Backoff Algorithm Optimization for IEEE802.11 Wireless Local Area Networks

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***Abstract*- In this paper, we propose a new backoff algorithm for wireless local area networks (WLANs). The proposed algorithm develops by using mathematical optimization function theory on Carrier Sensing Multiple Accesses with Collision Avoidance and Request-to-Send Clear-to-Send protocol (CSMA/CA RTS CTS). A new backoff algorithm is named Contending Stations Backoff Algorithm (CSBA). The performance of CSBA compares with old backoff algorithms such as Binary Exponential Backoff algorithm (BEB), Double Increment Double Decrement Backoff algorithm (DIDD) and Estimation Based Backoff algorithm (EBB) by mathematical analysis. We analyze performance of CSBA in distribute coordination function mode for IEEE802.11a/b/g standards. Our numerical results indicate that the performance of CSBA algorithm is stable than old backoff algorithms in term of saturation throughput efficiency.**

Keywords-CSMA/CA RTS CTS; CSBA; BEB; DIDD; EBB; IEEE802.11a/b/g; DCF; WLANs

I. INTRODUCTION

Today, Wireless Local Area Network (WLAN) is becoming increasingly important. The IEEE802.11 is one of the most popular WLAN standards. In WLAN system, medium access control (MAC) techniques use carrier sensing multiple access with collision avoidance (CSMA/CA) in distribute coordination function (DCF) mode. In CSMA/CA techniques, there are two access methods: Basic access and Request-to-Send (RTS) and Clear-to-Send (CTS) access methods. RTS/CTS technique has been introduced to reduce the performance degradation due to hidden terminal. This paper considers only CSMA/CA protocol by using RTS/CTS technique. Currently, WLAN system resolves collision problems by used backoff algorithm. High channel throughput and low delay are two important characteristics of a good backoff algorithm. The legacy backoff algorithms such as Binary Exponential Backoff (BEB) in [4] [5], Double Increment Double Decrement (DIDD) backoff Algorithm in [6] and Estimation Based Backoff (EBB) Algorithm in [7] are considered in this research. A big problem of old backoff algorithms is that the throughput performances are unstable when the numbers of contending stations in service area are increased. In this paper, we study the optimization function theory for improved throughput efficiency of backoff algorithm in IEEE802.11 standards. In this research, we assume that

- Channel is ideal condition and no capture effect
- Channel is saturated condition
- All stations know the total of station in service area

The paper is organized as follows: In section II, we review discrete Markov chain model for IEEE802.11 WLAN. In section III, the old backoff algorithms are analyzed. In section IV, we introduce Contending Stations Backoff Algorithm (CSBA) and throughput calculation procedures. The numerical results discuss in section V. Finally, section VI is the conclusion.

II. DISCRETE MARKOV CHAIN MODEL

A. Two Dimensions Discrete Markov Chain Model

Giuseppe Bianchi in [4] developed a simple discrete Markov chain model for IEEE802.11 DCF shown in Fig.1. This model evaluates performance of the DCF under error-free channel. Each transmission ignores the number of retransmissions and the packet collides with a constant probability (p).

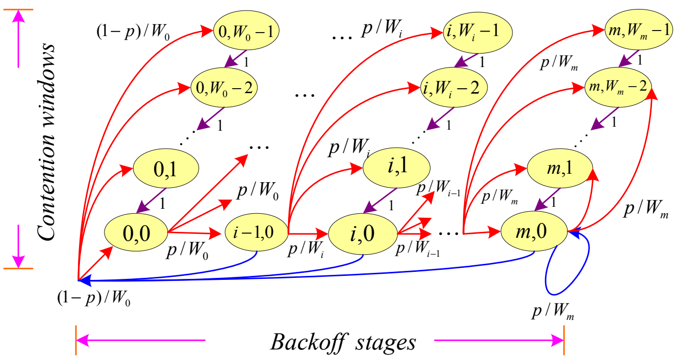

Figure 1. Discrete Markov chain model (Bianchi's model).

Let τ is the transmission probability that depends on the collision probability (p) and contention window (CW). The contention windows determine by the Physical layer characteristics. From Bianchi's model, we have

$$\tau = \frac{2(1-2p)(1-p)^{m+1}}{(1-2p)+CW[(1-2p)+p(1-(2p)^m)]} \quad (1)$$

Parameter p is the collision probability that at least one of the n -1 remaining stations transmit in the same time slot. If we assume that all stations see the system at steady state and transmit with probability τ . The collision probability p is given by

$$p = 1-(1-\tau)^{n-1} \quad (2)$$

Equations (1) and (2) represent a non-linear system with two unknown τ and p, which can be solved using numerical techniques.

B. Saturation Throughput

In [4], the author has represented saturation throughput that has denoted as S, as follow

$$Throughput = S = \frac{E[Payload\ \ Information\ \ in\ \ a\ \ slot\ \ time]}{E[Length\ \ of\ \ a\ \ slot\ \ time]}$$

$$S = \frac{P_S P_{tr}(MSDU \times 8)}{(1-P_{tr})T_{slot} + P_S P_{tr} T_S + P_{tr}(1-P_S)T_C} \quad (3)$$

$$P_{tr} = 1-(1-\tau)^n \quad (4)$$

$$P_S = \frac{P_{Success}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \quad (5)$$

Where P_{tr} is the probability that in a slot time there is at least one transmission

P_s is successful probability in a slot time

$MSDU$ is MAC service data unit size in bytes

$P_{tr}P_S$ is probability of successful transmission

$(1-P_{tr})$ is probability that a slot time is empty

$P_{tr}(1-P_S)$ is probability of collision transmission

T_C is collision transmission time in µs

T_S is successful transmission time in µs

m is maximum back off stages

n is the number of contending stations

III. The Legacy Backoff Algorithms

Binary Exponential Backoff (BEB) Algorithm in [4] and [5] has been the contention window size for backoff stage i. The algorithm of BEB is specified by the following.

$$CW_{BEB} = 2^i(CW_{\min}+1) \qquad i = 0,1,2,\ldots m \quad (6)$$
$$m = \log_2(CW_{\max}/CW_{\min})$$

The contention window is initially set to be $CW_{\min}$. If the transmission fails i stage, then the contention window is increased by 2^i.The $CW_{\min}$ is minimum contention window size and $CW_{\max}$ is the maximum contention window size. P. Chatzimisios *et al.* in [6] proved Double Increment Double Decrement (DIDD) backoff algorithm which has contention window size for backoff stage i as

$$CW_{DIDD} = [2(1-2a)(1-a^{m+1}) - \tau(1-2a)]/\tau(1-(2a)^{m+1})(1-a)$$
$$a = p/(1-p) \quad (7)$$

S. Won Kang *et al.* in [7] showed Estimation-Based Backoff (EBB) algorithm that has been the optimal contention window.

$$CW_{EBB} \approx n \quad (8)$$

Where n is the number of contending stations

IV. Contending Stations Backoff Algorithm (CSBA)

We modify the throughput equation in (3) of Bianchi's model by using optimization function theory [8]. The throughput equation (S) is a function of contention window (CW) and differentiating throughput respects to contention window (CW). The derivative can be expressed as

$$\frac{dS}{dCW} = \frac{d}{dCW}\left[\frac{P_S P_{tr}(MSDU \times 8)}{(1-P_{tr})T_{slot} + P_{tr}P_S T_S + P_{tr}(1-P_S)T_C}\right] \quad (9)$$

Clearly, optimum function occurs where the slop is zero or the throughput is greatest.

$$\frac{d}{dCW}\left[\frac{P_S P_{tr}(MSDU \times 8)}{(1-P_{tr})T_{slot} + P_S P_{tr} T_S + P_{tr}(1-P_S)T_C}\right] = 0 \quad (10)$$

From (1) (4) and (5), substituting in (10) yields

$$\frac{d}{dCW}\left[\frac{A(MSDU \times 8)}{BT_{slot} + AT_S + CT_C}\right] = 0$$

$$\left[\begin{array}{l}\dfrac{(MSDU \times 8)}{[BT_{slot} + AT_S + CT_C]}\dfrac{dA}{dCW} - \\ \dfrac{A(MSDU \times 8)}{[BT_{slot} + AT_S + CT_C]^2}\dfrac{d}{dCW}[BT_{slot} + AT_S + CT_C]\end{array}\right] = 0 \quad (11)$$

Where
$$A = \left[\frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n}\right]\left[1-(1-\tau)^n\right]$$
$$B = 1-(1-(1-\tau)^n) = (1-\tau)^n$$
$$C = \left[1 - \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n}\right]\left[1-(1-\tau)^n\right]$$

and
$$\tau = \frac{2(1-2p)(1-p)^{m+1}}{(1-2p) + CW[(1-2p) + p(1-(2p)^m)]}$$

Finally, we have an optimum contention window

$$CW_{optimum} = \frac{[2(1-2p)(1-p)^{m+1} - (1-2p)]}{T_C} \quad (12)$$

When the optimal contention window relates to contending stations in backoff mode, a new backoff algorithm is given by

$$CW_{CSBA} = \frac{[2(1-2p)(1-p)^{m+1} - (1-2p)] \times n}{T_C} \quad (13)$$

Equation (13) is Contending Stations Backoff Algorithm (CSBA). In modeling of single hop wireless local area network, all of these models assume to use saturated traffic load which mean a node always has a packet ready for transmission. The data frame exchange sequence of CSMA/CA in RTS CTS mechanism for IEEE802.11a/b/g standards is shown in Fig. 2. Before transmitting a data frame MSDU (MAC service data unit), a shot RTS frame is transmitted. If the RTS frame success, the receiver station responds with a shot CTS frame. Then, a data frame and an ACK frame will follow. All four frames (RTS, CTS, DATA and ACK) are separated by SIFS time.

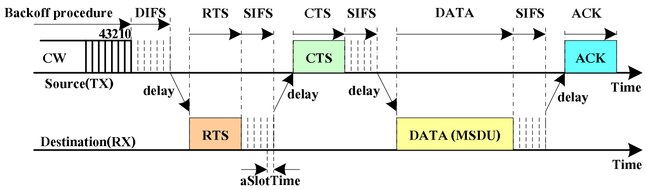

Figure 2. Data transmission procedure of CSMA/CA RTS CTS Protocol

Where DIFS is Distributed Inter Frame Space (µs)
SIFS is Shot Inter Frame Space (µs)
RTS is Request-to-Send frame (µs)
CTS is Clear-to-Send frame (µs)
ACK is Acknowledgement frame (µs)
MSDU is MAC Service Data Unit frame (bytes)

The time periods of T_S and T_C for CSMA/CA RTS CTS protocol are obtained as follows

$$T_{S[CSMA/CA\ RTS\ CTS]} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{ACK} + T_{DIFS} \quad (14)$$

$$T_{C[CSMA/CA\ RTS\ CTS]} = T_{DIFS} + T_{RTS} + T_{delay} \quad (15)$$

$$T_{MSDU} = \frac{MSDU \times 8}{Data\ rate} \quad (16)$$

MathCAD engineering tool [9] is used for calculation the throughput efficiency. In analysis, we use same parameters for all backoff algorithms in CSMA/CA RTS CTS access method that are listed in table I. The calculation algorithm is given by

Begin

Step 1: Fixed parameters p:=0.05, m:=6, MSDU:=2500 n:= 1..40

Step 2: calculated contention windows of BEB algorithm by used equation (6)

Step 3: calculated contention windows of DIDD algorithm by used equation (7)

Step 4: calculated contention windows of EBB algorithm by used equation (8)

Step 5: calculated contention windows of CSBA algorithm by used equation (13)

Step 6: calculated τ by used equation (1)

Step 7: calculated P_{tr} by used equation (4)

Step 8: calculated P_S by used equation (5)

Step 9: calculated $T_{S[CSMA/CA\ RTS\ CTS]}$ by used equation (14)

Step 10: calculated $T_{C[CSMA/CA\ RTS\ CTS]}$ by used equation (15)

Step 11: calculated throughput of BEB, DIDD, EBB and CSBA algorithm by used equation (3)

End

The slot lengths and the duration of spacing in the different standards are shown in Table I.

TABLE I.
THE TRANSMISSION TIMES IN CSMA/CA RTS CTS PROTOCOL [1] [2] [3]

Transmissions description	802.11a	802.11b	802.11g
T_{SIFS}	16 µs	10 µs	10 µs
T_{DIFS}	34 µs	50 µs	28 µs
$T_{aSlotTime}$	9 µs	20 µs	9 µs
T_{delay}	1 µs	1 µs	1 µs
T_{RTS} OFDM 24-Mbps	28 µs	-	34 µs
T_{CTS} OFDM 24-Mbps	28 µs	-	32 µs
T_{ACK} OFDM 24-Mbps	28 µs	-	32 µs
T_{RTS} OFDM 54-Mbps	24 µs	-	30 µs
T_{CTS} OFDM 54-Mbps	24 µs	-	30 µs
T_{ACK} OFDM 54-Mbps	24 µs	-	30 µs
T_{RTS} HR 11-Mbps	-	352 µs	-
T_{CTS} HR 11-Mbps	-	304 µs	-
T_{ACK} HR 11-Mbps	-	304 µs	-
CWmin	15 SlotTimes	31 SlotTimes	16 SlotTimes
CWmax	1023 SlotTimes	1023 SlotTimes	1024 SlotTimes

V. NUMERICAL RESULTS

In this section, we show some numerical results of proposed backoff algorithm. Figure 3 represents the saturation throughput of CSBA algorithm in IEEE802.11a standard and we compare the performance of CSBA with BEB, DIDD and EBB algorithms. From the result, the throughput of CSBA yields better performance than BEB, DIDD and EBB algorithms when the contention windows and data rate are fixed at 24-Mbps and 15xaSlotTimes, respectively.

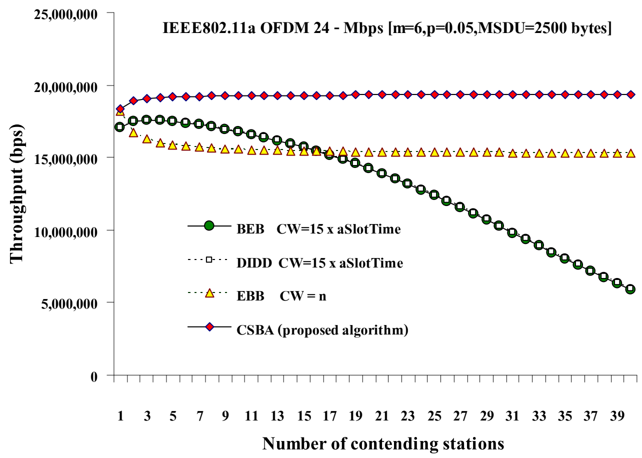

Figure 3. Throughput performance of CSBA in IEEE802.11a standard.

In Fig.4, we choose parameters of IEEE802.11b at data rate 11-Mbps standard. The maximum backoff stage (m) is 6, collision probability (*p*) is 0.05, MAC service data unit size (MSDU) is 2500 bytes and contention window of BEB and DIDD algorithms are 31xaSlotTimes, respectively. In this case, we can see that the throughput efficiency of CSBA algorithm is higher than BEB, DIDD and EBB algorithms.

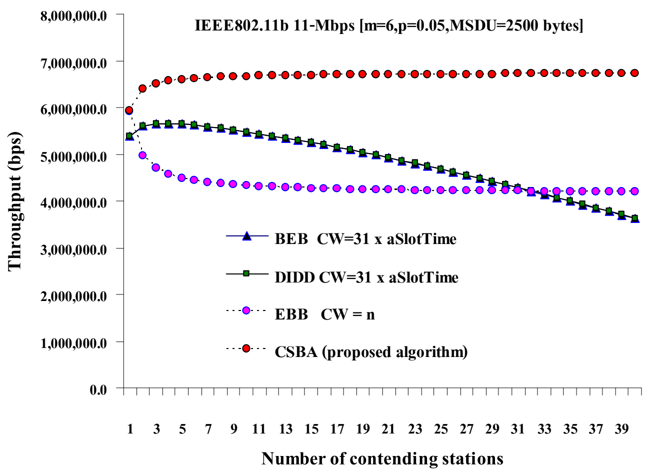

Figure 4. Throughput performance of CSBA in IEEE802.11b standard.

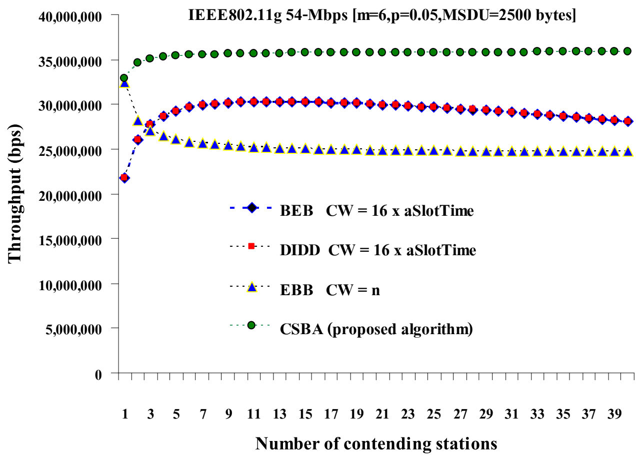

Figure 5. Throughput performance of CSBA in IEEE802.11g standard

Figure 5 illustrates saturation throughput of CSBA in IEEE802.11g standard when the data rate is fixed at 54-Mbps and the contending stations are increased. From the comparison results in this case, CSBA algorithm seem to stabilize when the number of contending stations is increased.

VI. Conclusion

In this research, we present a new backoff algorithm for CSMA/CA RTS CTS protocol in IEEE802.11a/b/g WLAN standards. The proposed backoff algorithm is called Contending Stations Backoff Algorithm (CSBA). The numerical results show that the performance of CSBA algorithm is stable when the number of stations is changed. The comparison results guarantee that mathematical optimization techniques can improve the performance of backoff algorithm. Next step, we will be interesting to see results when the backoff stages, collision probability and MSDU sizes will be changing in program procedure. As future work, we will plan to investigate the performance of CSBA in non-saturated and fading channel in IEEE802.11e and IEEE802.11n wireless local area network by using Network Simulator-2 on Linux Ubuntu-11.10.

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