CSMA with Enhanced Collision Avoidance: 
a Performance Assessment

Invited Paper

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Abstract—CSMA with Enhanced Collision Avoidance (CSMA/ECA) uses a deterministic backoff after successful transmissions to significantly reduce the number of collisions. This paper assesses by means of simulations the throughput and conditional collision probability obtained from a single-hop ad-hoc network using CSMA/ECA. A comparison with the legacy CSMA/CA reveals that the proposed protocol outperforms the legacy one in all considered scenarios. Specifically, it is shown that CSMA/ECA presents advantages for both rigid and elastic flows.

I. INTRODUCTION

The proliferation of IEEE 802.11 [1] networks makes the research associated to this family of protocols particularly relevant. After its success in Wireless Local Area Networks (WLANs), the IEEE 802.11 family is growing to cover other fields of applications, such as mesh and vehicular networks.

The Medium Access Control (MAC) is the mechanism that arbitrates the sharing of the channel among competing stations. In IEEE 802.11 networks, the MAC layer employs a combination of Carrier Sense Multiple Access andCollision Avoidance (CSMA/CA). The resultant protocol is called Distributed Coordination Function (DCF), and its behaviour significantly impacts the overall performance of the network.

The optimization of the performance of the MAC layer of IEEE 802.11 has deserved large research efforts. A simple model for the DCF is presented in [2] and its maximum throughput is derived in [3]. If the number of contending stations is known, the backoff mechanism can be tuned to attain the optimal performance of CSMA/CA. However, the estimation of the number of contending stations is not a trivial task. Under the assumption of ideal channel conditions and saturated stations, advanced filtering techniques ([4], [5]) can be used to accurately estimate the number of contenders.

The estimation of the numbers of contenders is even more challenging when the saturation assumption is released. Unsaturated flows join the contention to transmit only one packet and hence, in most of the occasions, they manifest themselves only at the instant they stop competing for the channel.

Another line of research goes beyond the modification of the parameters of DCF and proposes a change in the protocol. In [6], it is proposed to modify the way that contention windows grow and shrink. Another approach is not to choose the backoff randomly, as proposed in [7]: if the stations are aware of the backoff values of the other contenders, collisions can be effectively avoided.

The aforementioned approaches exhibit one or more of the following weaknesses: a) they rely on the saturation assumption or on the ideal channel assumption, b) they require a modification of the packet headers or c) they cannot fairly coexist with legacy DCF.

In [8] it is shown that, by using a deterministic (and equal for all stations) backoff after successful transmissions, the collisions in the WLAN are significantly reduced, and even disappear. The reason is that collisions cannot occur among those stations that successfully transmitted and chose the same deterministic backoff value. We use the name CSMA with Enhanced Collision Avoidance (CSMA/ECA) to refer to the new protocol that uses a deterministic backoff after successes.

This last solution surpasses the maximum theoretical performance of DCF while maintaining the same packet headers and guaranteeing fair coexistence with legacy networks. In [8], the focus is placed on the channel efficiency (i.e. the fraction of channel time devoted to successful transmissions) under saturation conditions. The present paper completes that work by assessing the performance metrics as perceived by the stations (throughput and conditional collision probability), both for elastic and rigid flows.

In this paper, CSMA/ECA has been incorporated to an IEEE 802.11 simulator in order to evaluate the validity of the new protocol in a variety of scenarios. These are the main contributions:

• First assessment of the performance parameters of CSMA/ECA as perceived by the stations: throughput and conditional collision probability. The conditional collision probability is defined as the probability that a station suffers a collision conditioned to the fact that it is attempting a transmission.

• Evidence that CSMA/ECA outperforms CSMA/CA when the traffic is offered in the form of elastic flows, rigid flows or a combination of both.

• Comparison of CSMA/ECA and CSMA/CA for both the two-way-handshake and four-way handshake variants of IEEE 802.11.

The remainder of this paper is organized as follows: Section II describes the features of CSMA/CA that are relevant to the paper and also briefly introduces CSMA/ECA. Section III describes the scenario that has been used to assess the performance of CSMA/ECA. Section IV presents simulation results that show that CSMA/ECA outperforms CSMA/CA in
all scenarios under consideration. Final conclusions are drawn in Section V.

II. THE MEDIUM ACCESS CONTROL

The stations running CSMA/CA sense the channel for ongoing transmissions before sending a packet. A station is allowed to transmit only if it senses the channel idle. It may happen that two or more stations begin a transmission (almost) simultaneously and a collision occurs. In order to reduce the chances of collision, the channel time is divided in slots and the transmissions are deferred a random number of slots.

The backoff values \( B \) are chosen from a contention window:

\[
B \sim U[0, \min(CW_{\text{min}} \cdot 2^a, CW_{\text{max}}) - 1],
\]

where \( U \) represents the uniform distribution. \( CW_{\text{min}} \) and \( CW_{\text{max}} \) are the minimum and maximum contention windows, respectively. The number of transmission attempts for the current packet is denoted as \( a \) (It equals 0 for the first transmission attempt).

The contention window uses a minimum value \( CW_{\text{min}} \) for the first transmission attempt and doubles after each failed transmission attempt, up to a maximum value of \( CW_{\text{max}} \). This binary exponential growth reduces the number of transmission attempts in a congested scenario.

It is common to use a simple two-way handshake mechanism in which the data is transmitted in one packet and acknowledged by the receiver in a second packet. This modality is called Basic Access (BA).

There is an optional four-way-handshake floor-reservation mechanism to minimize the channel time waste due to collisions and prevent the hidden terminal impairment [9]. Request-To-Send and Clear-To-Send (RTS/CTS) packets are used before the actual data transmission in order to reserve the channel. When RTS/CTS is in use, collisions can only occur among control (short) packets, thus the amount of channel time wasted in collisions is reduced. However, the additional control packets penalize the overall efficiency of the network.

A. CSMA with Enhanced Collision Avoidance

CSMA with Enhanced Collision Avoidance (CSMA/ECA), behaves exactly the same as the CSMA/CA protocol with the exception that a deterministic backoff is chosen after successful transmissions. To guarantee a fair coexistence with legacy CSMA/CA stations, the value of the deterministic backoff has to be:

\[
V = \lceil E[\min(CW_{\text{min}} - 1)] \rceil = \lceil (CW_{\text{min}} - 1)/2 \rceil,
\]

where \( \lceil \cdot \rceil \) is the ceiling operator and \( E[\cdot] \) is the expectation operator. The deterministic backoff after successes is a key parameter of the system, since it is also the maximum number of stations that can be accommodated in the collision-free mode of operation of CSMA/ECA. This parameter can also be adjusted to attain prioritization properties or to accommodate more contenders. More details on the adjustment of \( V \) can be found in [10].

![Fig. 1. A ball represents a transmission attempt in a given slot. Different filling patterns have been used to differentiate the transmissions of different stations. In CSMA/ECA the stations that successfully transmit use a deterministic backoff value.](image-url)
to 50 packets and the BA two-way handshake is used unless otherwise stated. The MAC parameters are taken from the IEEE 802.11b specification, and the physical data rate under consideration is 2Mbps. The constant backoff after successes is $V = 16$.

In order to fully validate a MAC protocol, it is required to show that it delivers acceptable performance for both elastic and rigid flows. In [11], a comprehensive study of the coexistence of elastic and rigid flows in IEEE 802.11 networks is presented. The simulator used in that paper has been enhanced to support also CSMA/ECA and has been used to obtain the results which are presented in the following section. It is based on the Component Oriented Simulation Toolkit (COST) [12].

A. Rigid and Elastic Flows

In a simplification of the myriad of traffic patterns that can be found in a wireless network, we consider only two kinds of flows: elastic and rigid.

Elastic flows are characterized by the fact that they have a clear tendency to consume all the bandwidth that is available in the network. They are typically associated to the use of the Transport Control Protocol (TCP) at the transport layer. At the MAC layer, they manifest as saturated stations. Web traffic, email, and peer-to-peer file interchange are good examples of elastic flows.

Rigid flows consume a fixed amount of bandwidth and are often encapsulated by the User Datagram Protocol (UDP) at the transport layer. During normal (uncongested) network operation, rigid flows do not saturate the station. On the contrary, the MAC queue remains empty for most of the time. A single packet is periodically received from the upper layer and, after the packet is serviced, the queue remains empty until a new packet arrives. Nevertheless, if the network is highly loaded and cannot transmit all the packets arriving from the upper layers, the MAC queues quickly build up and packet loss occurs due to queue overflow. If that is the case, we say that the network is congested. Voice over IP (VoIP) is an example of a service that uses rigid flows.

Elastic and rigid flows have different requirements regarding the MAC layer. When elastic flows are considered, the focus is placed on maximizing the throughput. In contrast, the goal in a network that forwards rigid flows is to prevent congestion and the associated packet loss.

IV. PERFORMANCE RESULTS

This section presents a simulation assessment of the performance of CSMA/ECA in scenarios with elastic flows, rigid flows and a combination of both.

A. Results for Elastic Flows

In Fig. 2, the throughput, conditional collision probability and expected backoff are plotted for an increasing number of elastic flows. The figure compares the performance of the proposed CSMA/ECA mechanism and the legacy CSMA/CA. It can be observed that CSMA/ECA maintains a constant (maximum) throughput as the number of contending stations increases. In contrast, the aggregated throughput of CSMA/CA is penalized when the number of contenders increases.

Note that the throughput when there is one single flow is the same in CSMA/CA and CSMA/ECA. The advantage of CSMA/ECA is that collisions cannot occur between two stations that successfully transmitted. This advantage cannot manifest when there is only one saturated station.

The higher throughput achieved by CSMA/ECA is a consequence of the lower number of collisions and the lower average backoff value. Since collisions are effectively suppressed, the backoff value is always $V = 16$ (See Fig. 2c). In the plots, it can be observed that there is a turning point when the number of active stations is equal to the deterministic backoff value $V$. At this point collisions can no longer be avoided and the performance of CSMA/ECA is degraded. If the number of flows continued to increase, the curves for CSMA/ECA would tend asymptotically to the ones obtained for CSMA/CA.

B. Results for Rigid Flows

In Fig. 3 the aggregated throughput and conditional collision probability for rigid flows are plotted for both CSMA/ECA and CSMA/CA. The simulations are performed for 50kpps and 100Kbps flows.

Throughput plots for rigid flows (Figs. 3a and 3c) are read as follows: while the throughput grows linearly with the number of flows, it means that the network can absorb the traffic offered by the stations. As soon as the throughput deviates from the linear growth, it is a symptom that congestion has appeared and packets are lost in the buffer queues.

While the number of flows is small and the contention is low, the MAC queues remain empty for most of the time. Thus, after a successful transmission, there is not a second packet to transmit, and the CSMA/ECA rule that states that a deterministic backoff is used after successes never applies.

For this reason, it can be observed that, when the network is lightly loaded, the performance metrics delivered by CSMA/ECA are exactly the same as the ones that can be obtained from CSMA/CA. Nevertheless this situation changes when the load increases and the network approaches congestion.

At this point, the MAC queues build up and, as the probability to find more than one packet in the queue increases, the CSMA/ECA rule for deterministic backoff after successes applies and hence the collisions are reduced or even suppressed.

The performance boost obtained by CSMA/ECA thanks to the suppression of collisions allows the network to satisfactorily support more rigid flows than CSMA/CA.

C. Results for the Coexistence of Elastic and Rigid Flows

In this scenario, a single elastic flow coexists with an increasing number of rigid flows. Fig. 4a depicts the aggregated throughput obtained by the rigid flows while Fig. 4b is the throughput of the elastic flow. These plots show that the advantages of CSMA/ECA for both elastic and rigid flows
Fig. 2. Performance results for elastic flows.

Fig. 3. Performance results for rigid flows

are also apparent in mixed scenarios. The two kinds of traffic benefit from the fact that CSMA/ECA is used.

Fig. 4c shows the conditional collision probability as perceived by the rigid flows. CSMA/ECA significantly reduces the chances of collision for both 50Kbps and 100Kbps flows. As the number of simultaneous flows increases, the packet service time also increases. As a consequence, the probability that a station holds multiple packets in its queue is higher. When there is more than one packet in the queue, CSMA/ECA actuates to lower the collision probability.

Note that, since CSMA/ECA as presented in this paper does not support traffic differentiation, the presence of elastic flows is detrimental for the performance of the rigid ones. Although it is possible to combine CSMA/ECA with prioritization mechanisms, it is out of the scope of the present paper.
D. The impact of RTS/CTS on the performance

RTS/CTS minimizes the time wasted due to collisions, but increases the channel access overhead because of the additional control packets. In Fig. 2a, the impact of the RTS/CTS mechanism on the performance of elastic flows can be observed. CSMA/CA + RTS/CTS outperforms CSMA/CA + BA when the number of contenders is large. However, when CSMA/ECA is used, the four-way-handshake mechanism offers little advantage. Since the collisions are already prevented by the enhanced collision avoidance mechanism, RTS/CTS penalizes the throughput because of the associated overhead.

From the results, it is clear that the best performance is obtained by CSMA/ECA combined with BA. Nevertheless, if RTS/CTS is to be used for reasons out of the scope of this paper (e.g. to prevent the hidden terminal effect), CSMA/ECA still presents a performance advantage when compared with CSMA/CA.

The effect of RTS/CTS on rigid flows is depicted in Fig. 3. Because of the four-way-handshake, the time required to transmit each packet is significantly increased. As a consequence, the number of packets that can traverse the network in a given time interval is reduced. Thus, a network using the RTS/CTS mechanism can support a lower number of rigid flows than a network using BA. A final observation is that CSMA/ECA also outperforms CSMA/CA when RTS/CTS is used.

V. CONCLUSION

This article assesses the performance of CSMA/ECA in single-hop ad-hoc networks. CSMA/ECA is a modification of CSMA/CA that uses deterministic backoff values after successful transmissions, which reduces the chances of collision. In order to validate the goodness of CSMA/ECA, it is necessary to show that it delivers higher performance for the most common kinds of traffic: elastic flows and rigid flows. Throughout the article, the performance metrics of CSMA/ECA have been compared with those delivered by CSMA/CA.

Simulation has been used to evidence that CSMA/ECA delivers higher throughput when elastic flows are considered. Regarding rigid flows, CSMA/ECA allows for a larger number of simultaneous flows before reaching the congestion condition. In a mixed scenario that includes both rigid and elastic flows, CSMA/ECA still attains higher throughput for the elastic flows and increased protection for the rigid flows.

In summary, CSMA/ECA outperforms CSMA/CA in all considered scenarios.

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REFERENCES