

Dynamic Parameter Adjustment in CSMA/ECA

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Abstract. CSMA/ECA is a modification of CSMA/CA that delivers higher performance by reducing the number of collisions. This paper presents an algorithm to adapt a configuration parameter of the protocol to ensure high performance for any given number of competing stations. Performance is measured in terms of efficiency and fairness. The proposed algorithm has been tested by means of simulation to show that it takes half a second for the system to re-adjust the configuration and suppress the collisions when the number of contending stations suddenly increases from zero to twenty.

Key words: CSMA, WLAN, IEEE 802.11, throughput, fairness.

1 Introduction

Wireless Local Area Networks (WLAN) have flourished in homes, campuses and enterprises. The vast majority adhere to the IEEE 802.11 [1] protocol that relies on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to share the channel time among the participating stations. It is desired that only a single station transmits at a given time, since overlapping transmissions can easily result in packet loss.

In CSMA/CA, the stations sense the channel for ongoing transmissions before attempting to transmit. If a station senses the channel busy, it will refrain from transmitting and it will delay its transmission a random amount of time. A caveat of CSMA/CA is that only a fraction of the channel time is devoted to successful transmissions while the remainder is wasted in the form of empty channel or collisions. In this article we will study Carrier Sense Multiple Access with Enhanced Collision Avoidance (CSMA/ECA) which is a variant of CSMA/CA that reduces the number of collisions.

Since CSMA/CA curtails the overall network performance, it has deserved many research efforts. Some relevant previous work is revised in Sec. 2. Then, in Sec. 3, the CSMA/CA protocol is detailed, with particular emphasis on the backoff mechanism. It is explained that using a deterministic backoff value after successful transmissions presents several advantages and the modification of the protocol is called CSMA/ECA. Just as it happens in CSMA/CA, it is also

possible to increase the performance of CSMA/ECA by adjusting its contention parameters. Sec. 4 investigates the impact of parameter selection on the performance of CSMA/ECA in different situations. These results are then used in Sec. 5 to suggest an algorithm that dynamically adjusts the configuration of the contending stations to adapt to a changing scenario. Finally, Sec. 6 concludes the article.

2 Related Work

The CSMA/CA medium access control is easy to implement and can be executed in a distributed fashion. These properties make CSMA/CA an ideal candidate for the medium access control of WLAN. It is not an overstatement that the IEEE 802.11 suite of protocols that rely on CSMA/CA has enjoyed a tremendous success in a spectrum of different scenarios. Nevertheless, the research community was concerned from the very beginning by the fact that CSMA/CA does not make an efficient use of the channel time. In [2] the maximum performance that can be delivered using CSMA/CA is studied. The exact values of the efficiency depend on the parameter setting, but in any case it can be concluded that the efficiency of CSMA/CA in IEEE 802.11 is far from 100%. Furthermore, this efficiency significantly degrades as the number of contending stations increases.

A valuable insight into the underlying behaviour of CSMA/CA is provided in [3], where the protocol is modelled as a Markov Chain and key parameters such as transmission probability and conditional collision probability are computed.

Many authors have proposed solutions to improve the performance of CSMA/CA. As an example, the authors of [4] propose that the stations advertise their backoff values to prevent collisions. This approach requires a modification of the headers of the packet and therefore backward compatibility is compromised. The idea of gathering information about other stations intentions to transmit is very promising, and we will use that very same principle in our approach. The difference lies in the fact that in CSMA/ECA this information is distributed implicitly by using a deterministic backoff after successful transmissions, without requiring an additional field in the packet headers.

CSMA/ECA is also related to Reservation Aloha [5] since both approaches separate successful transmissions by a deterministic number of slots. Nevertheless, there is no reservation mechanism in CSMA/ECA.

The adjustment of the contention parameters of CSMA/CA is also a good alternative to improve performance. In [6], an advanced filtering method is proposed to accurately estimate the number of contending nodes in a network and then this information is used to adjust the contention parameters. The approach is fully distributed and it does not require a central entity.

When a central entity is available, it can be used to compute the contention parameters and then distribute them to the remainder of stations using beacon control frames. The solution proposed in [7] is of particular interest because it does not need to estimate the number of contenders. In our approach, we will

also make use of a central entity and propose an algorithm that does not need an estimation of the number of contending stations.

Note that both [6] and [7] use CSMA/CA. As a consequence, they are limited in terms of performance by the upper bound presented in [2]. In order to obtain better results, it is necessary to change the protocol. CSMA/ECA proposes a subtle change to the protocol that substantially increases its efficiency.

The performance of CSMA/ECA has already been extensively studied. In [8], simulation is used to assess its performance as perceived by the stations. Specifically, throughput and conditional collision probability plots are provided. It is also shown that CSMA/ECA is advantageous for both elastic (TCP-like) and rigid (UDP-like) traffic flows. Some of these results are captured by an analytical model that is presented in [9].

The ability of CSMA/ECA to handle traffic differentiation is addressed in [10]. That paper also hints the need to adjust the contention parameters of CSMA/ECA in order to accommodate a large number of contenders. This idea is further developed in the present paper.

Some practical issues regarding CSMA/ECA, such as the coexistence with legacy networks, are presented in [11]. It is concluded that CSMA/CA and CSMA/ECA can fairly coexist in the same network since the new protocol is backward compatible with the legacy one. This is an interesting property because it allows for an incremental deployment of CSMA/ECA. The present paper does not address mixed scenarios with new and legacy stations and focuses on a greenfield scenario in which all the stations follow the CSMA/ECA rules.

Previous studies on CSMA/ECA have not considered the possibility of parameter adjustment. When the number of contenders is large and the contention parameters are not adjusted, CSMA/ECA cannot completely suppress the occurrence of collisions. And those collisions prevent an effective use of the channel time. The present paper introduces parameter adjustment for CSMA/ECA and therefore allows for collision-free operation for any number of contending stations.

The main contributions with respect to previous work are as follows. First, the study of fairness among individual CSMA/ECA stations. Second, the assessment of the effect that parameter selection has on performance in a variety of situations. And third, an algorithm that allows the dynamic adjustment of the network parameters to adapt to different network conditions.

3 Carrier Sense Multiple Access with Enhanced Collision Avoidance

When a IEEE 802.11 station joins the CSMA contention for the channel time, it senses the channel for a distributed inter-frame space (DIFS). If the channel is sensed idle, the station transmits. However, if the channel is sensed busy, the transmission will be deferred. A backoff counter is initialized to:

$$B \sim \mathcal{U}[0, CW - 1], \quad (1)$$

where \mathcal{U} represents the uniform random distribution and CW is the value of the contention window, that takes its minimum value CW_{min} for the first transmission attempt.

This backoff counter is decremented every T_e seconds while the channel is sensed idle. Thus T_e is the duration of an empty slot. The backoff counter count-down is frozen while the channel is sensed busy.

When the backoff counter reaches zero, the station transmits. The transmission is successful if the receiver correctly decodes and acknowledges the packet and the sender decodes the acknowledgement control packet. Otherwise, the transmission is a failure and a new random backoff value is selected after doubling the contention window. The contention window value is doubled after each unsuccessful attempt, until reaching its maximum value CW_{max} . There is also a maximum number of retransmissions R .

After a packet has been serviced (either successfully transmitted or discarded due to excessive retransmissions), the contention window is set to its minimum value CW_{min} and the station has to backoff before transmitting another packet. The reason is to prevent that a single station captures the channel by continuously submitting packets.

Although the actual protocol behaviour involves the transmission of signaling packets (ACKs) and different kinds of inter-frame spaces (SIFS and DIFS), it is a common approach in the study of contention protocols to obviate these details (See Fig. 1) . In the following, we consider a simplified model in which we discriminate three kinds of slots, namely: empty, success and collision. The actual content of the successful and collision slots is irrelevant for our discussion.

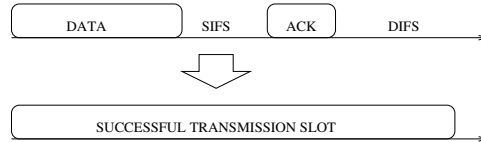


Fig. 1. The behaviour of the protocol is simplified to the slot level.

We will assume that the simultaneous transmission of two or more packets results always in a collision, and all the involved packets are lost.

Using the simplification that the channel time can be represented as a succession of slots, we can differentiate three cases in which the backoff is used.

- (i) When a station joins the contention and senses the channel busy.
- (ii) After unsuccessful transmissions.
- (iii) After successful transmissions.

The selection of the backoff should be random for cases (i) and (ii). The reasons are as follows.

Case (i): We have to consider the possibility that two stations join the contention while a third one is transmitting. Then, if the two stations that joined

the contention used the same backoff, they would collide in their first transmission attempt. Fig. 2 shows an example in which two stations join the contention (represented as an small arrow) while a third one is transmitting. The two new stations choose the initial backoff randomly.

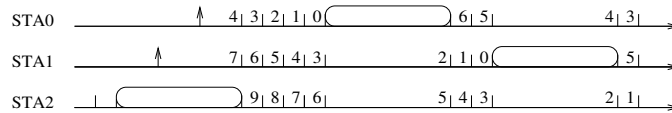


Fig. 2. Example of CSMA/CA. A random backoff is used when the channel is sensed busy after joining the contention.

Case (ii): Collisions easily result in unsuccessful transmissions. If the stations that collided chose the same backoff value, they would collide in their next transmission attempt. Fig. 3 shows two stations that collide and then choose random backoffs values and successfully transmit.

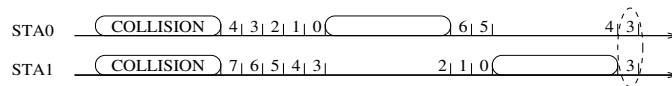


Fig. 3. Example of CSMA/CA. A random backoff is used after successful and unsuccessful transmissions.

In CSMA/CA, all the backoff values are selected randomly. In contrast, CSMA/ECA uses a deterministic backoff after successes (case (iii)). The behaviour of the protocols in each of the three identified cases is summarized in Table 1.

Table 1. Randomness in contention protocols

	CSMA/CA	CSMA/ECA
(i) initial	random	random
(ii) after collision	random	random
(iii) after success	random	deterministic

CSMA/ECA has an advantage over CSMA/CA: two stations that successfully transmitted in their last transmission attempt will not collide among them in their next transmission attempt. Consequently, after all stations have consecutively successfully transmitted, the system operates in a collision-free mode, substantially improving the network performance.

The difference between CSMA/CA and CSMA/ECA can be easily explained by means of an example. Consider Fig. 3 which represents CSMA/CA contention and notice that, after the two stations have successfully consecutively transmitted, it is possible that they share the same backoff value. This will result in a new collision in the stations' next transmission attempt.

Compare this behaviour with the one presented by CSMA/ECA which is depicted in Fig. 4. Consider the second successful transmission that occurs in the figure. After a successful transmission, CSMA/ECA uses a deterministic backoff. Since one and only one station transmitted in the successful slot, the backoff value of the station that just transmitted will be strictly greater than the backoff values from the other stations that successfully transmitted in previous slots. Therefore, collisions are not possible among stations that have successfully transmitted in their last transmission attempt.

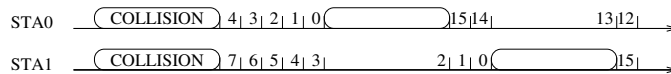


Fig. 4. Example of CSMA/ECA. A random backoff is used after unsuccessful transmissions. Then a deterministic backoff is used after successes.

The proposed protocol, CSMA/ECA, exhibits the following properties:

- Reduced number of collisions when compared with CSMA/CA.
- Possibility of collision-free mode of operation when the number of simultaneous contenders is lower than the deterministic backoff value that it is used after successes.
- The collision-free mode of operation is reached after a transient state, in which the stations perform a random search for empty slots until all the stations consecutively successfully transmit.

In order to make the backoff value deterministic, we use for CSMA/ECA a backoff value V which is equal to the expectancy of the backoff that is used in CSMA/CA. Therefore, V is a function of CW_{min} , which can be dynamically adjusted by means provided in the standard.

$$V = \lceil E[\mathcal{U}[0, CW_{min} - 1]] \rceil, \quad (2)$$

where $\lceil \cdot \rceil$ is the ceiling operator.

4 Parameter Selection and Performance

In the remainder of the article, we will focus on finding the right values for V and CW_{min} . We will use two metrics to assess the performance of the system: efficiency and fairness. As in our previous work, we define efficiency as the fraction of time devoted to successful transmissions (See (2) and (3) in [11]). This metric

is also a function of the length of the successful, collision and empty slots. We will assume the default parameter settings in IEEE 802.11b and a frame length of 1500 bytes.

For illustration purposes, simulation results are presented for a scenario with $\varsigma = 8$ contending stations. We have used a custom simulator³ in Octave [12] that only implements the contention mechanism. In all the plots, the values obtained using CSMA/CA are also provided for comparison purposes. All the simulations in this section are repeated 1000 times and average values and 95% confidence intervals have been computed. To assess short-term performance, we perform simulations that are 1000 slots long and include the transient-state. On the other hand, to assess long-term performance, the simulations are 10,000 slots long and the transient-state is not taken into account.

Fairness will be computed using Jain’s fairness index [13] on the number of successful slots by the end of the simulation. Since we will perform simulations of different lengths, we will obtain results for short-term and long-term fairness. All of them are interesting properties of a medium access mechanism.

From the theoretical standpoint, and under the ideal channel and steady-state assumptions, CSMA/ECA delivers its maximum performance when the minimum contention window doubles the number of contending stations ($CW_{min} = 2\varsigma$), *i.e.*, when the deterministic backoff after successes is equal to the number of contending stations ($V = \varsigma$). In this particular case all the slots are filled with successful transmissions and the stations transmit in a round-robin fashion. In fact, both the efficiency and the fairness are equal to one in these ideal conditions.

Fig. 5 plots the efficiency and fairness of CSMA/ECA in long simulations where the steady-state assumption is fulfilled. Since the number of contenders is eight, the maximum efficiency (one) is obtained when $V = \varsigma = 8$ and $CW_{min} = 2\varsigma = 16$. The maximum fairness one is obtained for any $V \geq \varsigma = 8$ and $CW_{min} \geq 2\varsigma = 16$.

Unfortunately, this simple approach to performance optimization may not be useful for real network configuration. The reason is that in CSMA/ECA the steady-state assumption may be unrealistic. Notice that in shorter simulations where the transient-state has been taken into consideration (See Fig. 6⁴), the maximum of the performance curves differ from those obtained in the steady-state.

5 Dynamic Parameter Adjustment

An interesting observation is that the curves for CSMA/ECA are relatively flat when $CW_{min} \geq 2\varsigma = 16$. In this region, CSMA/ECA delivers high performance results across all the different plots. The ability of CSMA/ECA to deliver high

³ Source code is available upon request to the first author.

⁴ There are small oscillations in the fairness curves presented in Fig. 6. They are a measure error related to the use of a measurement window (1000 slots) and they cannot be suppressed by increasing the number of simulations.

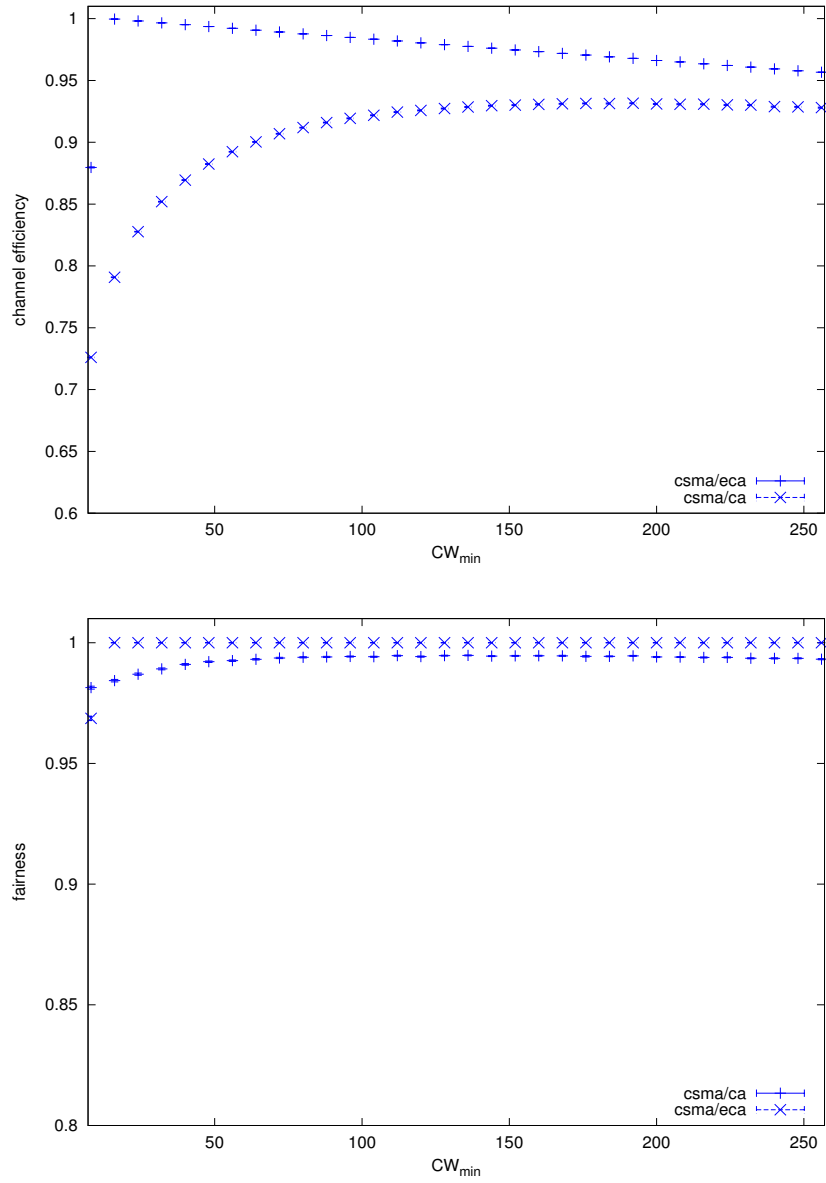


Fig. 5. Long term (steady-state) efficiency and fairness as a function of CW_{min} when the number of contenders equals 8.

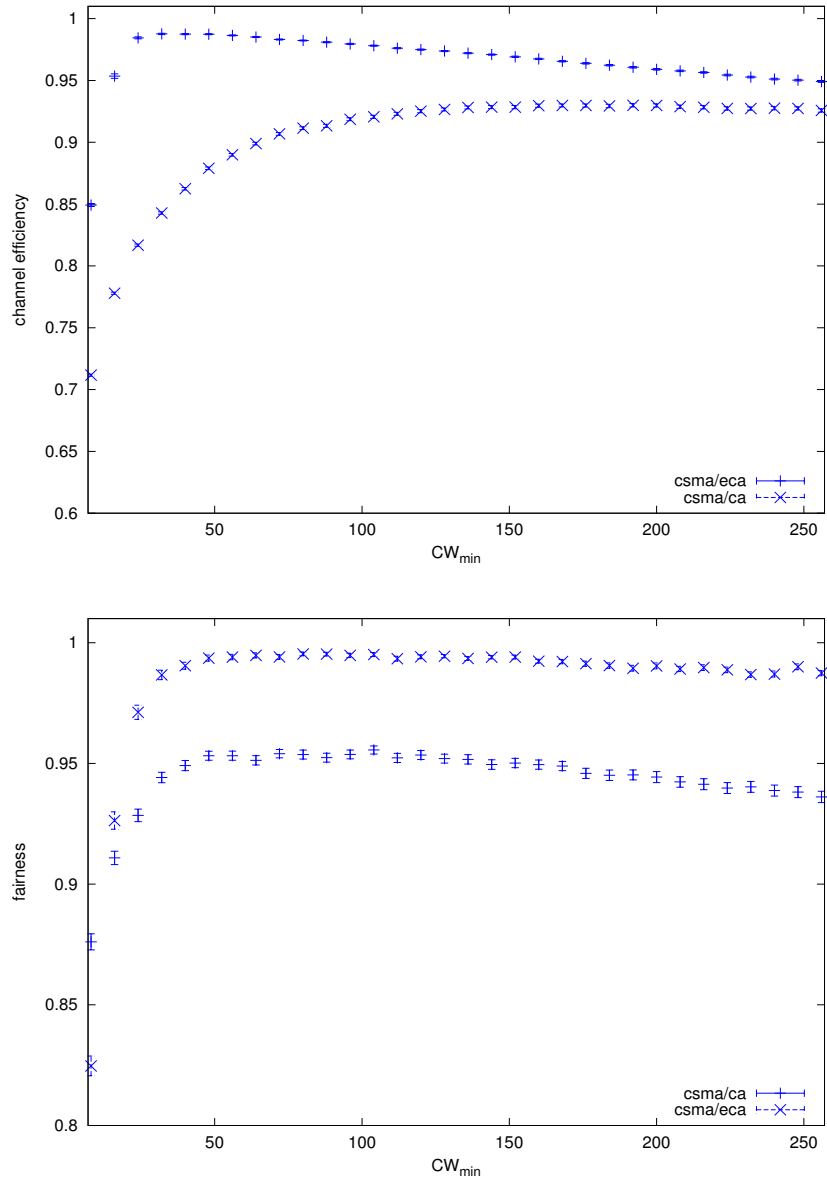


Fig. 6. Short term (transient) efficiency and fairness as a function of CW_{min} when the number of contenders equals 8.

performance for a wide range of values of CW_{min} will be very useful in real deployments. Our goal is to propose an approach that dynamically adjusts the configuration parameter CW_{min} to guarantee that the network stays in this favorable region of operation.

We want to guarantee that $CW_{min} \geq 2\varsigma$, and this can be achieved by setting⁵

$$CW_{min} \approx 8\varsigma. \quad (3)$$

Since CSMA/ECA is capable of preventing collisions and a deterministic backoff V is used after successes, each station successfully transmits in one out of V slots. Consequently, the ratio of busy slots in the overall system is:

$$\beta = \frac{\varsigma}{V} = \frac{2\varsigma}{CW_{min}}. \quad (4)$$

By substituting (3) into (4) we obtain that our target fraction of busy slots should be:

$$\beta_{target} = \frac{1}{4} \quad (5)$$

As in [7], we adopt a centralized approach to parameter adjustment. In particular, the access point takes measures of the channel, computes the configuration parameters and distributes this parameters to the stations using the beacon frames that are transmitted every 100ms. The information regarding CW_{min} is codified in a 4-bit field in the beacon frame. The standard restricts CW_{min} to be an integer power of two, and the information contained in the 4-bit field is, actually, the exponent.

Our proposed algorithm that adjusts CW_{min} to attain β_{target} while adhering to the standard restrictions is iterative. The access point measures the actual fraction of busy slots β during a 100ms interval, and then it uses that value and the previous minimum contention window $CW_{min,i}$ to compute the next contention window $CW_{min,i+1}$ as follows:

$$\begin{aligned} CW_{min,0} &= CW_{min}^{default}, & i &= 0 \\ CW_{min,i+1} &= \max(CW_{min}^{default}, CW_{min,i} \cdot 2^{round(\log_2(\beta/\beta_{target}))}), & i &> 0 \end{aligned} \quad (6)$$

where the $round()$ operator approximates a given value to the closest integer. Note that when $\beta = \beta_{target}$ the value of CW_{min} is maintained ($CW_{min,i+1} = CW_{min,i}$). Note also that we restrict CW_{min} to be larger or equal to the default value of the standard.

A common approach in the literature to evaluate the performance of an adaptation algorithm is to test its reaction when the number of contending stations suddenly changes. As an example, [6] studies the case in which the

⁵ The use of the value 8 is a design decision that ensures a fast convergence to the (collision-free) steady state and a good steady-state performance. See [11] for details on the duration of the transient state and the steady-state efficiency.

number of contenders jumps from 6 to 11. Similarly, [7] presents an example in which the number of stations instantaneously changes from 15 to 30.

In order to evaluate the performance of the proposed algorithm, we will stress it by simulating a scenario where twenty saturated stations simultaneously join an empty network. We will take measures such as the achieved efficiency, fairness and number of successful transmissions. We also will see how the algorithm updates CW_{min} in order to adapt to the new situation. Every 100ms, measures are taken and then the new value of the contention window is computed and sent using the beacon frame. The idealistic assumption that the access point transmits its frame in an empty slot has been used. It should not be difficult to prevent collision between data frames and the control beacon frame by using the *smart entry* approach presented in [11].

Table 2. Performance of the adaptive algorithm when the number of contending stations instantaneously changes from zero to twenty.

time (s)	CW_{min}	Success	Collision	Empty	Efficiency	Fairness
0-0.1	32	33	27	30	0.55	0.45
0.1-0.2	64	53	5	31	0.91	0.62
0.2-0.3	128	56	2	90	0.95	0.72
0.3-0.4	256	56	1	208	0.94	0.80
0.4-0.5	256	57	0	210	0.96	0.87
0.5-0.6	256	56	0	202	0.96	0.93
0.6-0.7	256	57	0	203	0.96	0.93

The results of the simulation are presented in Table 2. It can be observed that the adaptation algorithm repeatedly doubles the contention window to make room for the new entrants. Meanwhile, CSMA/ECA reduces the collisions. As a result, the network is delivering high performance half a second after the sudden increase of the number of contending stations.

6 Conclusions

CSMA/ECA is a contention protocol that is identical to CSMA/CA, with the exception that it uses deterministic backoffs after successful transmission. In previous work, we have shown that CSMA/ECA significantly outperforms CSMA/CA. However, when used with static configuration parameters, CSMA/ECA is not suited for networks where the number of contenders is very large. We have addressed that particular problem in the present paper.

First, we have studied how the performance of CSMA/ECA varies as we change the configuration parameters. We have obtained results both for efficiency and fairness, since they are important measures to evaluate a random medium access control protocol.

We have seen that a theoretical approach that disregards the transient state is not useful to predict the performance of CSMA/ECA in a real network. Therefore, we have also used short simulations that reflect the behaviour of the protocol in a highly dynamic network.

We have used that information to propose an adaptation protocol to guarantee that CW_{min} is within the range of values that deliver high performance. We have verified that the proposed protocol works by means of simulation and we have included an example of the operation of the protocol.

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References

1. IEEE 802.11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification (2007)
2. Cali, F., Conti, M., Gregori, E., Aleph, P.: Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Theoretical Throughput Limit. *IEEE/ACM Trans. Netw.* **8**(6) (2000) 785–799
3. Bianchi, G.: Performance Analysis of the IEEE 802.11 Distributed Coordination Function. *IEEE J. Sel. Areas Commun.* **18**(3) (2000) 535–547
4. Choi, J., Yoo, J., Choi, S., Kim, C.: EBA: An Enhancement of the IEEE 802.11 DCF via Distributed Reservation. *IEEE Trans. Mobile Comput.* **4**(4) (2005) 378–390
5. Crowther, W., Rettberg, R., Walden, D., Ornstein, S., Heart, F.: A System for Broadcast Communication: Reservation-ALOHA. In: *Hawaii Int. Conf. Syst. Sci.* (1973) 596–603
6. Lopez-Toledo, A., Vercauteren, T., Wang, X.: Adaptive Optimization of IEEE 802.11 DCF Based on Bayesian Estimation of the Number of Competing Terminals. *IEEE Trans. Mobile Comput.* **5**(9) (2006) 1283
7. Patras, P., Banchs, A., Serrano, P.: A Control Theoretic Approach for Throughput Optimization in IEEE 802.11 e EDCA WLANs. *Mobile Networks and Applications* (2009) 697–708
8. Barcelo, J., Bellalta, B., Sfairopoulou, A., Cano, C., Oliver, M.: CSMA with Enhanced Collision Avoidance: a Performance Assessment. In: *IEEE VTC Spring*. (2009)
9. Barcelo, J., Bellalta, B., Cano, C., Sfairopoulou, A., Oliver, M.: Carrier Sense Multiple Access with Enhanced Collision Avoidance: a Performance Analysis. In: *ACM IWCMC*. (2009)
10. Barcelo, J., Bellalta, B., Cano, C., Sfairopoulou, A., Oliver, M., Zuidweg, J.: Traffic Prioritization fo Carrience Sense Multiple Access with Enhanced Collision Avoidance. In: *MACOM*. (2009)
11. Barcelo, J., Lopez-Toledo, A., Cano, C., Oliver, M.: Fairness and Convergence of CSMA with Enhanced Collision Avoidance. In: *ICC*. (2010)
12. Eaton, J.W.: *GNU Octave Manual*. Network Theory Limited (2002)
13. Jain, R.: *The Art of Computer Systems Performance Analysis*. John Wiley & Sons New York (1991)