Fairness in Collision-Free WLANs

Luis Sanabria-Russo, Jaume Barcelo, Boris Bellalta

Universitat Pompeu Fabra, Barcelona, Spain
{luis.sanabria, jaume.barcelo, boris.bellalta}@upf.edu

***Abstract*—CSMA/ECA is a contention protocol that makes it possible to construct a collision-free schedule by using a deterministic backoff after successful transmissions. In this paper, we further enhance the CSMA/ECA protocol with two properties that make it possible to fairly accommodate a large number of contenders in a collision-free schedule. The first property, called *hysteresis*, instructs the contenders not to reset their contention window after successful transmissions. Thanks to hysteresis, the protocol sustains a high throughput regardless of the number of contenders. The second property, called *fair-share*, preserves fairness when different nodes use different contention windows. We present simulations results that evidence how these properties account for performance gains that go even further beyond CSMA/CA.**

***Index Terms*—Wireless, MAC, Collision-free, CSMA/ECA.**

I. Introduction

IEEE 802.11 networks use a shared medium to establish communication among nodes. Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is the protocol in charge of coordinating access to the wireless medium in order to avoid simultaneous transmissions by different nodes. If two or more nodes (N) attempt transmission at the same time, a *collision* occurs and the resulting transmission is discarded by the receivers.

Carrier Sense Multiple Access with Enhanced Collision Avoidance (CSMA/ECA) [1] was introduced as an enhancement to CSMA/CA. It is capable of achieving a collision-free state by making very simple changes on the way CSMA/CA behaves: choosing a deterministic backoff after successful transmissions.

The performance evaluation for CSMA/ECA has been presented in [2]. Nevertheless, to the best of our knowledge this is the first work that introduces further enhancements to the protocol, making it possible to allocate a larger number of contenders and achieve greater throughput than CSMA/CA while providing the same service time to all users. This is the first step towards the construction of a totally distributed MAC protocol with better performance than the current standard as a consequence of its collision-free operation.

II. Related work

Time in WLANs is slotted, and each slot can be classified as empty, successful or collision (accounting for no transmission, successful transmission or collision, respectively).

In CSMA/CA, each contender attempting to transmit a packet chooses a backoff counter $B \in [0, CW(k) - 1]$ randomly, where $k \in [0, \dots, m]$ is the *backoff stage* and $CW(k) \in [2^k CW_{\min},\ 2^m CW_{\min}]$ is the contention window, with $CW_{\min}$ its minimum value. Each passing empty slot decrements B by one; when the backoff counter reaches zero, the contender will attempt transmission. The success of the transmission attempt is only confirmed by the reception of an acknowledgement (ACK) frame from the receiver, otherwise a collision is assumed. If that is the case, each contender involved in the collision doubles its contention window by incrementing its backoff stage and the packet is retransmitted. If the transmission is successful, the sender resets its contention window to the minimum value ($k = 0 \therefore CW(k) = CW_{\min}$).

CSMA/ECA achieves less collisions and outperforms CSMA/CA in most typical scenarios [1]. The only difference with CSMA/CA is that a deterministic backoff $B_{\text{d}} = CW_{\min}/2$ is chosen after each successful transmission. From here on $B_{\text{d}} = N^{\text{cf}}_{\max}$, where $N^{\text{cf}}_{\max}$ is defined in (1) as the *collision-free constraint* and represents the maximum number of nodes participating in the contend for transmission able to achieve a collision-free state.

$$N^{\text{cf}}_{\max} = \lceil CW_{\min}/2 \rceil \tag{1}$$

In a scenario where $N \leq N^{\text{cf}}_{\max}$, eventually all contenders will be able to pick different transmission slots, therefore achieving a collision-free state.

When the system is overcrowded, $N > N^{\text{cf}}_{\max}$, CSMA/ECA suffers a decrease in throughput as seen in Figure 1. This effect is caused by collisions originated by $N - N^{\text{cf}}_{\max}$ contenders forced to generate a random backoff counter and attempting transmission on slots previously picked by $N^{\text{cf}}_{\max}$ nodes using a deterministic backoff.

Furthermore, as $N - N^{\text{cf}}_{\max}$ nodes are unable to successfully transmit, collisions force the nodes that chose a deterministic backoff, to switch to a random one. The outcome is a mixed system composed of contenders using either deterministic or random backoff counters. The throughput degradation depicted in Figure 1 when $N = 16$, is a consequence of the great number of collisions resulting from this behavior. Nevertheless, the throughput in CSMA/ECA is greater than CSMA/CA's for any number of contenders.

III. A decentralized and fair CSMA/ECA

Nodes will double $CW(k)$ after collisions and reset it ($CW(k) = CW_{min}$) upon each transmission success, augmenting the collision probability. Because CSMA/ECA is totally distributed, the number of nodes (N) is unknown to

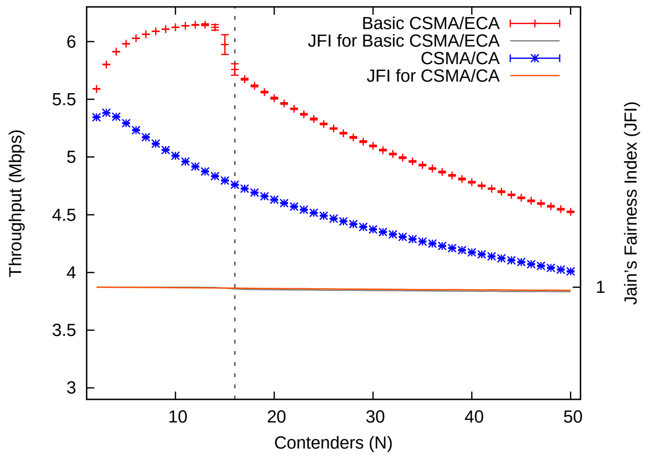

Fig. 1. The throughput is CSMA/ECA decreases when the number of contenderes N exceeds $N_{\max}^{\text{cf}}$, which is the maximum number of contenders that can be allocated in a collision-free fashion.

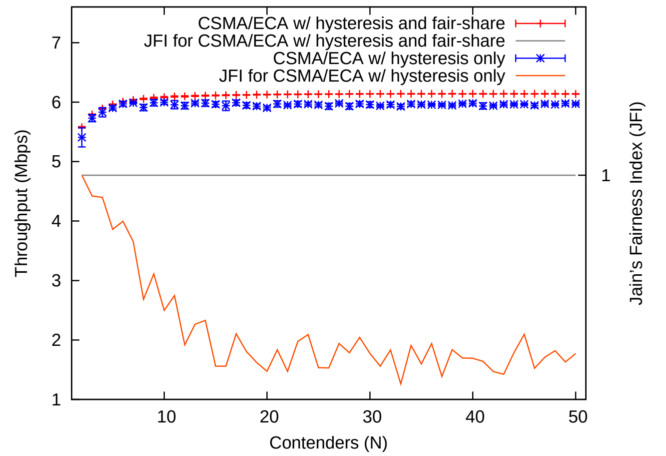

Fig. 2. Throughput and Jain's Fairness Index when implementing fair-share in CSMA/ECA

all contenders. Therefore, $CW(k)$ is used to relate collisions to the number of users in the system.

To make it possible to achieve a collision-free state when the system is overcrowded ($N > N_{\max}^{\text{cf}}$), we instruct nodes not to reset $CW(k)$ after successful transmissions and modify the collision-free constraint to $N_{\max}^{\text{cf}} = CW(k)/2$. This is called *hysteresis* from here forward.

Hysteresis forces nodes to *stick* to the value of the current backoff stage, k; resulting in a larger $CW(k)$. This measure leads to a collision-free state while $N \leq N_{\max}^{\text{cf}}$.

Having a greater collision-free constraint means that more nodes are able to achieve a collision-free state. Nevertheless, in a $N \leq N_{\max}^{\text{cf}}$ scenario, contenders may have different deterministic backoff counters which provoke some nodes to access the channel more often than others. This fairness issue is averted with *fair-share*.

Fair-share consist in allowing each contender to send 2^k packets at every transmission, making sure that contenders with longer backoff are compensated proportionally.

Figure 2, depicts how CSMA/ECA with hysteresis and fair-share achieves greater throughput than CSMA/ECA alone, maintaining a collision-free state while being fair (Jain's Fairness Index [3] (JFI) equal to 1), for any number of contenders.

The concept of fair-share, was first introduced by Fang et al. in [4]. This work evaluates the performance of CSMA/ECA when implementing the concept in a customized C++ simulator.

IV. Evaluation

CSMA/ECA preserves backward compatibility with CSMA/CA (details in [1] and [5]), which is paramount for the coexistence and progressive adoption of the protocol.

Implementation is performed on a customized version of the COST [6] simulator. The system was set to be under saturation (nodes always have packets to transmit) during a period of ten seconds at a maximum throughput of 11Mbps. The number of contenders ranges from 2 to 50 and a hundred simulations are performed for each number of contenders. Further MAC-related parameters as well as the code for the whole CSMA/ECA implementation can be found in [7].

Figure 1 and Figure 2 are results derived from the evaluation platform with 95% confidence intervals.

V. Future directions

CSMA/ECA is the basic idea, but there are many issues to investigate in the future. One of them, is to make it adaptive to a variable number of nodes without fairness between nodes. Open topics include how to provide traffic differentiation (i.e. Quality of Service) in top of CSMA/ECA, or how to adapt novel features such as Multi-packet Transmission / Reception and channel bonding on top of it.

As it is shown in [2], the combination of CSMA/ECA with the Auto Rate Fallback mechanism to select the transmission rates provides a huge gain in the network performance as, once collisions are removed, they do not interfere with the ARF operation. If similar gains can be obtained when combining it with the previously mentioned mechanisms are still open challenges.

References

[1] J. Barcelo, A. Toledo, C. Cano, and M. Oliver, "Fairness and Convergence of CSMA with Enhanced Collision Avoidance (ECA)," in *2010 IEEE International Conference on Communications (ICC)*, may 2010, pp. 1 –6.

[2] G. Martorell, F. Riera-Palou, G. Femenias, J. Barcelo, and B. Bellalta, "On the performance evaluation of CSMA/E2CA protocol with open loop ARF-based adaptive modulation and coding," *European Wireless. 18th European Wireless Conference*, pp. 1 –8, april 2012.

[3] R. Jain, D. Chiu, and W. Hawe, *A Quantitative Measure of Fairness and Discrimination for Resource Allocation in Shared Computer System*. Eastern Research Laboratory, Digital Equipment Corporation, 1984.

[4] M. Fang, D. Malone, K. Duffy, and D. Leith, "Decentralised learning MACs for collision-free access in WLANs," *Wireless Networks*, vol. 19, pp. 83–98, 2013. [Online]. Available: http://dx.doi.org/10.1007/s11276-012-0452-1

[5] Y. He, R. Yuan, J. Sun, and W. Gong, "Semi-Random Backoff: Towards resource reservation for channel access in wireless LANs," in *17th IEEE International Conference on Network Protocols*. IEEE, 2009, pp. 21–30.

[6] E. Yücesan, C. Chen, J. Snowdon, and J. Charnes, "COST: A component-oriented discrete event simulator," in *Winter Simulation Conference*, 2002.

[7] L. Sanabria-Russo, J. Barcelo, and B. Bellalta. (2012) Implementing CSMA/ECA in COST. [Online]. Available: https://github.com/SanabriaRusso/CSMA-E2CA