Dynamic Optimization for IEEE 802.11 DCF Access Method over Noisy Channels

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Abstract*-The basic access method in IEEE 802.11 protocol is the distributed coordination function (DCF). This strategy incurs a high collision probability and channel utilization is degraded in bursty arrival or congested scenarios. Besides, when a frame is collided on wired network, extending the backoff time just makes matters worse because it brings bandwidth wastage. In this paper, we attempt to identify the relationship between backoff parameters and channel BER and put forth a pragmatic problem-solving solution. In addition to theoretical analysis, simulations are conducted to evaluate the performance scheme. As it turns out, our design indeed provides a remarkable improvement in a heavy load and error-prone WLANs environment.*

Keywords: DCF, Backoff, BER, Wireless LAN.

1. Introduction

Flexibility and mobility have made wireless local area networks (WLANs) a rapidly emerging field of activity in computer networking, attracting significant interests in the communities of academia and industry [1]-[11]. In the meantime, the IEEE standard for WLANs, IEEE 802.11 [12], has gained global acceptance and popularity in wireless computer networking markets and has also been anticipated to continue being the preferred standard for supporting WLANs applications. In WLANs, the medium access control (MAC) layer protocol is the main element that determines the efficiency of sharing the limited and unreliable communication bandwidth of the wireless channel. For IEEE 802.11 protocol, the basic access method in its MAC layer protocol is the distributed coordination function (DCF). The DCF, designed for supporting asynchronous data transmission, is based on the mechanism of carrier sense multiple access with collision avoidance (CSMA/CA). According to the actual version of the standard, the backoff parameters of its collision avoidance mechanism are *hard-wired* in the physical layer, and are far from the optimal setting in some network configuration conditions especially in congested or noisy scenario.

The collision avoidance portion of CSMA/CA is performed by a variable time-spreading of the users' access. The stations start to transmit their frames in random moments to decrease the probability of collision. However, collisions still occur if two or more stations select the same backoff slot. When this happens, these stations have to reenter the competition with an exponentially increasing backoff parameter value, and the increase of the backoff parameter value after collisions is the mechanism provided by CSMA/CA to make the access adaptive to channel conditions. This strategy avoids long access delays when the load is light because it selects an initial (small) parameter value of contention window (CW) by assuming a low level of congestion in the system. However, it incurs a high collision probability and channel utilization is degraded in bursty arrival or congested scenarios. In other words, this strategy might allocate initial size of CW, only to find out later that it is not enough when the load increased. The size of CW must be reallocated with a larger size, but each increase of the CW parameter value is obtained paying the cost of a collision (bandwidth wastage). Furthermore, after a successful transmission, the size of CW is set again to the minimum value without maintaining any knowledge of the current channel status.

Besides, the performance of CSMA/CA access method will be severely degraded not only in congested scenarios but also when the bit error rate (BER) increases in the wireless channel. One principal problem also comes from the backoff algorithm. In CSMA/CA access method, immediate positive acknowledgement informs the sender of successful reception of each data frame. This is accomplished by the receiver initiating the transmission of an acknowledgement frame after a small time interval, SIFS, immediately following the reception of the data frame. In case an acknowledgement is not received, as we mention above, the sender will presume that the data frame is

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lost due to collision, not by frame loss. Consequently, when a timer goes off, it exponentially increases backoff parameter value and retransmits the data frame less vigorously. The idea behind this approach is to alleviate the probability of collision. Unfortunately, wireless transmission links are noisy and highly unreliable. The proper approach to dealing with lost frames is to send them again, and as quickly as possible. Extending the backoff time just makes matters worse because it brings bandwidth wastage.

Although in the past there were adequate discussions on issues about DCF and the performance thereof, there were few papers on the relationship between backoff parameters and channel bit error rate (BER). In fact, as disclosed by research conducted in the past [1]-[3], the performance of DCF will be significantly affected by channel BER in the wireless channels. That is, the proper choice of the CW parameter values has substantial influence on the network performance. In this paper, we attempt to identify the relationship between backoff parameters and channel BER and put forth a pragmatic problem-solving solution. The proposed distributed adaptive contention window mechanism not only dynamically expands and contracts the contention window size according to the current network contention level and channel BER, but also provably optimal in that it achieves optimal channel utilization for IEEE 802.11 DCF access method. The proposed scheme is performed at each station in a distributed manner, and it can be implemented in the present IEEE 802.11 standard with relatively minor modifications. In addition to theoretical analysis, simulations are conducted to evaluate the performance scheme. The performance of our design is examined in detail. As it turns out, our design indeed provides a remarkable improvement in a heavy load and error-prone WLANs environment especially when the bit error rate is severely degraded.

The remainder of this paper is organized as follows. In Section 2, we describe the proposed scheme in detail. Simulation and experimental results are reported in Section 3. Section 4 concludes this paper.

2. Proposed Scheme

An analytical model has been proposed in [4] and [6], which analyze the performance of DCF without BER and frame loss in the WLANs. Here we extend the analytical model for the above purpose. Our scheme is also based on the results of the capacity analysis model of the IEEE 802.11 protocol originally proposed in [1] and [8] as well as the concept introduced in [5] and [7].

A natural strategy for expansion and contraction is to allocate a new contention window size at the end of each transmission time. However, such a common heuristic would conduct the size of contention window to fluctuate rapidly between expansion and contraction. To avoid this undesirable behavior, each station runs the algorithm to estimate the optimal contention window size, and use the following formula to update its contention window:

$$New\_CW = \chi \cdot Current\_CW + (1-\chi) \cdot Estimate\_Optimal\_CW$$

where $\chi \in [0,1]$ is a smoothing factor. Finally, instead of using the backoff time generation function defined in the IEEE 802.11 standard, we refine the backoff time generation function as $\left\lfloor ranf() \cdot 2^{\lceil \log(New\_CW) \rceil} \right\rfloor \cdot t_{slot}$ to complete our scheme.

3. Simulations Results

Our simulation model is built using the Simscript tool [13]. Performance is measured in terms of the throughput, the average access delay, the dropping probability, the offer-load, among others. The default values used in the simulation are listed in Table I. The values for the simulation parameters are chosen carefully in order to closely reflect the realistic scenarios as well as to make the simulation feasible and reasonable.

Table 1. Default attribute values used in the simulation.

Attribute	Value	Meaning & Explanation
Channel rate	11 Mb/s	Data rate for the wireless channel
Slot_Time	20 us	Time needed for each time slot
SIFS	10 us	Time needed for each short interframe space
DIFS	50 us	Time needed for each DCF interframe space
MAC header	272 bits	Header length of MAC layer header
PHY header	192 bits	Header length of physical layer header
RTS	160 bits + PHY header	Frame length of each request-to-send frame
CTS	112 bits + PHY header	Frame length of each clear-to-send frame
ACK	112 bits + PHY header	Frame length of each Acknowledgement
Time out	300 us	ACK/CTS frame time out
χ	0.5	Smoothing factor
r_c	32 kb/s	Voice source data rate
δ	32 ms	Tolerable jitter for voice source
π	5 ms	Time needed for handoff
d	50 ms	Maximum packet delay for video source

buffer	1 frame	Size of buffer for frames
W	16 slots	Minimum contention window size
m	6	Maximum backoff stages

In what follows, the performances of the proposed scheme and the conventional IEEE 802.11 DCF protocol are compared based on simulations. Figures 1, 2, and 3 show the effect of channel BER by plotting throughput (average bandwidth utilization), frame drop probability, and average frame delay for two representative network sizes (M=5 and 50). As illustrated in Figure 1, the performance of conventional DCF access method was severely degraded when the channel BER increased, but the performance of proposed scheme was satisfactory all the time until the channel BER approximates to 10^{-5}. In fact, we believe that it is almost impossible to increase the probability of success of transmitting a frame excepting frames fragmentation or FEC (Forward Error Control) in an extremely noisy wireless environment.

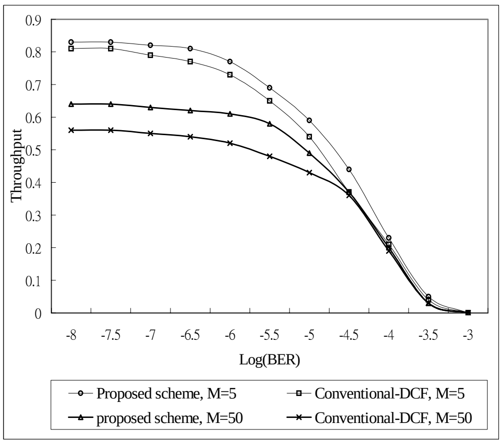

Fig. 1. Throughput against channel BER, for M=5, and 50 respectively.

Figure 2 presents the frame drop probability as a function of the channel BER. We can see that although there is not much difference in the values of the performance measures when BER is low, however, the proposed scheme provides better performance than the conventional DCF access method when the channel BER increased. For voice and video traffic, the allowable loss probability is about 10^{-2} [14] and 10^{-3} [15], respectively. With this criterion, the proposed scheme can tolerate a BER of 10^{-6}. This simulation result reveals that the proposed scheme is appropriate for transmitting high priority real-time traffic such as voice and video traffic in real-time applications. However, the frame drop probability shows a sharp rise as the BER higher than 10^{-4} for both schemes due to the increased number of error transmissions. Conversely, number of stations only marginally affects frame drop probability for proposed scheme.

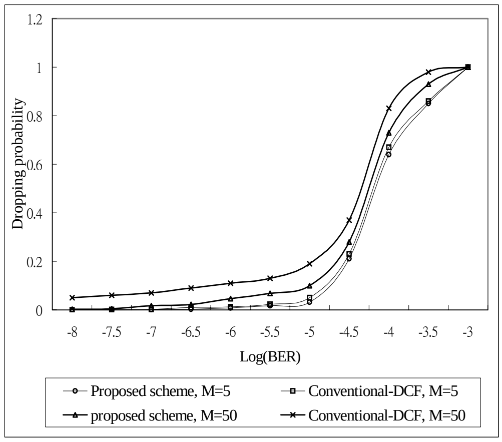

Fig. 2. Dropping probability against channel BER, for M=5, and 50 respectively.

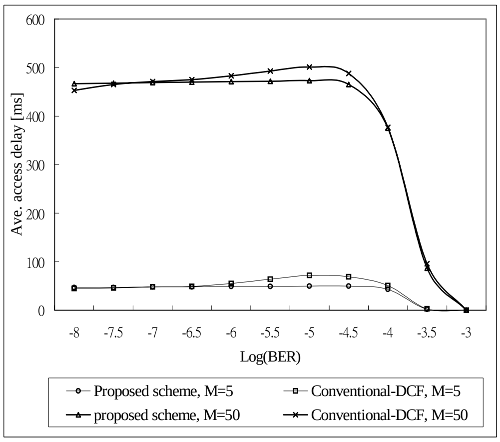

Fig. 3. Average access delay against channel BER, variance=363.65 (proposed scheme, M=5), 561.25 (conventional-DCF, M=5), 29410.25 (proposed scheme, M=50), and 30325.49 (conventional IEEE 802.11, M=50)

As mentioned earlier, in the noisy and highly unreliable wireless environments, the proper approach to dealing with lost frames is to send them again, and as quickly as possible. Extending the backoff time just makes matters worse because it brings bandwidth wastage. In other words, in an environment full of noise and susceptible to interference, the size of CW should not increase with the number of times packets are sent all over again. Hence, we might have an intuition that CW should be inversely proportional to BER. As a matter of fact, as discovered by our research, the initial size of CW should be marginally positively correlated with BER. In Figure 3, we prove that our hypothesis, a relatively large size of CW is recommended in a high-BER environment, is true. As shown in the figure, with the conventional DCF access method, the average access delay increases with channel BER, whereas the increase is moderate if our method is adopted. The increasing frame access delay could result from either retransmitted frames in conventional DCF access method or relatively large size of CW in proposed scheme. However, please note that it will reach a maximum value and then decreases gradually and finally drops to 0 as the simulation outcome obtained in [1]. The reason is that when channel BER is high enough to result in a significant increase in the drop probability, for example, higher than 10^{-4} , frame delay starts decreasing since the long delays of dropped frames do not contribute to the average frame delay. Thus, the low frame access delay values at high BER concern only a small number of successfully received frames due to high drop probability and, therefore, have a very small significance.

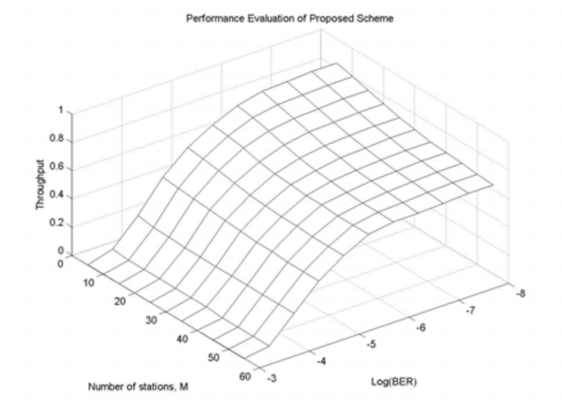

Fig. 4. Throughput versus channel BER and number of stations.

Figure 4 shows the value of the channel BER and the number of stations versus the throughput for the proposed scheme. As the analytical results, it illustrated that the throughput of our scheme is not affected by the channel BER between 10^{-8} to 10^{-5}, but decreases greatly when the channel BER grows to 10^{-4} . Besides, the throughput of our scheme changes little when the number of stations, M , changes. This indicates that, although the proposed scheme has proven it satisfactory superiority in most of the cases, it provides a remarkable improvement over congested and noisy wireless environments.

4. Conclusions

The backoff parameters in IEEE 802.11 DCF access method are far from the optimal setting in heavy-load and error-phone WLANs environment. First, this strategy incurs a high collision probability and channel utilization is degraded in bursty arrival or congested scenarios. Besides, in the noisy and highly unreliable wireless environment, an unacknowledged frame could result from not only collision but also frame loss. When the sender is unable to discriminate the cause of the frame loss, the performance of DCF access method is significantly affected by the channel BER. In this paper, we attempt to identify the relationship between backoff parameters and channel BER and put forth a pragmatic problem-solving solution. The proposed distributed adaptive contention window mechanism not only dynamically expands and contracts the contention window size according to the current network contention level and channel BER, but also provably optimal in that it achieves optimal channel utilization for IEEE 802.11 DCF access method. The proposed scheme is performed at each station in a distributed manner, and it can be implemented in the present IEEE 802.11 standard with relatively minor modifications. Through extensive simulations, we have demonstrated a satisfactory performance of our proposed scheme in a quantitative way. It shows that the proposed scheme has proven it satisfactory superiority in most of the cases. Notable is the remarkable improvement in congested and noisy wireless environments, even with fairly numerous stations.

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