DIDD backoff scheme: An enhancement to IEEE 802.11 DCF under burst transmission errors

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Abstract - ***IEEE 802.11 is the most worldwide established and deployed protocol for Wireless Local Area Networks (WLANs). In this paper, we extend previous work by studying the proposed DIDD (Double Increment Double Decrement) contention window-resetting scheme, which is utilized to enhance IEEE 802.11 performance, under an error-prone environment. By considering both independent and time-variable burst errors, we provide for the first time a simple but comprehensive error performance analysis for both basic access and RTS/CTS medium access mechanisms.***

Keywords: WLANs, IEEE 802.11, DIDD, throughput, packet delay, independent errors, burst errors

I. INTRODUCTION

Wireless Local Area Networks (WLANs) are becoming more and more popular attracting the interest of researchers, system integrators and manufacturers of wireless devices. The IEEE 802.11 protocol [1] is the dominant standard for WLANs and is deployed almost everywhere including offices, public places and homes.

A major thread of research has focused on enhancing IEEE 802.11 protocol performance by proposing various improvements. Authors in [2]-[3] suggested an improvement of the backoff scheme by proposing a slow decrease of the Contention Window (*CW*); their work considers an error-free environment and does not study the packet delay performance improvement. In [4] we have proposed a new and easy-to-implement backoff algorithm, namely DIDD (Double Increment Double Decrement) that gently decreases the *CW* after a successful packet transmission. However, our analysis was carried out under error-free conditions since the probability of a packet received in error was always assumed to be zero (note that when the channel is error-prone, performance degradation can be either due to packet collisions or transmission errors).

Work in [5] and [6] considered independent transmission errors utilizing a Markov chain model to evaluate saturation throughput only. Latest work in [7]-[10] studies error-prone environments for independent errors or only focuses in the effect of retry limits on the IEEE 802.11 performance. Servetti in [14] studies QoS under burst transmission errors but his work is based only in simulation results. Most of work presented in the literature either does not consider transmission errors (independent or in bursts) or the derived analysis is limited only to throughput performance. Moreover, in many cases the mathematical analysis is too complex and, thus, not easily applicable to any network scenario.

In this paper, our approach extends previous work in the literature by taking into account transmission errors and develops a simple and accurate analytical model that calculates throughput and packet delay performance. Transmission errors are categorized to independent with fixed Bit Error Rate (*BER*) and to time-variable burst errors modelled by the widely used two-state Gilbert-Elliot Markov chain model [11]. All previous error-free performance results for the proposed DIDD scheme will be re-examined in the light of realistic link error rate conditions. More specifically, we evaluate the impact of an error-prone channel on unsuccessful transmission probability and its impact on the overall performance in terms of throughput and average packet delay figures.

II. MATHEMATICAL MODELLING

The mathematical modeling of the proposed DIDD backoff scheme can be developed by utilizing three different approaches [4]; we can either employ a 2-dimensional or a 1-dimensional Markov chain model or elementary conditional probability arguments. We follow closely [2][4] by making use of the same assumptions; each station has always a packet ready for transmission and the collision-error probability p_f of a transmitted packet is independent of the number of collisions or errors this packet has suffered in the past.

By utilizing either of the previously mentioned approaches, we can calculate the probability τ that a station transmits a packet in a randomly chosen slot time as [4]:

$$\tau = \frac{2(1-2a)(1-a^{m+1})}{(1-(2a)^{m+1})(1-a)W + (1-2a)(1-a^{m+1})} \quad (1)$$

where $a = p_f / 1 - p_f$, m is the number of backoff stages and p_f is the collision-error probability that a transmitted packet encounters a collision (with probability p) or is received in error (with probability PER):

$$p_f = 1-(1-p)(1-PER) = 1-(1-\tau)^{n-1}(1-BER)^{l+H} \quad (2)$$

where n is the network size, BER the link bit error rate under independent errors, l the packet size and H the packet header length.

Next, we work out an accurate estimate of the link BER for the case of burst errors utilizing the well known Gilbert-Elliott model [11]. The wireless channel is modeled as a discrete time Markov chain and is assumed as having two states; the *GOOD* state (representing the channel under normal conditions) and the *BAD* state (representing a channel fade). Within each state, bit errors occur independently with rates BER_G and BER_B, respectively ($BER_G << BER_B$). The mean sojourn time intervals in the two states i.e. the average time T_{BAD} of transmitting bits in *BAD* (error burst) and T_{GOOD} in *GOOD* (error-free burst) states are given by the following equations:

$$T_{BAD} = \frac{1}{p_{bg}} = \frac{1}{1-p_{bb}} \quad \text{and} \quad T_{GOOD} = \frac{1}{p_{gb}} = \frac{1}{1-p_{gg}} \quad (3)$$

where p_{gb} and p_{bg} represent the transition probabilities from the *GOOD* to the *BAD* state and from the *BAD* to the *GOOD* state respectively and p_{gg} and p_{bb} the probabilities of staying in the *GOOD* and the *BAD* state respectively.

In order to calculate the collision-error probability p_f for the case of burst errors, BER in equation (2) is replaced by either BER_G or BER_B depending whether the wireless channel is in *GOOD* or *BAD* state:

$$p_{f_{GOOD}} = 1-(1-p)(1-PER) = 1-(1-\tau)^{n-1}(1-BER_G)^{l+H} \quad (4)$$

$$p_{f_{BAD}} = 1-(1-p)(1-PER) = 1-(1-\tau)^{n-1}(1-BER_B)^{l+H} \quad (5)$$

Equations (1) and (2), (1) and (4), (1) and (5) form non-linear systems that can be solved using numerical methods and have a unique solution (the proof of the uniqueness is similar to the one in [12]).

A. Saturation throughput efficiency

The system throughput efficiency can be calculated by dividing the time utilized for transmitting payload information in a slot time by the average duration of a slot time $E[slot]$:

$$S_{ie} = \frac{P_{tr}\,P_S\,l/C}{E[slot]} = \frac{P_{tr}\,P_S\,l/C}{(1-P_{tr})\sigma + P_{tr}\,P_S\,T_S + P_{tr}\,P_C\,T_C + P_{tr}\,P_{er}\,T_{er}} \quad (6)$$

where C is the data rate, P_{tr}, P_s, P_c, P_{er} are the probabilities of the events (transmission, successful transmission, packet collision, transmission error respectively) that occur in a randomly chosen slot time and are calculated as a function of τ and p_f [1], σ is the duration of an empty slot time, T_s, T_c and T_{er} are the average time intervals that the medium is sensed busy due to a successful transmission, a collision or an error respectively[2]. The above expression holds only for the case of independent errors.

In the case of burst errors modeled by the Gilbert-Elliott model, a slightly different way to calculate the throughput efficiency is needed. In particular, we calculate throughput efficiency S_{GOOD} for the *GOOD* state and S_{BAD} for the *BAD* state by substituting into equation (6) the corresponding expressions for p_f that can be found in equations (4) and (5). Consequently, system throughput efficiency S_{burst} is calculated by:

$$S_{burst} = \frac{S_{GOOD}\,T_{GOOD} + S_{BAD}\,T_{BAD}}{T_{GOOD} + T_{BAD}} \quad (7)$$

B. Saturation average packet delay

The average packet delay $E[D]$ for a successfully transmitted packet, which is defined to be the time interval from the time a packet is at the head of its MAC queue ready for transmission, until its successful reception can be obtained directly from throughput:

$$E[D] = \frac{n\,l}{S\,C} \quad (8)$$

III. PERFORMANCE EVALUATION

As it was reported earlier, the current work considers two different error models; independent errors with fixed BER and time-variable errors that follow a bursty behavior according to Gilbert-Elliot error model ($BER_G = 10^{-10}$, $BER_B = 10^{-5}$, $T_{GOOD} = 33.333$ and $T_{BAD} = 10$).

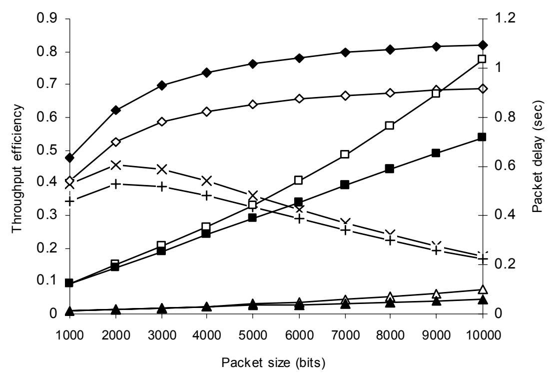
[1] [2] The analytical expressions can be found in [9] and are not reported here due to limited space.

We employ the DSSS physical layer utilized in IEEE 802.11b [1] for C=1 Mbit/s[3].

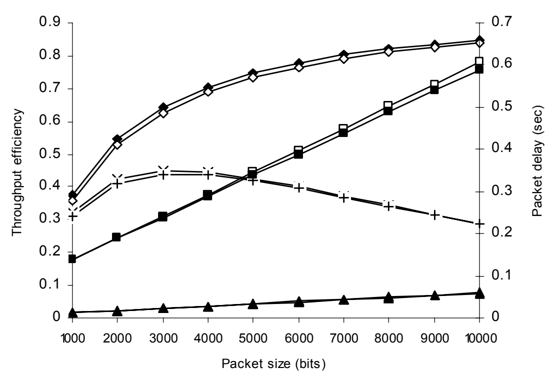
All previous analyses in [12][13] considered a fixed packet size of $l = 8184$ bits. However, the probability of a packet being in error highly depends on packet size apart from *BER*. Therefore, we examine the performance dependency on packet size by plotting throughput and packet delay versus l, for two different network sizes (n=5 and 50).

As it has been shown in [12][13], throughput efficiency increases with increasing packet length in an ideal channel ($BER = 0$) because packet overhead is reduced. In figure 1 we can clearly see that RTS/CTS achieves a better throughput and packet delay performance comparing to basic access due to the reduced collision duration. On the other hand, figure 1 illustrates that, in both basic access and RTS/CTS schemes, under an error-prone environment ($BER = 10^{-4}$),a trade-off exists between the desire to reduce the overhead by adopting a larger packet size and the need to reduce packet error rates by using smaller packet length. The figure clearly shows that there is a packet size that maximizes throughput performance in a heavily error-prone channel. This optimal packet length significantly depends on *BER*. More specifically, in the case of good quality channel ($BER < 10^{-6}$), excessive overhead in each packet actually limits the throughput; larger packet sizes improve throughput performance. As channel conditions deteriorate ($BER = 10^{-4}$), it is better to employ a smaller packet size rather than a large one; the optimal packet length under basic access is approximately equal to 2000 bits (4000 bits in the case of the RTS/CTS scheme) for any network size. Conversely, we see that for large packet and network size values, packet delay considerably increases especially under high *BER* values.

Figure 2 illustrates the effect of packet payload size (l) on throughput and packet delay performance for the employed Gilbert-Elliot burst error model and for both cases of basic access and RTS/CTS schemes. Note that in the Gilbert-Elliot model the *BER* in both the *GOOD* and *BAD* states is relatively low (10^{-10} and 10^{-5}, respectively) in addition to the average time spent on the two states, which is quite high. The figure illustrates that the performance of the proposed DIDD scheme is significantly sensitive to burst errors and to the utilized packet size. An interesting outcome is that the increase of network size plays an important role in attaining high packet delay values under a bursty error-prone environment. Additionally, the figure clearly depicts the advantage of the RTS/CTS mechanism over basic access since. It is not a surprise that the RTS/CTS mechanism achieves very similar performance in both the considered network sizes. This is due to the fact that the throughput and packet delay performance marginally depends on the number of stations.



(a) Basic access



(b) RTS/CTS

◆ Thr. efficien., BER=10^{-6}, n=5 ◇ Thr. efficien., BER=10^{-6}, n=50

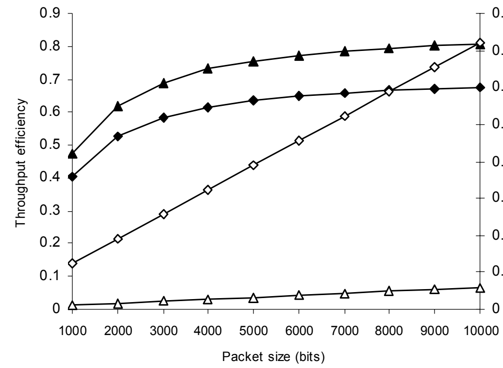
x Thr. efficien., BER=10^{-4}, n=5 + Thr. efficien., BER=10^{-4}, n=50

▲ Packet delay, BER=10^{-6}, n=5 ■ Packet delay, BER=10^{-6}, n=50

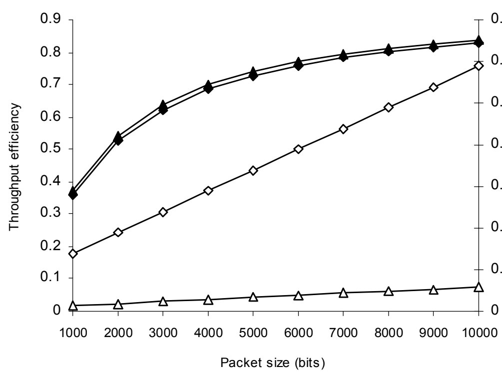
△ Packet delay, BER=10^{-4}, n=5 □ Packet delay, BER=10^{-4}, n=50

Fig. 1 Throughput efficiency and packet delay versus packet size for various network sizes under independent errors (W=32, m=5)

[3] The performance results presented for C=1 Mbit/s can be easily extended for the case of higher data transmission rates of IEEE 802.11a or 802.11b PHY layers.



(a) Basic access



(b) RTS/CTS

▲ Throughput efficiency, n=5 △ Packet delay, n=5

◆ Throughput efficiency, n=50 ◇ Packet delay, n=50

Fig. 2 Throughput efficiency and packet delay versus packet size for various network sizes under burst errors for Gilbert-Elliot model (W=32, m=5, p_{gg}= 0.97, p_{bb}= 0.9, BER_G=10^{-10}, BER_B=10^{-5})

IV. CONCLUSIONS

This paper proposes a new mathematical model that considers both independent and burst transmission errors for the proposed DIDD scheme that can significantly enhance the performance of IEEE 802.11 WLANs. In particular, we provide an extensive burst error analysis utilizing the Gilbert-Elliot model for both basic access and RTS/CTS schemes.

We explore the effect of errors, network and packet size by providing throughput and delay performance results for both the cases of independent and burst transmission errors. The derived results show that the overall performance significantly depends on transmission errors, especially on the time spent in the *GOOD* and *BAD* states when burst errors are being considered.

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