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Several Contention Window Adjustment techniques for Improving Unsaturated throughput of Wireless LANs

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Abstract. This paper proposes the several contention window adjustment schemes in backoff process as well-known backoff algorithm (BA) for improving the performance of wireless local area network (WLAN). In addition, this research introduces a new unsaturated discrete Markov chain model in fixed backoff stages and fixed contention window sizes technique (FBFC). The proposed contention window adjustment schemes are designed by applying the moment generating function concept in random variable and process theorem. Unsaturated throughput parameters are used to compare the performance of all contention window size adjustment techniques based on IEEE802.11b WLAN standards. The comparison results show that Bernoulli and Double adjustment schemes are good contention window size adjustments at light traffic load, and the Even contention window size adjustment operates well at high traffic load condition.

Introduction

In wireless local area network, the collision problem of a transmitted data packet occurs whenever two or more contending stations wish to transmit packets in a same timeslot. Basically, backoff algorithm is a good technique for reducing the collision problem. A legacy binary exponential backoff algorithm (BEB) is a backoff algorithm that is used in several distributed coordination function WLAN standards. A popular model in [2] deeply analyzed the performance of BEB algorithm in saturated discrete Markov chain model as well-known Bianchi's model. Furthermore, a new backoff algorithm as called the exponential increment exponential decrement (EIED) backoff algorithm introduced in [3] and the performance of EIED was guaranteed that it was better than the BEB backoff algorithm.

However, the previous researches analyze the performance of all backoff algorithms in saturated traffic condition. Therefore, this paper extends and remodels the work of [2] and [3] into the unsaturated traffic condition that is near a real wireless local area network channel. Furthermore, the moment generating functions of Bernoulli, Binomial, Normal, Poisson, Chi-square, Even, Odd and Double are used to find the optimal backoff algorithms. The paper is organized as follow. Section 2 introduces a new unsaturated discrete Markov chain model, and the difference contention window size adjustments are presented in Section 3. Next, unsaturated throughput efficiencies of all contention window size adjustments are shown in Section 4. Finally, the summary is presented in Section 5.

A proposed unsaturated discrete Markov chain model

A new unsaturated discrete Markov chain model in fixed backoff stage and fixed contention window size technique is clearly shown in Fig.1. The maximum values of backoff stage and contention window size are fixed at 8 stages and 1024 timeslots, respectively.

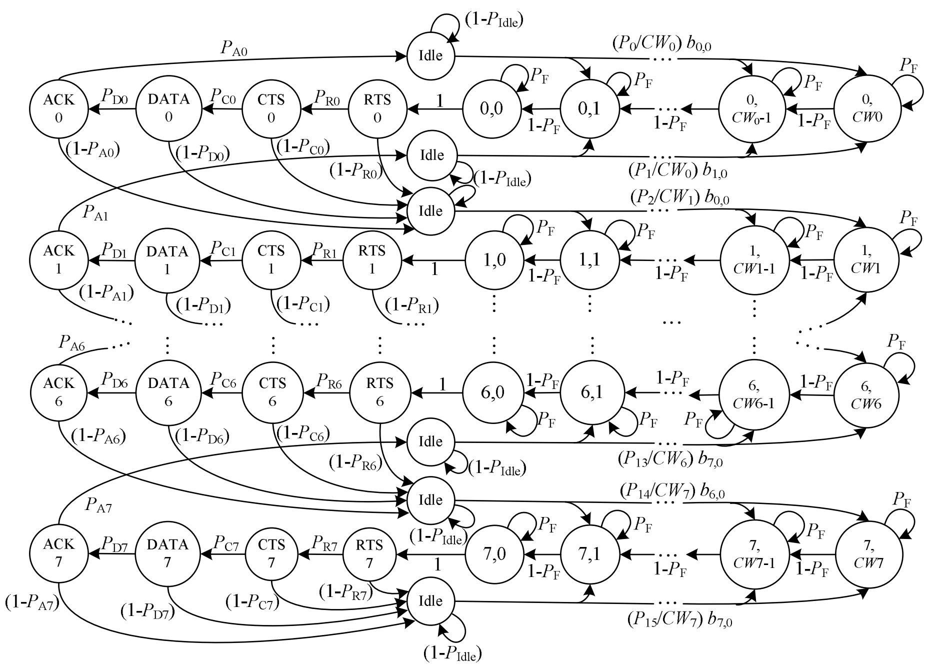

Fig.1. Unsaturated discrete Markov chain model in FBFC technique.

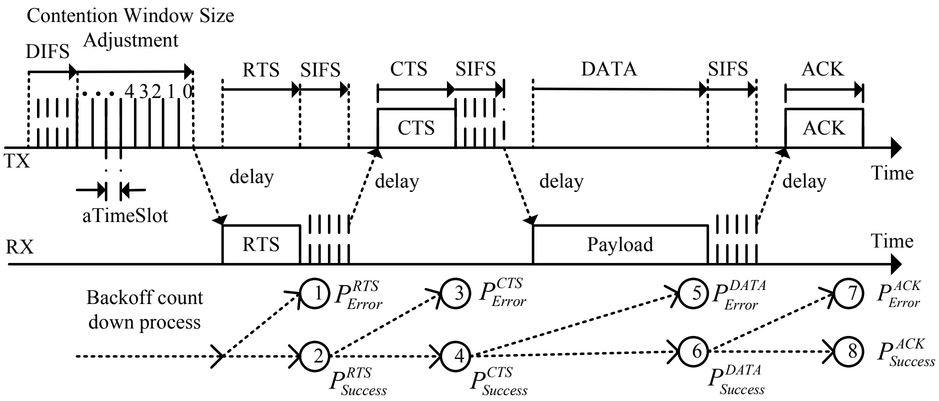

Fig.2. Tree error probability diagram of CSMA/CA RTS CTS protocol.

In unsaturated condition, parameter P_{Idle} is the idle period probability of wireless LAN channel when it isn't used to transmit packets, and P_{F} is the pause probability that a contending station suspends its backoff countdown process when the other active nodes have been transmitting a packet. The erroneous tree diagram of CSMA/CA RTS CTS protocol in Fig.2 will be used to analyze the effect of Additive White Gaussian Noise (AWGN) in term of bit error rate (BER) probability, and it is fixed at 10^{-5}. The collision probability ($P_{\text{collision}}$) and the error probability of RTS, CTS, DATA, and ACK frames due to AWGN can be calculated by

$$P_{\text{Collision}} = 1-(1-\tau)^{n-1} \tag{1}$$

$$P^{\text{RTS}}_{\text{Success}} = (1-BER)^{\text{RTS}} = P_{R0} = P_{R1} = \cdots = P_{R7} \tag{2}$$

$$P^{\text{RTS}}_{\text{Error}} = 1-P^{\text{RTS}}_{\text{Success}} = 1-(1-BER)^{\text{RTS}} = (1-P_{R0}) = (1-P_{R1}) = \cdots = (1-P_{R7}) \tag{3}$$

$$P^{\text{CTS}}_{\text{Success}} = (1-BER)^{\text{RTS}}(1-BER)^{\text{CTS}} = P_{C0} = P_{C1} = \cdots = P_{C7} \tag{4}$$

$$P^{\text{CTS}}_{\text{Error}} = (1-BER)^{\text{RTS}}[1-(1-BER)^{\text{CTS}}] = (1-P_{C0}) = (1-P_{C1}) = \cdots = (1-P_{C7}) \tag{5}$$

$$P^{\text{DATA}}_{\text{Success}} = (1-BER)^{\text{RTS}}(1-BER)^{\text{CTS}}(1-BER)^{\text{DATA}} = P_{D0} = P_{D1} = \cdots = P_{D7} \tag{6}$$

$$P^{\text{DATA}}_{\text{Error}} = (1-BER)^{\text{RTS}}(1-BER)^{\text{CTS}}[1-(1-BER)^{\text{Payload}}] = (1-P_{D0}) = (1-P_{D1}) = \cdots = (1-P_{D7}) \tag{7}$$

$$P_{\text{Success}}^{\text{ACK}} = (1-BER)^{\text{RTS}}(1-BER)^{\text{CTS}}(1-BER)^{\text{MSDU}}(1-BER)^{\text{ACK}} = P_{A0} = P_{A1} = \cdots = P_{A7} \tag{8}$$

$$P_{\text{Error}}^{\text{ACK}} = (1-BER)^{\text{Payload}}(1-BER)^{\text{RTS}}(1-BER)^{\text{CTS}}[1-(1-BER)^{\text{ACK}} = (1-P_{A0}) = (1-P_{A1}) = \cdots = (1-P_{A7})] \tag{9}$$

Parameter τ is the transmission probability of contending stations in service area and n is the number of contending stations. Failure transmission probabilities P_2, P_4, P_6, P_8, P_{10}, P_{12}, P_{14} and P_{15} due to the collision phenomenon and error of transmitted packets are given by

$$P_2 = P_4 = P_6 = P_8 = P_{10} = P_{12} = P_{14} = P_{15} = P_{\text{Idle}}\left(1-P_{\text{Success}}^{\text{RTS}}\right)\left(1-P_{\text{Success}}^{\text{CTS}}\right)\left(1-P_{\text{Success}}^{\text{DATA}}\right)\left(1-P_{\text{Success}}^{\text{ACK}}\right)P_{\text{Collision}} \tag{10}$$

Also, the successful transition probabilities P_0, P_1, P_3, P_5, P_7, P_9, P_{11} and P_{13} are given by

$$P_0 = P_1 = P_3 = P_5 = P_7 = P_9 = P_{11} = P_{13} = P_{\text{Idle}}\, P_{\text{Success}}^{\text{RTS}}\, P_{\text{Success}}^{\text{CTS}}\, P_{\text{Success}}^{\text{DATA}}\, P_{\text{Success}}^{\text{ACK}}\, [1-P_{\text{Collision}}], \tag{11}$$

Parameters $P_{\text{Success}}^{\text{RTS}}, P_{\text{Success}}^{\text{CTS}}, P_{\text{Success}}^{\text{DATA}}, P_{\text{Success}}^{\text{ACK}}, P_{\text{Error}}^{\text{RTS}}, P_{\text{Error}}^{\text{CTS}}, P_{\text{Error}}^{\text{DATA}}$ and $P_{\text{Error}}^{\text{ACK}}$ are the successful and error transmission probability of the Request-to-Send, Clear-to-Send , Data and Acknowledgement frame. $b_{\text{i,k}}$ is the state probability of backoff stage i and contention window size k. The global balance equation concept in discrete Markov chain is used to derive the transition probability (τ). A contending station can be transmitted data packets through wireless LAN channel when its contention window sizes are decremented by 1 every timeslot to zero ($b_{\text{i,0}}$) and WLAN channel is idle more than DIFS time. The transition probability of $b_{0,0}$, $b_{1,0}$, $b_{2,0}$, $b_{3,0}$, $b_{4,0}$, $b_{5,0}$, $b_{6,0}$ and $b_{7,0}$ are defined by

$$b_{0,0} = (P_0/CW_0)\sum_{L=1}^{CW_0} B^L\, b_{0,0} + (P_1/CW_0)\sum_{L=1}^{CW_0} B^L b_{1,0}, \qquad b_{1,0} = (P_2/CW_1)\sum_{L=1}^{CW_1} B^L\, b_{0,0} + (P_3/CW_1)\sum_{L=1}^{CW_1} B^L b_{2,0} \tag{12}$$

$$b_{2,0} = (P_4/CW_2)\sum_{L=1}^{CW_2} B^L\, b_{1,0} + (P_5/CW_2)\sum_{L=1}^{CW_2} B^L b_{3,0}, \qquad b_{3,0} = (P_6/CW_3)\sum_{L=1}^{CW_3} B^L\, b_{2,0} + (P_7/CW_3)\sum_{L=1}^{CW_3} B^L b_{4,0} \tag{13}$$

$$b_{4,0} = (P_8/CW_4)\sum_{L=1}^{CW_4} B^L\, b_{3,0} + (P_9/CW_4)\sum_{L=1}^{CW_4} B^L b_{5,0}, \qquad b_{5,0} = (P_{10}/CW_5)\sum_{L=1}^{CW_5} B^L\, b_{4,0} + (P_{11}/CW_5)\sum_{L=1}^{CW_5} B^L b_{6,0} \tag{14}$$

$$b_{6,0} = (P_{12}/CW_6)\sum_{L=1}^{CW_6} B^L\, b_{5,0} + (P_{13}/CW_6)\sum_{L=1}^{CW_6} B^L b_{7,0}, \qquad b_{7,0} = (P_{14}/CW_7)\sum_{L=1}^{CW_7} B^L\, b_{6,0} + (P_{15}/CW_7)\sum_{L=1}^{CW_7} B^L b_{7,0} \tag{15}$$

Similarly in [4], Bayes' theorem is used to derive the transmission probability (τ) in backoff stages i ($i = 0,1,2\ldots7$)

$$\tau = P(Tx) = 1/[\sum_{i=0}^{7} b_{i,0}] = 1/[b_{0,0} + b_{0,1} + b_{0,2} + b_{0,3} + b_{0,4} + b_{0,5} + b_{0,6} + b_{0,7}] \tag{16}$$

$P(\mathrm{T_X})$ is the probability that a contending station is being transmitting a frame into a time slot. Substituting (12) to (15) into (16), finally, the transmission probability of proposed model is simplified by

$$\tau = 1/[1 + (1/D_3) + S_1 + T_1 + U_1 + V_1 + W_1 + R_3 W_1], \tag{17}$$

where by

$$B = (1-P_{\text{F}})/(1-2P_{\text{F}}),\ D_1 = (P_0/CW_0)\sum_{L=1}^{CW_0} B^L,\ D_2 = (P_1/CW_0)\sum_{L=1}^{CW_0} B^L, D_3 = D_2/(1-D_1), E_1 = (P_2/CW_1)\sum_{L=1}^{CW_1} B^L,$$

$$E_2 = (P_3/CW_1)\sum_{L=1}^{CW_1} B^L, F_1 = (P_4/CW_2)\sum_{L=1}^{CW_2} B^L,\ F_2 = (P_5/CW_2)\sum_{L=1}^{CW_2} B^L, G_1 = (P_6/CW_3)\sum_{L=1}^{CW_3} B^L, G_2 = (P_7/CW_3)\sum_{L=1}^{CW_3} B^L,$$

$$H_1 = (P_8/CW_4)\sum_{L=1}^{CW_4} B^L, H_2 = (P_9/CW_4)\sum_{L=1}^{CW_4} B^L, I_1 = (P_{10}/CW_5)\sum_{L=1}^{CW_5} B^L, I_2 = (P_{11}/CW_5)\sum_{L=1}^{CW_5} B^L, Q_1 = (P_{12}/CW_6)\sum_{L=1}^{CW_6} B^L,$$

$$Q_2 = (P_{13}/CW_6)\sum_{L=1}^{CW_6} B^L, R_1 = (P_{14}/CW_7)\sum_{L=1}^{CW_7} B^L, R_2 = (P_{15}/CW_7)\sum_{L=1}^{CW_7} B^L, R_3 = R_1/(1-R_2), S_1 = (1-E_1 D_3)/E_2,$$

$$T_1 = (S_1 D_3 - F_1)/D_3 F_2, U_1 = (T_1 - G_1 S_1)/G_2, V_1 = (U_1 - H_1 T_1)/H_2, W_1 = (V_1 - I_1 U_1)/I_2$$

Different contention window size adjustments

Several kinds of the moment generating function in random variable and process theorem are used to design the increment and decrement scheme of CW_0 to CW_7 in unsaturated model as shown in Fig.1. The Contention window size adjustment of Bernoulli, Binomial, Normal, Poisson, Chi-square, Even, Odd and Double schemes are described by

Bernoulli $$CW_i = \left(Ae^i + C\right)CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } A = 0.5,\ C = 0 \tag{18}$$

Binomial $$CW_i = \left(De^i + E\right)^F CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } D = E = 0.5,\ F = 2 \tag{19}$$

Normal $$CW_i = \left(e^{\mu i + \frac{\sigma^2 i^2}{2}}\right)CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } \mu = \sigma = 0.5 \tag{20}$$

Poisson $$CW_i = \left(e^{R\left(e^i - 1\right)}\right)CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } R = 1 \tag{21}$$

Chi-square $$CW_i = \frac{1}{\left(1 - 2Y\right)^{\frac{i}{2}}}CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } Y = 0.4 \tag{22}$$

Even $$CW_i = H_1 CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } H_1 = 2, 4, 6, 8, 10, 12, 14, 16 \tag{23}$$

Odd $$CW_i = H_2 CW_{\min} \rightarrow i = 0,1,2..7 \text{ and } H_2 = 1, 3, 5, 7, 9, 11, 13, 15 \tag{24}$$

Double $$CW_i = 2^i CW_{\min} \rightarrow i = 0,1,2..7 \tag{25}$$

$$CW_{\max} = 128 CW_{\min} \le 1024 \text{ timeslots}$$

Unsaturated throughput calculation

This research uses the carrier sense multiple access with collision avoidance and request-to-send clear-to-send (CSMA/CA RTS CTS) protocol for controlling the accession in wireless LAN channel. Unsaturated throughput efficiency is an important parameter used to compare the performance of all contention window sizes adjustments. Similarly in [2], the unsaturated throughput can be calculated from

$$T_{\mathrm{S}} = T_{\mathrm{DIFS}} + T_{\mathrm{RTS}} + T_{\mathrm{CTS}} + 3T_{\mathrm{SIFS}} + 4T_{\mathrm{delay}} + T_{\mathrm{Data}} + T_{\mathrm{ACK}},\ T_{\mathrm{C}} = T_{\mathrm{RTS}} + T_{\mathrm{DIFS}} + T_{\mathrm{delay}} \tag{26}$$

$$P_{\mathrm{tr}} = 1 - (1-\tau)^n,\ P_{\mathrm{S}} = n\tau(1-\tau)^{n-1} / [1 - (1-\tau)^n],\ P_{\mathrm{C}} = 1 - P_{\mathrm{S}}, \tag{27}$$

$$\text{Unsaturated throughput} = \frac{P_{\mathrm{S}} P_{tr}(MSDU \times 8)}{(1 - P_{\mathrm{tr}})T_{\mathrm{aTimeSlot}} + P_{\mathrm{tr}} P_{\mathrm{S}} T_{\mathrm{S}} + P_{\mathrm{tr}} P_C T_{\mathrm{C}}}, \tag{28}$$

Parameter P_{S} is the successful transmission probability, P_{tr} is the transmission probability, P_{C} is the unsuccessful transmission probability, T_S is the successful transmission period, and T_{C} is the collision transmission period. The time periods of IEEE802.11b 11-Mbps are assigned: $T_{\mathrm{SIFS}} = 10$ µs, $T_{\mathrm{DIFS}} = 50$ µs, $T_{\mathrm{aTimeSlot}} = 20$ µs, $T_{\mathrm{delay}} = 1$ µs, $T_{\mathrm{RTS}} = 352$ µs, $T_{\mathrm{CTS}} = T_{\mathrm{ACK}} = 304$ µs and $T_{\mathrm{Data}} = 2311.45$ µs. Unsaturated throughput of all contention window adjustment schemes can be calculated by applying Algorithm 1.

Algorithm 1: Unsaturated throughput calculation

```
Begin Step: 1 fixed parameter $P_F$: = 0.05, $P_{Idle}$ := 0.95, $BER$ := $10^{-5}$, $n$ := 0,1..35
              RTS = 352 bits, CTS = ACK = 304 bits, MSDU = 1024 bytes
      Step: 2 to calculate $T_S$, $T_C$, $\tau$, $P_S$, $P_{tr}$, $P_C$ and $P_{Collision}$ by applying equation (1) to (27)
      Step: 3 to calculate the unsaturated throughputs of the Bernoulli, Binomial, Normal,
              Poisson, Chi-square, Even, Odd and Double by applying equations (28)
End
```

Numerical Results

Performances of all contention window adjustment techniques are compared based on IEEE802.11b standard at data speed 11-Mbps as shown in Fig.3. Unsaturated throughput results in Fig.3 confirms that Bernoulli and Double adjustment schemes are better than the Binomial, Normal, Poisson, Chi-square, Even and Odd adjustments techniques. However, the Even contention window size adjustment is higher than the other adjustment schemes when the number of contending stations is varied more than 15 stations.

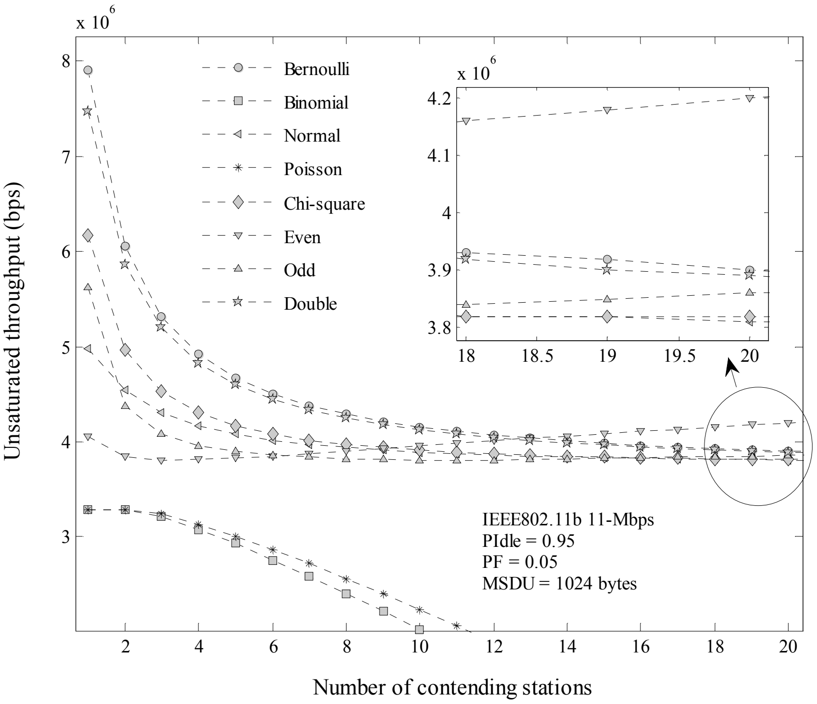

Fig. 3. Unsaturated throughput based on IEEE802.11b standard.

Summary

In this research, we introduce many contention window size adjustments for IEEE802.11 wireless local area network. Moreover, we propose a new unsaturated discrete Markov chain model that its maximum backoff stage is fixed at 8 stages, and maximum contention window size is fixed at 1024 timeslots. Our numerical results clearly illustrate that the contention window size adjustment of Bernoulli and Double schemes operate well under light traffic load condition (1-14 stations). On the other hand, the Even adjustment scheme is a good technique at high traffic load condition (more than 15 stations).

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