take the new sets of saturated and non saturated AC's resulting from the first step and repeat the throughput computation. Note that, from Sections 3.1 and 3.2, we can express the τ_i of a saturated and of a non saturated AC, respectively, as a function of all the τ_i's. Therefore, we have a new system of N nonlinear equations from which we can obtain the τ_i's and the corresponding throughputs.
- In the next step, we compare again the throughputs obtained in the previous step for the saturated AC's against their sending rates, and move those AC's whose throughput is larger than their sending rate to the set of non saturated AC's.[8] After this reorganization of the sets, we repeat the throughput computation.
- The above is done iteratively until the resulting throughputs of all the saturated AC's are smaller than their sending rates. This last scenario represents a stable solution, and therefore the throughput values resulting from this step give us the throughput that each AC will obtain in the WLAN under stationary conditions.

Note that, as number of AC's (N) is limited to 4 by the standard, the above process requires the execution of five steps at most (we start with all AC's saturated, at every step at least one AC becomes non saturated, and in the worst case we stop when all AC's are non saturated). In each step, a system of N equations (i.e., no more than 4) has to be resolved. Therefore the computational cost of the proposed algorithm is reasonably low, as it requires solving no more than five systems of at most four equations. This is confirmed by the quantitative results on computational cost given in the following section.

The above terminates the analysis of the throughputs. For the computation of the delays, we use the delay model of [8], but taking the τ_i-values obtained from the algorithm presented in this section, instead of the τ_i's used in [8] which correspond to saturation conditions.

4. Model Validation

We validated the accuracy of the model by comparing the analytical values against those obtained via simulation. The simulations were performed for a WLAN with the system parameters of the IEEE 802.11b physical layer. We considered the following four AC's (which we name "voice," "video," "data," and "background," respectively):

- In the first AC, 80 byte packets were generated every 10 ms (i.e., at a constant bit rate of 64 Kbps) to model the behavior of a G.711 voice codec.
- In the second AC, we modeled video traffic with a variable bit rate source sending variable size packets with a constant interarrival time. The average bit rate of the source was set equal to 250 Kbps and the packet length distribution was taken from the video traffic measurements of [15].

[8] Note that an AC that was not saturated in the previous step can never become saturated again. In fact, if such an AC always had packets ready for transmission, it would obtain a throughput even larger than in the step where it became non saturated (since in the current step there are fewer saturated AC's). Therefore, it would be sending more packets than those generated.

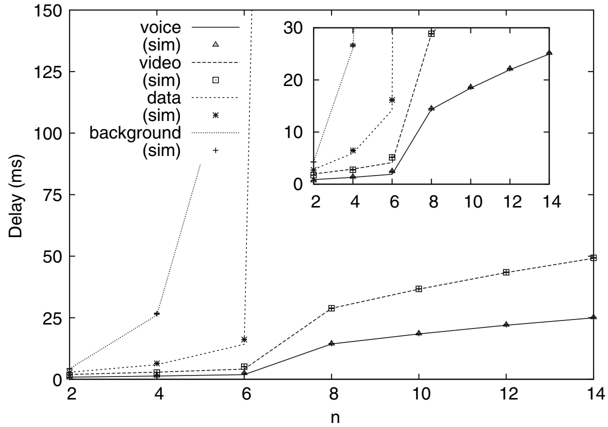

Figure 3. Average delay analysis validation.

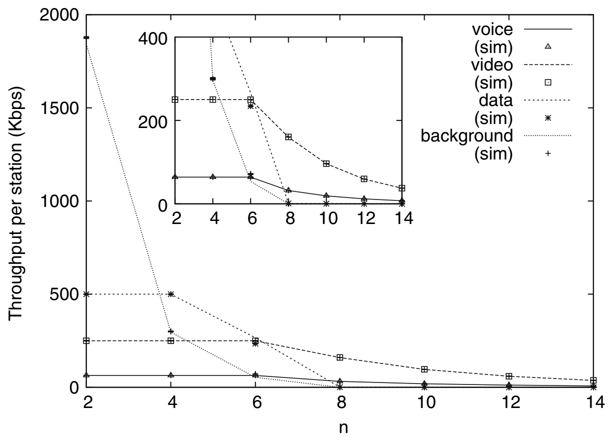

Figure 4. Throughput analysis validation.

- In the third AC, data traffic was generated according to a Poisson process of 500 Kbps average bit rate and packet sizes following the distribution of the data traffic measurements of [16].
- Finally, in the fourth AC stations always had 1000 byte packets ready for transmission, modeling the behavior of a data transfer.

The configuration of each AC was derived from the recommendations given by the standard 802.11e [1]. Experiments were performed for a varying number of stations per AC (all AC's had n stations each). The queue size of all the stations was set equal to 100 packets.

Figures 3 and 4 plot the average delay and throughput values obtained analytically (lines) and via simulation (points). Subplots are given for better observation of the low values. Simulation results are plotted with 95% confidence interval bars (note that confidence intervals are so small that they can barely be appreciated in the graphs).

From the figures, we observe that EDCA is effective in providing service differentiation. Both in terms of throughput and delay, higher priority AC's always perform better than lower priority ones. Furthermore, higher priority AC's also saturate later: AC 3 (data) saturates for $n > 4$ while AC's 1 and 2 (voice and video) saturate for $n > 6$ (AC 4 is by definition always saturated). Beyond this saturation point, in all AC's throughput decreases gradually with n, while delay increases drastically. For all cases, we have that analytical results match simulations remarkably well, which confirms the accuracy of our model.

We further validated the computational cost of the model by measuring the number of flops (floating point operations) required to execute a *Matlab* implementation of the algorithm. For all the presented experiments, results ranged from 25 to 325 Kflops. Although our implementation is not necessarily optimized, we believe that these results validate the model's computational efficiency. For instance, execution on a typical WLAN Access Point CPU with 100 MFlops capacity takes less than 10 ms, which is fully acceptable for admission control.

5. Conclusions

In this paper, we have presented a model to analyze the behavior of the 802.11e EDCA protocol under non saturation conditions. Simulation results have shown that the model accurately captures the behavior of the protocol under (i) typical source models (including voice, video, and data), (ii) realistic packet lengths as derived from measurements, and (iii) the configuration guidelines recommended by the standard. We conclude that, in contrast to previous works, our analysis can be used to model EDCA under *realistic* conditions.

The model presented here can be used for the design of admission control policies. Specifically, admission control can be implemented as follows: if (according to the model) the admittance of a new station in the WLAN degrades the service of the stations already present below a certain quality criterion, the new station is rejected. In line with the 802.11e standard [1], in a WLAN running under the infrastructure mode this algorithm can be executed at a centralized entity like, e.g., the Access Point.

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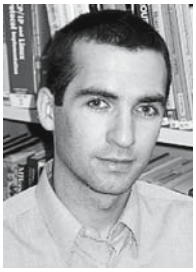

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