A Linear Back-off Algorithm for IEEE 802.11 Wireless LAN

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Abstract:

The exponential back-off algorithm doubles the back-off size after each collision without considering network traffic status, which causes degradation of system performance. In this paper, we propose a linear random back-off mechanism which dynamically selects the back-off window size based on the channel status which includes the number of active stations and collisions to significantly increase the protocol capacity. We present an analytical model for the saturated throughput of our linear random back-off algorithm. Simulation results show that performance can be substantially enhanced if binary exponential back-off algorithm is replaced by a linear back- off algorithm.

1. INTRODUCTION

In recent years, the proliferation of portable and laptop computers has led to LAN technology being required to support wireless connectivity. Besides providing for computers mobility, wireless LANs (WLANs) are easier to install and save the cost of cabling. Since a WLAN relies on a common transmission medium, the transmissions of the network stations must be coordinated by the medium access control (MAC) protocol.

The IEEE 802.11 protocol uses a set of slotted windows for the back-off, whose size is doubled after each collision. Previous works [6~8] have shown that the exponential back-off mechanism of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol suffers from several performance drawbacks including unfairness problem and degradation of performance such as throughput and the packet transfer delay due to a number of collisions at high traffic intensities.

In this paper, we propose a linear back-off algorithm to dynamically tune the back-off window size depending on the channel status which includes the number of active stations and collisions. We present an analytical model for the saturated throughput of our linear random back-off algorithm. Simulation results show that performance can be substantially enhanced if binary exponential back-off algorithm is replaced by a linear back-off algorithm.

The paper is organized as follows. Section 2 briefly presents IEEE 802.11 DCF (Distributed Coordination Function) and examine problems of the exponential back-off algorithm. In Section 3, our linear random back-off algorithm is described and an analytical model for the saturated throughput is presented. Numerical results obtained from analytical model and experiments are presented in Section 4. Finally, we conclude the paper in Section 5.

2. IEEE 802.11 DCF

The DCF uses the Binary slotted Exponential Back-ff mechanism (BEB) to avoid the collision. The BEB algorithm used in wireless network operates in the following way. If a packet has been transmitted unsuccessfully i times, the packet will be retransmitted again k slots later, where k is a random number uniformly distributed over the interval of $[0, 2^{3+i}-1]$ If a packet is transmitted successfully or is expired and dropped, i is reset to 0.

The philosophy behind the BEB algorithm is that, for a given packet, a number of unsuccessful retransmissions imply that more stations are competing for the available bandwidth, and, as a result, a larger back-off window should be adopted to reduce the probability of collision.

However, the BEB has several problems. First, the BEB has unfairness problem in the saturation condition. Under high loads, some stations which has lost in a competition, and joins another competition. At this time, there may be some new joiners attending the competition, and they are given shorter CW's by the BEB. So, the new joiners have a higher probability than the backlogged stations since their slots can be positioned earlier in CW. This is undesirable because the slots that have been chosen are more likely to be chosen again.

Second, the BEB may generate a number of collisions at high traffic intensities, as a result, a long contention interval is required to determine the winner. This results in degradation of performance such as throughput and packet transfer delay.

3. A LINEAR RANDOM BACK-OFF ALGORITHM

To alleviate the problems of the BEB, we propose a linear random back-off algorithm, which dynamically tunes the length of CW depending on the channel status. Our algorithm determines CW size depending on two network parameters reflecting the network traffic status which include the number of active stations and the number of collisions.

Let M denote the average number of empty slots in a frame. In our algorithm, if a packet has been transmitted unsuccessfully i times in the n^th^ frame, the station will try to transmit the packet again k slots later, where k

is a random number uniformly distributed over the interval of $[0,(i+1)\cdot K_n]$, where K_n is the number of active stations in the current frame.

Provided that the average number of the empty slots in a virtual transmission time is known, the value of can be estimated from the following analytical formula induced by Cali [2]

$$K_n = \frac{1-q}{M \cdot q} \qquad (1)$$

where q means the average back-off interval.

In our algorithm, we use a weighted moving average estimator to obtain the value of K_{n+1} for minimizing the bias against transient situations. So, we have

$$K_{n+1} = \alpha K_{n-1} + (1-\alpha)K_n \qquad (2)$$

where α is the smoothing factor between 0 and 1.

4. MODEL VALIDATION OF A LINEAR RANDOM BACK-OFF ALGORITHM

Giuseppe proposed an analytical model for the IEEE 802.11 DCF based on the bi-dimensional discrete-time Markov chain which represented the back-off stage (the number of collisions) and back-off window size of the station at time t [3]. We use his model to analyze our algorithm as illustrated in Fig. 1 where means the collision probability, and mean maximum back-off stage.

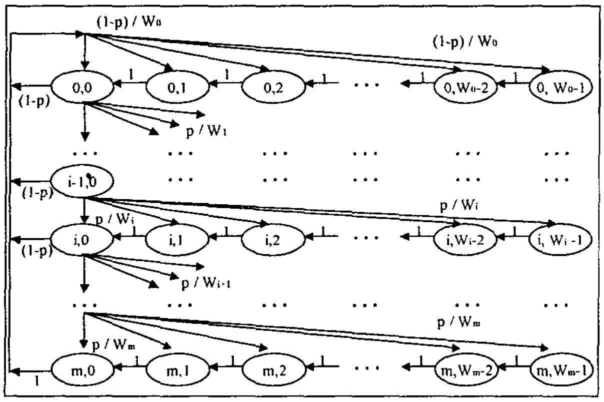

Fig 1. Markov chain for CW

In our linear algorithm, the back-off time W_i is expressed by.

$$W_i = (i+1)\cdot K \qquad i \in (0,m) \qquad (3)$$

The transition probabilities of Markov chain are

$$P\{i,k \mid i,k+1\} = 1 \qquad k \in (0,W_i - 2) \quad i \in (0,m) \qquad (4a)$$

$$P\{0,k \mid i,0\} = \frac{1-p}{W} \qquad k \in (0,W-1) \quad i \in (0,m) \qquad (4b)$$

$$P\{i,k \mid i-1,0\} = \frac{p}{W_i} \qquad k \in (0,W_i - 1) \quad i \in (1,m) \qquad (4c)$$

$$P\{0,k \mid m,0\} = \frac{p}{W} \qquad k \in (0,W-1) \qquad (4d)$$

$$P\{0,k \mid 0,0\} = \frac{1-p}{W} \qquad k \in (0,W-1) \qquad (4e)$$

Eq. (4a) accounts the back-off counter decrement, and Eq. (4b) accounts that a new packet chooses the back-off counter in the range $[0,K-1]$ after a successful transmission at the back-off stage i. Eq. (4c) accounts that the station experiences a collision at the back-off stage $i-1$. Eq. (4d) accounts that CW is reset when the transmission is successful or unsuccessful; that is, the maximum retransmission limit is over because of collision, and then the station chooses initially the back-off counter for a new packet. Eq. (4e) accounts that a new packet chooses the back-off counter in the range $[0,K-1]$ after a successful transmissions.

Let $b_{i,k}$ be the stationary distribution of the Markov chain, then we have

$$b_{i,0} = p^i \cdot b_{0,0} \qquad 0 \le i \le m \qquad (5)$$

from the following recursive relationship between the consecutive distributions :

$$b_{i,0} = p \cdot b_{i-1,0} \qquad 0 < i \le m \qquad (6)$$

Because the chain is regular, we have

$$b_{i,k} = \frac{W_i - k}{W_i} \cdot \begin{cases} (1-p)\sum_{j=0}^{m} b_{j,0} + b_{m,0} & i = 0 \\ p \cdot b_{i-1,0} & 0 < i \le m \end{cases} \qquad (7)$$

Substituting (5) into (7), we can rewrite

$$b_{i,k} = \frac{W_i - k}{W_i} \cdot b_{i,0} \qquad 0 \le i \le m \quad 0 \le k \le W_i - 1 \qquad (8)$$

Since $1 = \sum_{i=0}^{m}\sum_{k=0}^{W_i-1} b_{i,k} = \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i - k}{W_i}$, we get

$$b_{0,0} = \frac{2(1-p)^2}{N\left[(1-p^{m+1})(2-p)-(1-p)(m+1)p^{m+1}\right]+(1-p^{m+1})(1-p)} \qquad (9)$$

The probability ϖ that a station transmits a frame in a randomly chosen slot time when its back-off counter reaches zero can be obtained by

$$\varpi = \sum_{i=0}^{m} b_{i,0} = \frac{1-p^{m+1}}{1-p} b_{0,0} = \frac{2}{1+2N} \qquad (10)$$

where $b_{0,0}$ is obtained from (9).

Since each station transmits a packet with probability ϖ in the steady state, there is a collision when at least one of the $n-1$ remaining stations try to transmit. So, the collision probability p can be expressed by

$$p = 1-(1-\varpi)^{n-1} \qquad (11)$$

Let P_t denote the probability that there are at least one transmission in a given slot time. Then, since n stations contend to access the medium and each station transmits with probability ϖ, is given by

$$P_t = 1-(1-\varpi)^n \qquad (12)$$

Let P_S denote the probability of successful transmission, which means the probability that a station is transmitting and the remaining $n-1$ stations remain silent. Then, we have

$$P_s = \frac{n\varpi(1-\varpi)^{n-1}}{P_t} = \frac{n\varpi(1-\varpi)^{n-1}}{1-(1-\varpi)^n} \qquad (13)$$

Finally, we can express channel utilization S by dividing the time needed to transmit payload information transmitted in a slot time with the average length of a slot time :

$$\begin{aligned} S &= \frac{E[Payload\ transmission\ time]}{E[total\ time]} \\ &= \frac{P_s P_t T_P}{(1-P_t)\delta + P_s P_t T_F + (1-P_s)P_t T_F} \end{aligned} \qquad (14)$$

where T_F is a frame transmission time, and T_P is a constant payload transmission time.

5. SIMULATION

In this section, we evaluate performance of our linear random back-off algorithm. The system model for analysis is a Basic Service Set of wireless LAN which consists of an Access Point (AP) and stations. It is assumed that all stations only transmit their packets to AP and AP does not generate its own packets except ACK packets.

Several assumptions have been made to reduce the complexity of the simulation model :

- The effects of propagation delay are neglected.
- The channel is error-free that means that each transmitted packet was successfully and correctly received at its destination.
- Channel is in the saturation state.

In addition, each station is assumed to be a Poisson traffic source and the parameters used for performance evaluation are listed in Table 1.

Table 1 Simulation parameters

Symbol	Meaning	Value(802.11a)
N	Number of Stations	Variable
T_{slot}	ASlot_Time	9us
T_D	DIFS	34us
T_{ACK}	ACK transmission time	5us
T_P	Packet transmission time	45us
R	PHY rate	24us

Fig. 2 shows saturated channel utilizations of the linear back-off algorithm obtained from analytical model and simulation. In this figure, we can see a sound agreement between analytical and simulation results.

Fig 3 shows throughput in the saturation state. As observed in this graph, our mechanism offers a higher throughput than the BEB algorithm in the saturation status.

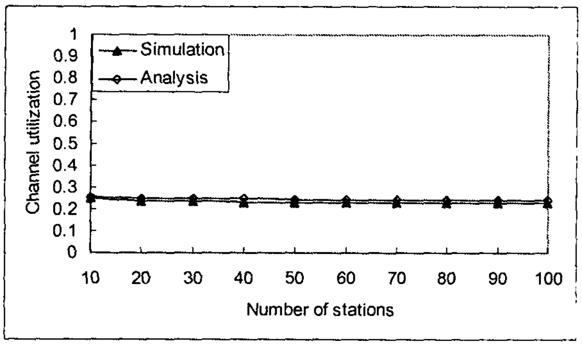

Fig. 2. Saturation channel utilization of linear back-off algorithm

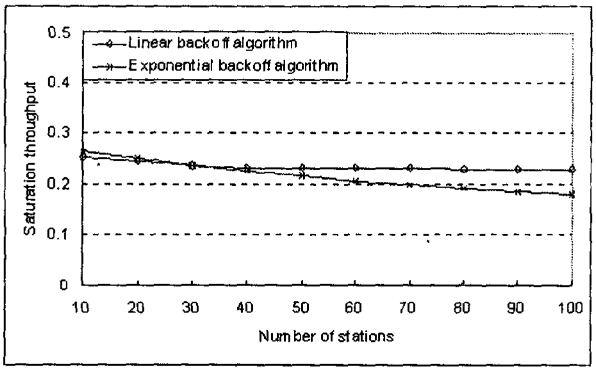

Fig. 3. Saturation throughput of linear and exponential backoff algorithms

Fig. 4 indicates that the BEB algorithm provides fewer a collisions than our algorithm under relatively low traffic loads since it uses a longer CW. However, our algorithm shows a better performance at high traffic intensities because it adjusts CW size reflecting the channel status.

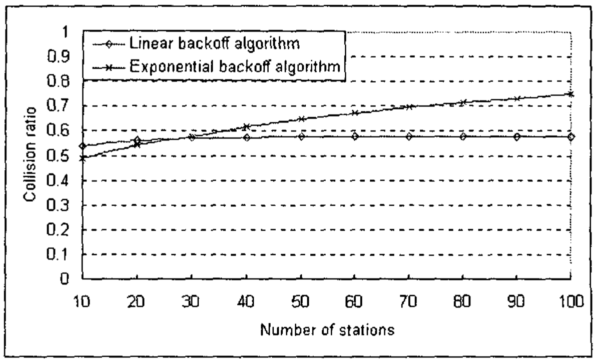

Fig. 4. Collision ratio of linear and exponential back-off algorithm

6. CONCLUSION

The back-off algorithm has a large influence on the network performance in wireless MAC protocol. We proposed a linear back-off algorithm which selects back-off time based on the number of collisions and the active stations to enhance the performance. From analytical model and simulations, we have shown that performance could be substantially enhanced if binary exponential back-off algorithm is replaced by the linear back-off algorithm.

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