Reducing the impact of legacy stations on voice traffic in 802.11e EDCA WLANs

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***Abstract*— The EDCA access mechanism of the 802.11e standard supports legacy DCF stations, but the performance of high priority traffic is substantially degraded in their presence. In a previous letter we proposed the *ACKS* technique to mitigate the impact of legacy stations and studied this technique under high priority data traffic. In this letter we analyze the suitability of the *ACKS* technique for protecting voice traffic. Results show that voice performance is significantly improved as a result of using this technique.**

***Index Terms*— WLAN, 802.11e, 802.11, EDCA, DCF, ACKS**

I. Introduction

THE EDCA (*Enhanced Distributed Channel Access*) mechanism of the IEEE 802.11e standard [1] has been designed with backward compatibility for legacy stations using the DCF (*Distributed Coordination Function*) mechanism. However, the contention parameters with which legacy stations compete cannot be controlled, and this can severely degrade the performance of high-priority traffic in the WLAN.

In order to tackle the above problem, in [2] we proposed the *ACK Skipping* (*ACKS*) technique, whose aim is to mitigate the impact of legacy stations on an 802.11e WLAN under the EDCA mechanism working in Infrastructure Mode. This technique requires only a small modification in the 802.11e Access Point (AP) and leaves the legacy stations untouched.

In [2], the effectiveness of *ACKS* was studied under data traffic, and voice traffic (whose protection is more critical due to its higher sensitivity) was not considered. The main contributions of the present letter are: $i)$ an analysis for voice traffic performance under the *ACKS* technique, $ii)$ an algorithm to find the optimal *ACKS* configuration for protecting voice traffic, and $iii)$ an evaluation showing that, under the proposed configuration, voice traffic performance improves significantly with *ACKS*.

II. 802.11 DCF and and 802.11e EDCA

DCF and EDCA execute a very similar algorithm to transmit packets, which is described as follows. A station with a new packet to transmit monitors the channel activity. If the channel is idle for a period of time named $DIFS$ in DCF and $AIFS$ in EDCA, the station transmits. Otherwise, it continues to monitor the channel until it is idle for a $DIFS/AIFS$, and, at this point, the backoff process starts. Upon starting the backoff process, the station initializes its backoff time counter to a random value uniformly distributed in the range $\{0, \ldots, CW-1\}$. The CW parameter is called the Contention Window and its value depends on the number of failed transmissions. At the first transmission attempt, it is set equal to CW_{min}.

The backoff time counter is decremented once every slot time as long as the channel is sensed idle, "frozen" when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for a $DIFS/AIFS$. As soon as the backoff time counter reaches zero, the station transmits. A collision occurs when two or more stations start transmission simultaneously. After each unsuccessful transmission, CW is doubled, up to a maximum value CW_{max}. If the number of failed attempts reaches a predetermined retry limit R, the packet is discarded.

From the above explanation, it can be seen that the behavior of a station depends on a number of parameters (namely $DIFS$ or $AIFS$, CW_{min} and CW_{max}). The main difference between DCF and EDCA is that, while in DCF the values of these parameters are fixed by the standard, in 802.11e EDCA they are configurable.

III. *ACKS*: the *ACK Skipping* technique

As we have seen in the previous section, legacy DCF stations start the backoff process with a CW equal to CW_{min}. This initial CW is fixed by the standard to a small value, and it only doubles after each failed attempt. These small CW values lead to an aggressive behavior of the legacy stations which may disturb the performance of sensitive applications such as voice. In order to avoid this, it would be desirable to increase the CW with which legacy stations contend; the *ACK Skipping* (*ACKS*) technique does this without modifying the legacy stations.

ACKS is based on the following behavior of legacy stations: after sending a packet, a legacy station waits for an Acknowledgement (ACK) frame, and, if the frame is not received within an ACK timeout, it assumes a collision and increases its CW. The central idea is then the following: if the AP skips the ACK reply to legacy stations with a probability δ, these stations will 'see' a collision rate higher than the actual one, and will contend with larger CW's, resulting this in a smaller impact on the 802.11e stations.

The challenge with the *ACKS* technique is the configuration of the probability δ. This adds to the inherent difficulty in 802.11e of configuring the EDCA contention parameters in order to provide the desired behavior. Next, we present an analysis of voice performance as a function of the skipping probability δ and the EDCA parameters.

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IV. *ACKS* PERFORMANCE ANALYSIS

We now present an analysis for the performance of a WLAN in which 802.11e EDCA stations with voice traffic co-exist with legacy 802.11 DCF stations with data traffic. Hereafter we refer to the former as voice stations and to the latter as legacy stations. Following traditional voice codecs, we model a voice station as a source that generates a voice packet of size l_v every time interval T. We assume that legacy stations always have a packet of maximum size l_l ready for transmission to ensure voice traffic protection even under worst-case conditions.

Let n_v and n_l be the number of voice and legacy stations in the WLAN. Let CW_{min}^v and CW_{max}^v be the configuration of the voice stations, and CW_{min}^l and CW_{max}^l the configuration of the legacy stations. Note that the configuration of the parameters of the legacy stations are fixed by the 802.11 standard. For the configuration of the voice stations, we take $CW_{max}^v = CW_{min}^v$, in order to avoid that the delay performance of packets that suffer one or more collisions is drastically degraded. In addition, we take the minimum $AIFS$ (i.e., $DIFS$) in order to provide voice traffic with the highest priority. This leaves two parameters to configure in the WLAN: CW_{min}^v and δ; next, we analyze the performance of the voice stations as a function of these two parameters.

The key variables upon which we base our analysis are τ_v and τ_l, defined as the probability that a voice and legacy station, respectively, transmit in a randomly chosen slot time. Based on these variables, the throughput r_v experienced by a voice station is given by [3]:

$$r_v = \frac{P_v l_v}{P_s T_s + P_c T_c + P_e T_e} \tag{1}$$

where P_v is the probability that a randomly chosen slot time contains a successful transmission of a given voice station, 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 T_e are the slot time durations in each case. These probabilities are computed as follows:

$$P_v = P_{s,v} \tag{2}$$
$$P_s = n_v P_{s,v} + n_d P_{s,l} \tag{3}$$
$$P_e = (1-\tau_v)^{n_v}(1-\tau_d)^{n_d} \tag{4}$$
$$P_c = 1 - P_e - P_s \tag{5}$$

where $P_{s,v}$ and $P_{s,l}$ are the probabilities that a slot time contains a success of a given voice and a given legacy station:

$$P_{s,v} = \tau_v(1-\tau_v)^{n_v-1}(1-\tau_l)^{n_l} \tag{6}$$
$$P_{s,l} = \tau_l(1-\tau_l)^{n_l-1}(1-\tau_v)^{n_v} \tag{7}$$

Given $\tau_v \ll 1$, we can use the following approximations

$$\tau_v(1-\tau_v)^{n_v-1} \approx \tau_v - (n_v-1)\tau_v^2 \tag{8}$$
$$(1-\tau_v)^{n_v} \approx 1 - n_v\tau_v + (1/2)n_v(n_v-1)\tau_v^2 \tag{9}$$

which allows us to express the numerator and denominator of Eq. (1) as second order functions of τ_v.

From the above, we have a formula to compute the throughput as a function of τ_v and τ_l. The remaining challenge is the computation of these τ's. From the fact that legacy stations are saturated (they always have a packet ready for transmission), we can compute their τ from [3] (given $R > m$):

$$\tau_l = \frac{2(1-2p_l)(1-p_l^{R+1})}{W_l(1-(2p_l)^{m_l+1})(1-p_l) + (1-2p_l)(1-p_l^{R+1}) + W_l 2^{m_l} p^{m_l+1}(1-2p_l)(1-p_l^{R-m_l})} \tag{10}$$

where $W_l = CW_{min}^l$, m_l is such that $CW_{max}^l = 2^m CW_{min}^l$ and p_l is the probability that a legacy station does not receive an ACK after transmitting a frame [2],

$$p_l = 1 - (1-\tau_l)^{n_l-1}(1-\tau_v)^{n_v}(1-\delta) \tag{11}$$

For the computation of τ_v we proceed as follows. We initially analyze the throughput that voice stations would obtain if they were saturated. Under the saturation assumption, the τ of voice stations is given by [3],

$$\tau_{v,sat} = \frac{2}{CW_{min}^v + 1} \tag{12}$$

With the above, we have that Eq. (10) can be expressed as a non-linear equation on τ_d that can be solved numerically. Then, the throughput that voice stations would obtain if there were saturated, $r_{v,sat}$, can be obtained from Eq. (1).

Based on the above, we obtain the throughput performance of voice stations as follows. If for a given configuration we have that the saturation throughput of voice stations is smaller than the incoming rate (i.e., $r_{v,sat} < l_v/T$), then voice stations will be saturated and their throughput performance in this case will be the given by $r_{v,sat}$. On the other hand, if $r_{v,sat} \geq l_v/T$, then they will not be saturated and their throughput will be equal to the incoming rate, l_v/T. The reader is referred to [4] for a more detailed discussion on this behavior.

Based on the above analysis, we now study the τ_v value at which voice stations operate. In case of saturation, the value of τ_v is directly given by Eq. (12). In case of non saturation, the throughput experienced by voice stations has to be equal to their incoming rate, and therefore τ_v can be obtained from solving the following equation on τ_v:

$$r_v = l_v/T \tag{13}$$

We next analyze, with the τ_v value obtained above, the voice delay performance in terms of the average time elapsed between the beginning of the backoff process and the successful transmission of a packet. This delay is computed as:

$$E[d] = \sum_{j=0}^{R} P_{tx}(j)E[d_j] \tag{14}$$

where $P_{tx}(j)$ is the probability that a packet is successfully transmitted after j retries and $E[d_j]$ is the expected delay in this case. The reader is referred to [5] for the formulas to calculate $P_{tx}(j)$ and $E[d_j]$ as a function of τ_v, τ_l and CW_{min}^v.

V. ANALYSIS OF THE OPTIMAL $ACKS$ CONFIGURATION

Based on the above analysis, we now present an algorithm to compute the optimal δ and CW_{min}^v configuration to guarantee that the average delay voice traffic does not exceed a given threshold D_{max} while maximizing legacy stations throughput.

As the throughput of legacy stations decreases with δ, our goal is to find the minimum δ that meets the given requirements for voice traffic. Specifically, we want to find the minimum δ that, with CW^v_{min} set such that average delay does not exceed the given threshold, ensures that voice stations are not saturated.

To find the above δ configuration, we look at the maximum τ_l that, while meeting the delay requirements for voice stations, does not saturate them. To find this value, we conduct the following search on τ_l using the bisection method. In each step of the search, we perform the following operations:

- We first compute the τ_v of operation for the given τ_l from Eq. (13). This computation is performed with the approximations of Eqs. (8) and (9) which allows calculating τ_v from a second order equation.
- With the above τ_v, we compute the CW^v_{min} configuration that provides voice stations with the desired delay requirements. Specifically, CW^v_{min} is calculated from the first order equation resulting from forcing that the average delay expression of Eq. (14) is equal to D_{max}.
- As a final step, we compute the throughput that voice stations would obtain with the above CW^v_{min} if they were saturated. The search ends when this throughput is equal to the sending rate of voice stations: this gives the largest possible τ_l that does not saturate voice stations while meeting the given delay requirements.

We then take the following two further steps to find the δ that leads to the τ_l obtained from the above search:

- First, we calculate the τ_v of operation corresponding to the given τ_l. Here we do not use the approximations of Eqs. (8) and (9); indeed, as opposed to the above, this operation is executed only once and therefore a search with the bisection method can be conducted to find the exact τ_v without paying a high price in terms of computational cost.
- Finally, we conduct a search using the bisection method to find the δ for which the expression of τ_l given by Eq. (10), with the value of τ_v obtained in the previous step, is equal to the target τ_l.

The above terminates our algorithm to find the $ACKS$ optimal configuration. This algorithm gives the configuration of δ for the legacy stations as well as the configuration of CW^v_{min} for the voice stations. Note that the algorithm is very efficient as only three one-dimensional searches (performed with the bisection method) need to be conducted.

VI. Performance Evaluation

In order to validate the effectiveness of the proposed scheme to protect voice stations, we performed the following experiment. We evaluated the number of voice stations that can be admitted to the WLAN while meeting the desired delay criterion. This experiment was performed both with $ACKS$, under the configuration proposed in Section V, and without $ACKS$, with the optimal CW^v_{min} configuration obtained from executing the same algorithm but forcing $\delta = 0$. Note that the latter corresponds to the best possible CW^v_{min} choice that can be used for protecting voice traffic without $ACKS$.

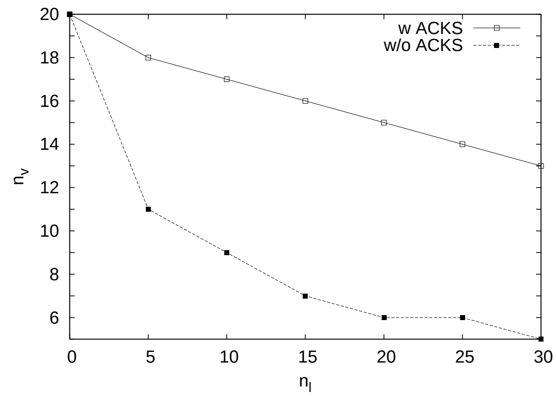

Fig. 1. Number of admissible voice stations as a function of n_l.

TABLE I

		Our algorithm				Exhaustive search		
n_l	n_v	CW^v_{min}	δ	$E[d]$	r_l	CW^v_{min}	δ	r_l
10	6	12	0	4.1	361	16	0	365
10	12	30	0.53	4.5	102	26	0.48	107
10	17	52	0.95	4.5	6	50	0.93	7
20	15	42	0.99	4.4	2	40	0.96	3
30	13	28	0.93	4.6	3	28	0.93	3

The system parameters taken for the simulation were the ones of the IEEE 802.11b physical layer, and the other parameters were taken as follows: $D_{max} = 5\ ms$, $l_v = 80$ bytes, $T = 10\ ms$ and $l_d = 1500$ bytes. The results, illustrated in Figure 1, confirm the effectiveness of $ACKS$, as this technique allows admitting many more voice stations.

We also validated our scheme to compute the optimal δ and CW^v_{min} configuration under different $\{n_l, n_v\}$ scenarios. For each scenario, we analyzed via simulation the performance of our scheme. The results, given in Table I (in units of ms and $Kbps$), show that in all cases the delay requirements are met. We further confirmed that our other objective of maximizing legacy stations throughput was also met. For this, we compared our results against the configuration resulting from performing an exhaustive search over the entire $\{\delta, CW^v_{min}\}$ space and choosing the point that gives the largest throughput while meeting delay requirements. As it can be observed from the table, our throughputs are very close to the exhaustive search ones. We therefore conclude that $i)$ $ACKS$ is very effective in protecting voice traffic and $ii)$ our configuration achieves the defined objectives.

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