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).

Let \( \tau \) is the transmission 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 \( \tau \). The collision probability \( p \) is given by

Let \( C \) is the number of contention window (CW), \( W \) is the contention window size and \( m \) is the number of stations transmits in the same time slot. Then, the transmission probability \( \tau \) can be calculated as

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

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 all stations see the system at steady state and transmit with probability \( \tau \). The collision probability \( p \) is given by

\[
p = \frac{1}{2^n - 1}
\]
\[ p = 1 - (1 - \tau)^{n-1} \] (2)

Equations (1) and (2) represent a non-linear system with two unknown \( \tau \) 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

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

\[ S = \frac{P_vP_s(\text{MSDU} \times 8)}{(1 - P_v)T_{\text{slot}} + P_sP_vT_s + P_v(1 - P_s)T_c} \] (3)

\[ P_v = 1 - (1 - \tau)^n \] (4)

\[ P_s = \frac{P_{\text{Success}}}{P_v} = \frac{n \tau(1 - \tau)^{n-1}}{1 - (1 - \tau)^n} \] (5)

Where \( P_v \) is the probability that in a slot time there is at least one transmission

\( P_s \) is successful probability in a slot time

\( \text{MSDU} \) is MAC service unit size in bytes

\( P_v, P_s \) is probability of successful transmission

\( 1 - P_v \) is probability that a slot time is empty

\( P_s(1 - P_v) \) is probability of collision transmission

\( T_c \) is collision transmission time in \( \mu s \)

\( T_s \) is successful transmission time in \( \mu s \)

\( m \) 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.

\[ \text{CW}_{\text{BEB}} = 2^i(\text{CW}_{\text{min}} + 1) \]

\[ m = \log_2(\text{CW}_{\text{max}} / \text{CW}_{\text{min}}) \] (6)

The contention window is initially set to be \( \text{CW}_{\text{min}} \). If the transmission fails \( i \) stage, then the contention window is increased by \( 2^i \). The \( \text{CW}_{\text{min}} \) is minimum contention window size and \( \text{CW}_{\text{max}} \) 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

\[ \text{CW}_{\text{DIDD}} = \left[ 2(1 - 2a)(1 - a^{n-1}) - \tau(1 - 2a) \right] / \tau(1 - (2a)^{n-1})(1 - a) \]

\[ a = p / (1 - p) \] (7)

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

\[ \text{CW}_{\text{EBB}} = n \] (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 (5) is a function of content window (CW) and differentiating throughput respects to contention window (CW). The derivative can be expressed as

\[ \frac{dS}{d\text{CW}} = \frac{d}{d\text{CW}} \left[ \frac{P_vP_s(\text{MSDU} \times 8)}{(1 - P_v)T_{\text{slot}} + P_sP_vT_s + P_v(1 - P_s)T_c} \right] \] (9)

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

\[ \frac{d}{d\text{CW}} \left[ \frac{P_vP_s(\text{MSDU} \times 8)}{(1 - P_v)T_{\text{slot}} + P_sP_vT_s + P_v(1 - P_s)T_c} \right] = 0 \] (10)

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

\[ \frac{d}{d\text{CW}} \left[ \frac{A(\text{MSDU} \times 8)}{(BT_{\text{slot}} + AT_s + CT_c) d\text{CW}} \right] = 0 \]

\[ \frac{d}{d\text{CW}} \left[ \frac{(\text{MSDU} \times 8)}{(BT_{\text{slot}} + AT_s + CT_c)^2 d\text{CW}} \right] = 0 \] (11)

Where

\[ A = \left[ n \tau(1 - \tau)^{n-1} / 1 - (1 - \tau)^n \right] \]

\[ B = 1 - (1 - (1 - \tau)^n) = (1 - \tau)^n \]

\[ C = \left[ n \tau(1 - \tau)^{n-1} / 1 - (1 - \tau)^n \right] \]

And

\[ \tau = \frac{2(1 - 2p)(1 - p)^{n-1}}{(1 - 2p) + \text{CW}[1 - (2p) + p(1 - (2p)^{n})]} \]

Finally, we have an optimum contention window

\[ \text{CW}_{\text{optimal}} = \left[ 2(1 - 2p)(1 - p)^{n-1} - (1 - 2p) \right] / T_c \]

(12)

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

\[ \text{CW}_{\text{CSBA}} = \left[ 2(1 - 2p)(1 - p)^{n-1} - (1 - 2p) \right] \times n / T_c \] (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](image)

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

$$T_{(CSMA/CA\ RTS\ CTS)} = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(802.11a)} + T_{ACK} + T_{DIFS}$$

$$T_{(CSMA/CA\ RTS\ CTS)} = T_{DIFS} + T_{RTS} + T_{delay}$$

$$T_{MSDU} = \frac{MSDU \times 8}{Data\ rate}$$

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

Step 1: Fixed parameters $p:=0.05, m:=6, MSDU:=2500$

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 $\tau$ by used equation (1)

Step 7: calculated $P_o$ by used equation (4)

Step 8: calculated $P_s$ by used equation (5)

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

Step 10: calculated $T_{(CSMA/CA\ RTS\ CTS)}$ 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.**

<table>
<thead>
<tr>
<th>Transmissions description</th>
<th>802.11a</th>
<th>802.11b</th>
<th>802.11g</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{SIFS}$</td>
<td>16 µs</td>
<td>10 µs</td>
<td>10 µs</td>
</tr>
<tr>
<td>$T_{DIFS}$</td>
<td>34 µs</td>
<td>50 µs</td>
<td>28 µs</td>
</tr>
<tr>
<td>$T_{\text{SlotTime}}$</td>
<td>9 µs</td>
<td>20 µs</td>
<td>9 µs</td>
</tr>
<tr>
<td>$T_{delay}$</td>
<td>1 µs</td>
<td>1 µs</td>
<td>1 µs</td>
</tr>
<tr>
<td>$T_{RTS\ OFDM\ 24-Mbps}$</td>
<td>28 µs</td>
<td>-</td>
<td>34 µs</td>
</tr>
<tr>
<td>$T_{CTS\ OFDM\ 24-Mbps}$</td>
<td>28 µs</td>
<td>-</td>
<td>32 µs</td>
</tr>
<tr>
<td>$T_{ACK\ OFDM\ 24-Mbps}$</td>
<td>28 µs</td>
<td>-</td>
<td>32 µs</td>
</tr>
<tr>
<td>$T_{RTS\ OFDM\ 54-Mbps}$</td>
<td>24 µs</td>
<td>-</td>
<td>30 µs</td>
</tr>
<tr>
<td>$T_{CTS\ OFDM\ 54-Mbps}$</td>
<td>24 µs</td>
<td>-</td>
<td>30 µs</td>
</tr>
<tr>
<td>$T_{ACK\ OFDM\ 54-Mbps}$</td>
<td>24 µs</td>
<td>-</td>
<td>30 µs</td>
</tr>
<tr>
<td>$T_{RTS\ HR\ 11-Mbps}$</td>
<td>-</td>
<td>352 µs</td>
<td>-</td>
</tr>
<tr>
<td>$T_{CTS\ HR\ 11-Mbps}$</td>
<td>-</td>
<td>304 µs</td>
<td>-</td>
</tr>
<tr>
<td>$T_{ACK\ HR\ 11-Mbps}$</td>
<td>-</td>
<td>304 µs</td>
<td>-</td>
</tr>
</tbody>
</table>

**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 15xSlotTimes, respectively.

![Figure 3. Throughput performance of CSBA in IEEE802.11a standard.](image)
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 31xSlotTimes, 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.](image)

Figure 4 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.

![Figure 5. Throughput performance of CSBA in IEEE802.11g standard](image)

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.

REFERENCES