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MESSAGE FROM
SECTION EDITOR-IN-CHIEF

From this issue, the ASEAN ENGINEERING JOURNAL PART D has entered the second year. The journal is published by the ASEAN University Network/Southeast Asia Engineering Education Development Network. It is my honor to be the editor-in-chief for this journal. First of all, I want to thank the editorial board members who have accepted to contribute their valuable time and experience to arrange the review of the submissions. I also want to thank all the authors who make the contribution to the journal. In this issue, there are 5 papers including an invited paper. I hope for an increase in the number of papers in the future.

One of the objectives of the journal is to enhance the opportunity for all scholars including students in ASEAN and other countries to publish their research in the areas of (i) electrical and electronic engineering and (ii) computer and information technology. In fact, the area of electrical and electronic engineering includes a variety of research fields such as (but not limited to) power systems, high-voltage engineering, electronics, biomedical engineering, instrumental and control, robotics and automation, communication engineering, multimedia and signal processing. On this occasion, I would like to encourage all the authors to publish their work in this journal, and hope that the publication can strengthen the academic network and lead to collaboration between researchers in the ASEAN, Japan and other countries.

Finally, I would like to express my gratitude to the previous board members and the former section editor-in-chief, Assoc. Prof. Dr. Ekachai Leelarasmee, for their contributions.

Assoc. Prof. Dr. Boonchai Techaumnat
Section Editor-in-Chief
Electrical and Electronics Engineering

A NEW BACKOFF ALGORITHM FOR IEEE802.11 DISTRIBUTED COORDINATION FUNCTION IN WIRELESS LOCAL AREA NETWORKS

Jesada Sartthong[1] and Suvepon Sittichivapak[2]

[1] Doctoral Scholarship student from the CHE Faculty Development Scholarship Program with the Collaboration of AUN/SEED - Net (JICA), Department of Telecommunications Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand
Email: Sartthong@yahoo.com
[2] Associate Professor, Department of Telecommunications Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand
Email: Kssuvepo@kmitl.ac.th

Abstract

In wireless local area networks (WLANs), backoff algorithms are used for reducing packet collision, and improving throughput efficiency. This paper proposes two new backoff algorithms which are named Double Increment Random Decrement (DIRD) and Binary Exponential Increment Half Decrement (BEIHD) backoff algorithms. The transmission probability of DIRD and BEIHD backoff algorithms are derived from a new discrete Markov chain model by applying the Fixed Backoff stages and Fixed Contention windows (FBFC) technique. The accuracy of transmission probability uses the global balance equation concept in steady state condition. The performance of DIRD and BEIHD backoff algorithms are compared with the lagacy backoff algorithms such as Binary Exponential Backoff (BEB) and Estimation-Based Backoff (EBB) algorithms. Saturated throughput and fairness index are used to measure the performance of all backoff algorithms under the same physical layer parameters. In medium access control technique, we use the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Request-to-Send/Clear-to-Send (RTS/CTS) protocol. Our numerical results show that the saturation throughput of BEIHD backoff algorithm is better than the DIRD, BEB and EBB backoff algorithms. However, the fairness index of DIRD algorithm is fairer than the BEIHD, BEB and EBB backoff algorithms.

Keywords: BEB, EBB, DIRD, BEIHD, FBFC, CSMA/CA with RTS CTS Protocol

Section 1: Introduction

Backoff algorithm is a technique for collision resolution in wireless local area network. A collision packet occurs whenever two or more contending stations wish to transmit the data packets in a same slot time. In previous researches, the author in [4] proposed a simple discrete Markov chains model to analyze the performance of IEEE802.11 Distributed Coordination Function (DCF) mode in ideal channel. Sometimes, this popular model is called Bianchi's model, and this model uses Binary Exponential Backoff (BEB) algorithm to solve the collision problems. In [5], the authors developed and extended Bianchi's model to predict packet delay under retransmission limit in saturated condition. Mostly, the transmission probability (τ) is derived in unlimited backoff stages and unlimited contention window sizes. Therefore, the key of this paper introduces a new technique to derive the transmission probability by using the Fixed Backoff stages and Fixed Contention windows (FBFC) technique. Saturated throughput and fairness index are two important parameters to measure the performance of all backoff algorithms. In this research, we assume that:

- Channel is ideal and it is divided into the equal timeslots
- All stations operate in saturated condition
- All stations know the number of contending station (n) in service area
- A transmission starts at the beginning of a slot and ends before the next slot

This paper is organized as follows. In section 2, we brief the legacy backoff algorithms which are the Binary Exponential Backoff and Estimation-Based Backoff algorithms. In section 3, we propose the two new backoff algorithms which are named the Double Increment Random Decrement backoff algorithm and the Binary Exponential Increment Half Decrement backoff algorithm. The mathematical analysis of saturated throughput and fairness indices are calculated in section 4. In section 5, we give some numerical results. Finally, the conclusion is explained in section 6.

Section 2: The Legacy Backoff Algorithms

Presently, Binary Exponential Backoff (BEB) algorithm is a basic scheme to solve the collision problem in wireless local area network. Figure 1 shows two-dimensional discrete Markov chain model of BEB algorithm in Fixed Backoff stages and Fixed Contention windows (FBFC) technique.
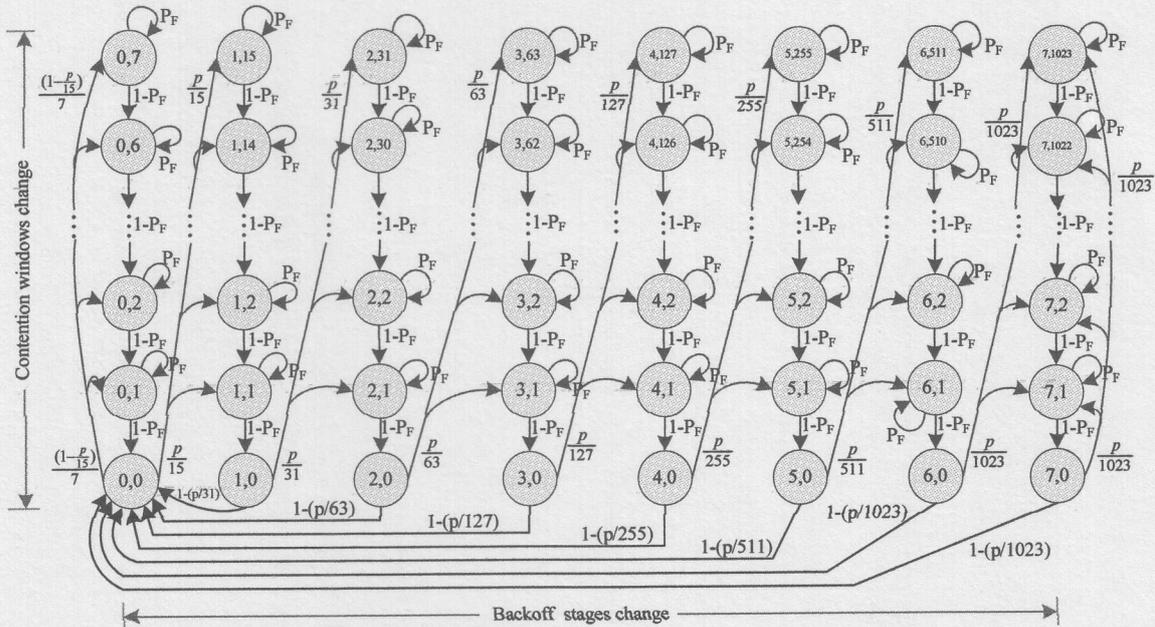
Figure 1. BEB backoff algorithm in FBFC technique

Basically, the contention window size of BEB backoff algorithm is uniformly chosen in range from the minimum contention window (CWmin) to maximum contention window size (CWmax). In this research, CWmin is fixed at 8 timeslots, and CWmax is fixed at 1024 timeslots. At the first transmission, the contention window size is set equal to a CWmin. The contention window sizes are decreased slot by slot until to zero when the channel is idle more than Distribute Inter Frame Space (DIFS) period. A contending station sends a data frame when the contention window sizes are counted down to zero. If the transmission is unsuccessful or the collision occurs, the current contention window size is doubled until reaching a CWmax. In BEB algorithm, the contention window size equals $2^i CW_{\min}$ where i is the backoff stages or retransmissions ($i = 0, 1, 2 \ldots m$). Therefore, the

maximum contention window size is $2^m CW_{\min}$. If channel is sensed as busy, the contending station must suspend its countdown process until the channel is sensed as idle more than the DIFS period again, the countdown process resumes. After a successful transmission, the contention window size is reset to the initial value (CWmin). In our model, $b_{i,k}$ is denoted the probability of backoff stage i and contention window k. The backoff stage i varies from 0 to 7 stages, and the contention window size k varies from 0 to 1023 timeslots. P_F is the pause probability that a contending station stops its countdown process when the WLAN channel is sensed as busy. p is the collision probability when a data packet is transmitted through the wireless channel. From Fig.1, we use the global balance equation concept to derive the transmission probability (τ). The transmission probability of the BEB algorithm (τ_{BEB}) under fixed backoff stages and fixed contention windows technique is given by

$$\tau_{BEB} = \cfrac{1}{\left[1+B_1+B_1C_1+B_1C_1D_1+B_1C_1D_1E_1+B_1C_1D_1E_1F_1+B_1C_1D_1E_1F_1G_1+\left[\cfrac{H_1}{1-H_1}\right]B_1C_1D_1E_1F_1G_1\right]} \tag{1}$$

Where
$$B = \frac{(1-P_F)}{(1-2P_F)}, \quad B_1 = \frac{p}{15}\sum_{L=1}^{15}B^L, \quad C_1 = \frac{p}{31}\sum_{L=1}^{31}B^L, \quad D_1 = \frac{p}{63}\sum_{L=1}^{63}B^L,$$

$$E_1 = \frac{p}{127}\sum_{L=1}^{127}B^L, \quad F_1 = \frac{p}{255}\sum_{L=1}^{255}B^L, \quad G_1 = \frac{p}{511}\sum_{L=1}^{511}B^L, \quad H_1 = \frac{p}{1023}\sum_{L=1}^{1023}B^L$$

A big problem with the EBB backoff algorithm occurs when the network has high the number of contending stations, as a result; this condition may increase the collision probability and decrease the saturated throughput. In [6], the authors suggested to choose a size of contention window according to the estimated number of contending stations. They proposed a new backoff algorithm which is named as the Estimation-Based Backoff (EBB) algorithm. Figure 2 shows two-dimension discrete Markov chain model of EBB algorithm in Fixed Backoff stages and Fixed Contention windows technique.
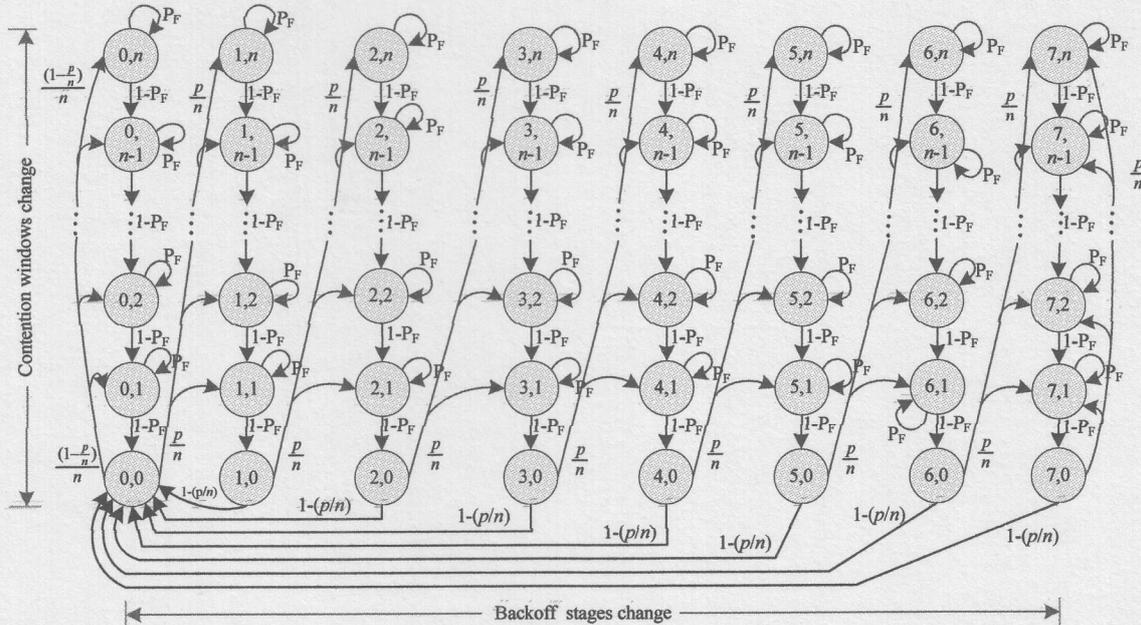
Figure 2. EBB backoff algorithm in FBFC technique

An optimal contention window of EBB algorithm can be derived as

$$CW_{optimal} = n \ (the \ number \ of \ contending \ stations) \tag{2}$$

Using the global balance equation concept, the transmission probability of the EBB algorithm (τ_{EBB}) under fixed backoff stages and fixed contention windows technique is given by

$$\tau_{EBB} = \frac{1}{[1+C_2+C_2{}^2+C_2{}^3+C_2{}^4+C_2{}^5+C_2{}^6+\frac{C_2{}^7}{(1-C_2)}]} \tag{3}$$

Where

$$C_2 = \frac{p}{n(A_2+\frac{p}{n})}\sum_{L=1}^{n}B^L, \ B=\frac{(1-P_F)}{(1-2P_F)}, \ A_2=(1-\frac{p}{n})$$

Section 3: Two proposed backoff Algorithms

In this section, we introduce the two new backoff algorithms which are the Double Increment Random Decrement (DIRD) and Binary Exponential Increment Half Decrement (BEIHD) backoff algorithms. Firstly, the discrete Markov chain model of DIRD backoff algorithm is shown in Fig.3. The CWmin and CWmax are fixed at 8, 1024 timeslots as the same BEB algorithm.
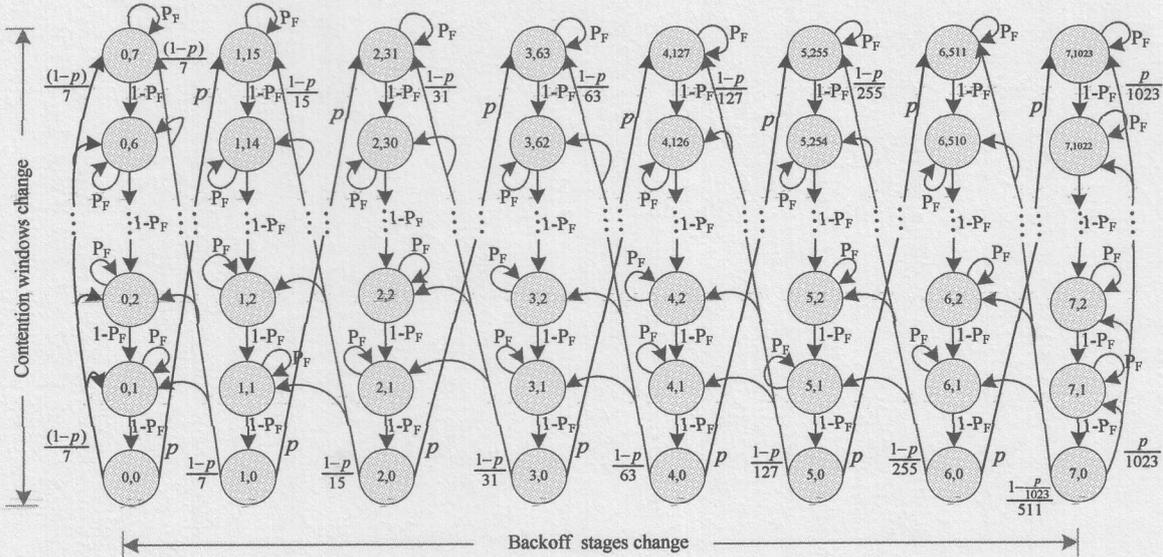
Figure 3. DIRD backoff algorithm in FBFC technique

Significantly, the difference between DIRD and BEB backoff algorithms is when the transmission is successful. After a failed transmission, the contention window size is doubled increment (DI) to be the same BEB algorithm. If the transmission is successful, the contention window size is not reset to the initial value (CWmin), but it jumps from the current backoff stage to the previous backoff stage (Random Decrement: RD). For example, if current backoff stage is 5, the range of contention window varies between 0 to 255 timeslots. After a successful transmission, the new backoff stage will be set to 4, and a new range of contention window size varies between 0 to 127 timeslots; similarly, using the global balance equation concept in fixed backoff stage and fixed contention window

technique. The $b_{i,k}$ is the probability of backoff stages i, and contention window size k timeslots. First of all, while the backoff stage i is 1, and the contention window size k is 15 timeslots, the state probability of $b_{1,15}$ is

$$pb_{0,0} + P_F\,b_{1,15} + \frac{(1-p)}{15}b_{2,0} = (1-P_F)\,b_{1,15}$$

$$b_{1,15} = \frac{p}{(1-2P_F)}b_{0,0} + \frac{(1-p)}{15(1-2P_F)}b_{2,0} \tag{4}$$

In case of $i = 1$ and $k = 14$, the state probability of $b_{1,14}$ is

$$(1-P_F)\,b_{1,15} + P_F\,b_{1,14} + \frac{(1-p)}{15}b_{2,0} = (1-P_F)b_{1,14}$$

$$b_{1,14} = \frac{(1-p)}{15(1-2P_F)}b_{2,0} + \frac{(1-P_F)}{(1-2P_F)}b_{1,15} \tag{5}$$

Substituting (4) into (5), we get

$$b_{1,14} = \frac{p}{(1-P_F)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^2 b_{0,0} + \frac{(1-p)}{15(1-P_F)}\sum_{L=1}^{2}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{2,0} \tag{6}$$

From (4) and (6), we can summarize that the state probability of $b_{1,1}$ is given by

$$b_{1,1} = \frac{p}{(1-P_F)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{15} b_{0,0} + \frac{(1-p)}{15(1-P_F)}\sum_{L=1}^{15}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{2,0} \tag{7}$$

In case of $i = 1$ and $k = 0$, the state probability of $b_{1,0}$ is

$$\frac{(1-p)}{7}b_{1,0} + pb_{1,0} = (1-P_F)b_{1,1}$$

$$b_{1,0} = \frac{7(1-P_F)}{(1+6p)}b_{1,1} \tag{8}$$

Substituting (7) into (8), we get

$$b_{1,0} = \frac{7p}{(1+6p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{15} b_{0,0} + \frac{7(1-p)}{15(1+6p)}\sum_{L=1}^{15}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{2,0} \tag{9}$$

In other states, we use the same concept to derive the transmission probability of $b_{2,0}$, $b_{3,0}$, $b_{4,0}$, $b_{5,0}$, $b_{6,0}$, $b_{7,0}$ as

$$b_{2,0} = \frac{15p}{(1+14p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{31} b_{1,0} + \frac{15(1-p)}{31(1+14p)}\sum_{L=1}^{31}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{3,0} \tag{10}$$

$$b_{3,0} = \frac{31p}{(1+30p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{63} b_{2,0} + \frac{31(1-p)}{63(1+30p)}\sum_{L=1}^{63}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{4,0} \tag{11}$$

$$b_{4,0} = \frac{63p}{(1+62p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{127} b_{3,0} + \frac{63(1-p)}{127(1+62p)}\sum_{L=1}^{127}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^L b_{5,0} \tag{12}$$

$$b_{5,0} = \frac{127p}{(1+126p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{255} b_{4,0} + \frac{127(1-p)}{255(1+126p)}\sum_{L=1}^{255}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{L} b_{6,0} \qquad (13)$$

$$b_{6,0} = \frac{255p}{(1+254p)}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{511} b_{5,0} + \frac{255(1-p)}{511(1+254p)}\sum_{L=1}^{511}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{L} b_{7,0} \qquad (14)$$

$$b_{7,0} = \frac{p\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{1023}}{\left[\frac{(1023-p)}{1023\times511}+\frac{p}{1023}-\frac{p}{1023}\sum_{L=1}^{1023}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{L}\right]} b_{6,0} \qquad (15)$$

From (9) to (15), all stationary probabilities are expressed in terms of $b_{0,0}$ and the sum of all probabilities must be 1.

$$\tau_{DIRD} = \sum_{i=0}^{7} b_{i,0} = b_{0,0} + b_{1,0} + b_{2,0} + b_{3,0} + b_{4,0} + b_{5,0} + b_{6,0} + b_{7,0} = 1 \qquad (16)$$

Substituting (9) (10) (11) (12) (13) (14) and (15) into (16), finally, the transmission probability of DIRD backoff algorithm is simplified as

$$\tau_{DIRD} = \frac{1}{\left[1+(A_3+A_4 R_3)+R_3+(D_3+D_4 Q_3)+Q_3+(G_3+G_4 K_3)+K_3+J_3\right]} \qquad (17)$$

Where:

$$B = \frac{(1-P_F)}{(1-2P_F)}, \qquad A_3 = \frac{7p}{(1+6p)}B^{15}, \qquad A_4 = \frac{7(1-p)}{15(1+6p)}\sum_{L=1}^{15}\left[\frac{(1-P_F)}{(1-2P_F)}\right]^{L}$$

$$B_3 = \frac{15p}{(1+14p)}B^{31}, \qquad B_4 = \frac{15(1-p)}{31(1+14p)}\sum_{L=1}^{31}B^{L}, \qquad C_3 = \frac{31p}{(1+30p)}B^{63}$$

$$C_4 = \frac{31(1-p)}{63(1+30p)}\sum_{L=1}^{63}B^{L}, \quad D_3 = \frac{(A_3 B_3 C_3)(1-A_4 B_3)}{(1-B_3 A_4)\left[(1-A_4 B_3)-C_3 B_4\right]}, \quad D_4 = \frac{C_4(1-A_4 B_3)}{\left[(1-A_4 B_3)-C_3 B_4\right]}$$

$$E_3 = \frac{63p}{(1+62p)}B^{127}, \qquad E_4 = \frac{(1-p)}{127(1+62p)}\sum_{L=1}^{127}B^{L}, \qquad F_3 = \frac{127p}{(1+126p)}B^{255}$$

$$F_4 = \frac{127(1-p)}{255(1+126p)}\sum_{L=1}^{255}B^{L}, \quad H_3 = \frac{255p}{(1+254p)}B^{511}, \qquad H_4 = \frac{255(1-p)}{511(1+254p)}\sum_{L=1}^{511}B^{L}$$

$$K_3 = \left[\frac{(H_3 G_3 + H_4 J_3)}{(1-H_3 G_4)}\right], \quad G_3 = \frac{(E_3 D_3 F_3)(1-E_3 D_4)}{(1-E_3 D_4)\left[(1-E_3 D_4)-E_4 F_3\right]}, \quad G_4 = \frac{F_4(1-E_3 D_4)}{\left[(1-E_3 D_4)-E_4 F_3\right]}$$

$$I_3 = \frac{pB^{1023}}{\left[\frac{(1023-p)}{1023\times511}+\frac{p}{1023}-\frac{p}{1023}\sum_{L=1}^{1023}B^{L}\right]}, \quad J_4 = \frac{(H_3 G_3 I_3)(1-H_3 G_4)}{\left[(1-H_3 G_4)-H_4 I_3\right](1-H_3 G_4)},$$

$$Q_3 = \left[\frac{E_3 D_3}{(1-E_3 D_4)}+\frac{E_4(G_3+G_4 K_3)}{(1-E_3 D_4)}\right], \qquad R_3 = \left[\frac{A_3 B_3}{(1-B_3 A_4)}+\frac{B_4(D_3+D_4 Q_3)}{(1-A_4 B_3)}\right]$$

Secondly, we introduce a new backoff algorithm which is the Binary Exponential Increment Half Decrement (BEIHD) backoff algorithm. The BEIHD backoff algorithm is

differentiated from BEB, EBB and DIRD backoff algorithm when the transmission is successful. After a transmission fails, the contention window size is doubled from the current backoff stage (Binary Exponential Increment: BEI). If a transmission is successful, the new contention window size is set to half of the previous backoff stage (Half Decrement: HD). Discrete Markov chain model of BEIHD backoff algorithm is shown in Fig.4.
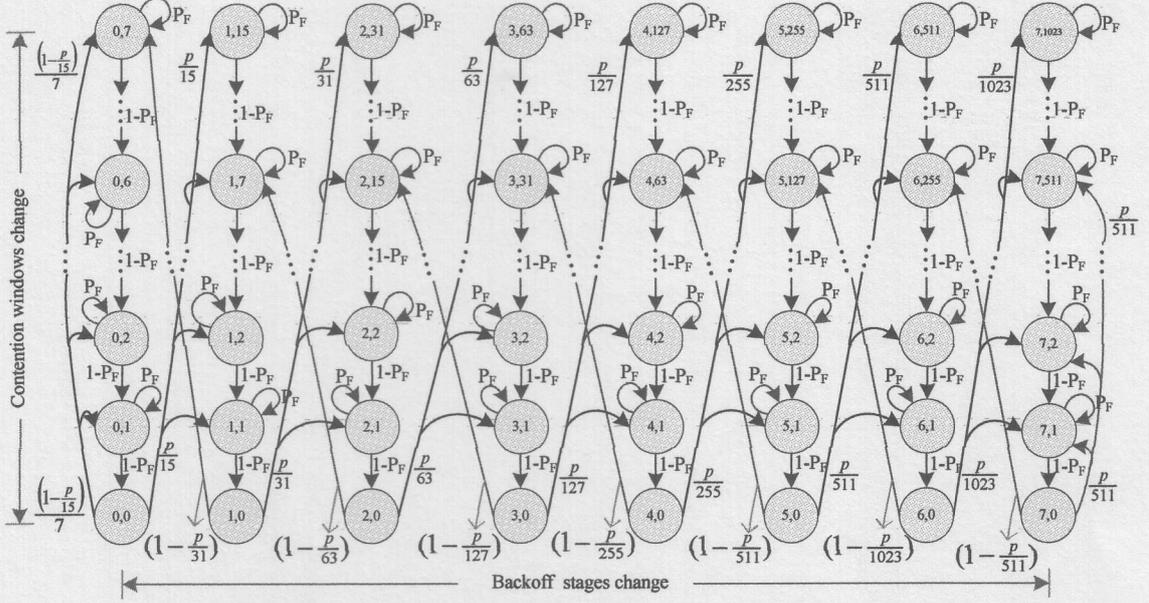
Figure 4. BEIHD backoff algorithm in FBFC technique

Using the global balance equation concept, the transmission probability of the BEIHD backoff algorithm is given by

$$\tau_{BEIHD} = \frac{1}{\left[1 + C_7 + D_7 + E_7 + F_7 + G_7 + H_7 + J_7\right]} \tag{18}$$

Where:

$$B = \frac{(1-P_F)}{(1-2P_F)}, \quad A_5 = \frac{\left(1-\frac{p}{15}\right)}{7}, \quad A_6 = \left(1-\frac{p}{31}\right), \quad A_7 = \left(1-\frac{p}{63}\right), \quad A_8 = \left(1-\frac{p}{127}\right)$$

$$A_9 = \left(1-\frac{p}{255}\right), \quad A_{10} = \left(1-\frac{p}{511}\right), \quad A_{11} = \left(1-\frac{p}{1023}\right), \quad A_{12} = \left(1-\frac{p}{511}\right), \quad C_5 = \frac{(1-\frac{p}{15})}{7(A_5+\frac{p}{15})}\sum_{L=1}^{7}B^L$$

$$C_6 = \frac{(1-\frac{p}{31})}{7(A_5+\frac{p}{15})}B^7, \quad C_7 = \frac{(1-C_6)}{C_7}, \quad D_5 = \frac{p}{15(A_6+\frac{p}{31})}\sum_{L=1}^{7}B^L + \frac{p}{15(A_6+\frac{p}{31})}B^7\sum_{L=1}^{8}B^L$$

$$D_6 = \frac{(1-\frac{p}{63})}{7(A_6+\frac{p}{31})}B^7, D_7 = \frac{(1-C_5-C_6D_5)}{C_6D_6}, E_5 = \frac{p}{31(A_7+\frac{p}{63})}\sum_{L=1}^{15}B^L + \frac{p}{31(A_7+\frac{p}{63})}B^{15}\sum_{L=1}^{16}B^L$$

$$E_6 = \frac{(1-\frac{p}{127})}{7(A_7+\frac{p}{63})}B^{15}, \quad E_7 = \frac{(D_7-E_5C_7)}{E_6}, \quad F_5 = \frac{p}{63(A_8+\frac{p}{127})}\sum_{L=1}^{31}B^L + \frac{p}{63(A_8+\frac{p}{127})}B^{31}\sum_{L=1}^{32}B^L$$

$$F_6 = \frac{(1-\frac{p}{255})}{7(A_8 + \frac{p}{127})} B^{31} \quad , \quad F_7 = \frac{(E_7 - F_5 D_5)}{F_6} \quad , \quad G_5 = \frac{p}{127(A_9 + \frac{p}{255})} \sum_{L=1}^{63} B^L + \frac{p}{127(A_9 + \frac{p}{255})} B^{63} \sum_{L=1}^{64} B^L$$

$$G_6 = \frac{(1-\frac{p}{511})}{7(A_9 + \frac{p}{255})} B^{63} \quad , \quad G_7 = \frac{(F_7 - G_5 E_7)}{G_6} \quad , \quad H_5 = \frac{p}{255(A_{10} + \frac{p}{511})} \sum_{L=1}^{127} B^L + \frac{p}{255(A_{10} + \frac{p}{511})} B^{127} \sum_{L=1}^{128} B^L$$

$$H_6 = \frac{(1-\frac{p}{1023})}{(A_{10} + \frac{p}{511})} B^{127} , \quad H_7 = \frac{(G_7 - H_5 F_7)}{H_6} , \quad I_5 = \frac{p}{511(A_{11} + \frac{p}{1023})} \sum_{L=1}^{255} B^L + \frac{p}{511(A_{11} + \frac{p}{1023})} B^{255} \sum_{L=1}^{256} B^L$$

$$I_6 = \frac{(1-\frac{p}{511})}{(A_{11} + \frac{p}{1023})} B^{255} , \quad I_7 = \frac{(H_7 - I_5 G_7)}{I_6} , \quad J_5 = \frac{p}{1023(A_{12} + \frac{p}{511})} \sum_{L=1}^{511} B^L + \frac{p}{1023(A_{12} + \frac{p}{511})} B^{511} \sum_{L=1}^{512} B^L$$

$$J_6 = \frac{p}{511(A_{12} + \frac{p}{511})} B^{511}, \quad J_7 = \frac{(I_7 - J_5 H_7)}{J_6}$$

Section 4: Mathematical Analysis of Saturated Throughput and Fairness Index

In medium access control scheme, we use the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Request-to-Send and Clear-to-Send (RTS/CTS) mechanism. Figure 4 shows a transmission process of CSMA/CA and RTS CTS protocol.
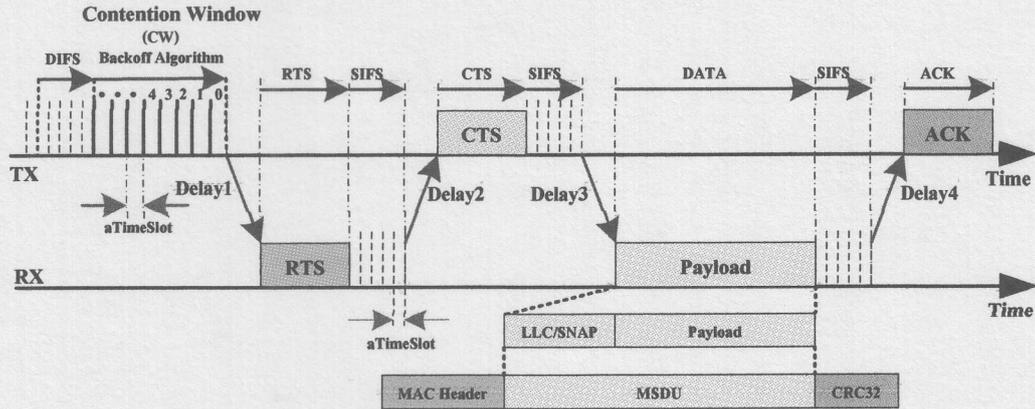
Figure 5. Transmission sequence of CSMA/CA and RTS CTS Protocol

Where: DIFS is the period of Distributed Inter Frame Space
SIFS is the period of Shot Inter Frame Space
RTS is the Request-to-Send frame
CTS is the Clear-to-Send frame
ACK is the Acknowledgement frame
MSDU is the MAC Service Data Unit frame

T_S is the average time of successful transmission, and T_C is the average time of collision transmission. T_S and T_C periods are calculated from

$$T_S = T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} + T_{ACK} + T_{DIFS} \qquad (19)$$

$$T_C = T_{DIFS} + T_{RTS} + T_{delay} \text{ , and } T_{MSDU(size)} = \frac{MSDU \times 8}{Data\,rate} \qquad (20)$$

In (59), the data rates of IEEE802.11b, IEEE802.11a and IEEE802.11g standards are fixed at 11 Mbps, 24 Mbps and 54 Mbps, respectively. Similarly in [4], the saturated throughput of BEIHD, DIRD, BEB and EBB backoff algorithms are calculated from

$$Saturated\ throughput = S = \frac{the\ average\ of\ Payload\ Information\ in\ a\ slot\ time}{the\ length\ average\ of\ a\ slot\ time} \qquad (21)$$

$$S = \frac{P_S P_{tr}(MSDU \times 8)}{(1 - P_{tr})T_{slot} + P_S P_{tr} T_S + P_{tr} P_C T_C} \qquad (22)$$

$$P_{tr} = 1 - (1 - \tau)^n \qquad (23)$$

$$P_S = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \qquad (24)$$

$$P_C = 1 - P_S = 1 - \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \qquad (25)$$

p is the probability that a transmission fails due to a collision. The collision probability p is given by

$$p = 1 - (1 - \tau)^{n-1} \qquad (26)$$

Parameters p and τ can be solved by the numerical method. Analysis parameters in this research are summarized as follows:

P_{tr} is the probability that there is at least one packet transmission in a same timeslot

P_S is the successful transmission probability

P_C is the collision transmission probability

$MSDU$ is the MAC Service Data Unit frame in bytes

T_C is the collision transmission time in µs

T_S is the successful transmission time in µs

T_{RTS} is the transmission period of a RTS frame in µs

T_{CTS} is the transmission period of a CTS frame in µs

T_{ACK} is the transmission period of ACK frame in µs

T_{SIFS} is the period of Shot Inter Frame Space in µs

T_{DIFS} is the period of Distribute Inter Frame Space in µs

T_{MSDU} is the transmission period of a data frame in µs

In this research paper, the parameters of CSMA/CA with RTS/CTS Protocol is used to calculate the saturated throughput and fairness index for all backoff algorithms which are described in Table 1.

Table.1 Transmission periods of CSMA/CA RTS CTS Protocol [1] [2] [3] and [7]

Periods	IEEE802.11 Standards		
	802.11a	802.11b	802.11g
T_{SIFS}	16 μs	10 μs	10 μs
T_{DIFS}	34 μs	50 μs	28 μs
$T_{sTimeSlot}$	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	-

The Fairness Index (FI) can be calculated from Jain's equation which defined in [8]. The fairness index equation is given by

$$Fairness\ Index = \frac{\left[\sum_{i=1}^{n} Throughput\ (i)\right]^2}{n\sum_{i=1}^{n}\left[Throughput\ (i)\right]^2} \tag{27}$$

Where n is the number of contending stations, and throughput (i) is the saturated throughput of station i achieved. A good backoff algorithm has the fairness index to approach one. Computer simulation tool in [9] is used to calculate the saturated throughputs and fairness indices efficiency by using algorithm 1.

Algorithm 1. Saturated throughput and fairness index calculation
    Begin
        Step 1: fixed parameters $P_F := 0.05$, MSDU: =1024 bytes and n: = 1...32
        Step 2: to calculate T_S and T_C by applying equation (19) and (20)
        Step 3: to calculate p, τ_{BEB}, τ_{EBB}, τ_{DIRD} and τ_{BEIHD} by applying equations (1), (3), (17), (18) and (26)
        Step 4: to calculate P_{tr}, P_S and P_C of BEB, EBB, DIRD and BEIHD backoff algorithms by applying equation (23), (24) and (25)
        Step 5: to calculate saturated throughput and fairness index of BEB, EBB, DIRD and BEIHD backoff algorithms by applying equation (22) and (27)
    End

Section 5: Numerical Results

In this section, the numerical results of all backoff algorithms are shown in terms of saturated throughput. Firstly, the saturated throughput is based on IEEE802.11a standard as shown in Fig.6. The numerical results show that BEIHD backoff algorithm is the highest saturated throughput performance. Dramatically, when the contending stations are increased, the saturated throughput of BEB and EBB backoff algorithms seem to reduce quickly, but the saturated throughput of BEIHD and DIRD backoff algorithms seem to be stable. Especially, under light load conditions (2-10 stations) the performance of BEB backoff algorithm is higher than the DIRD backoff algorithm. On the contrary, increasing the number of contending stations more than 12 stations, the performance of DIRD backoff algorithm is better than the BEB and EBB backoff algorithms.
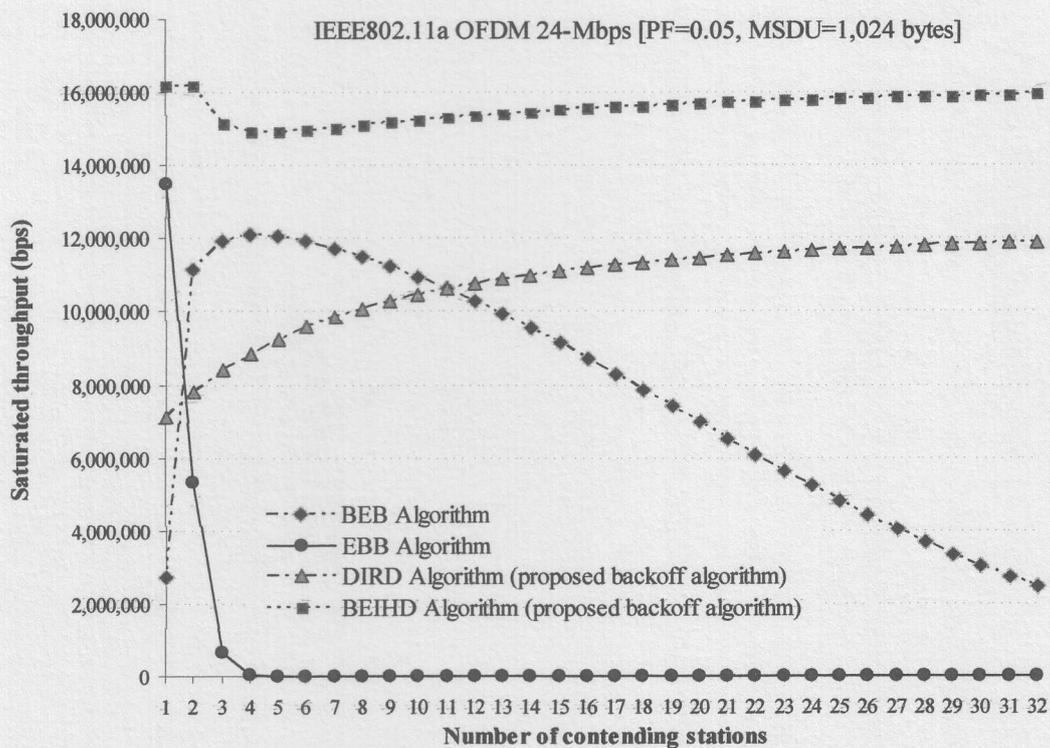
Figure 6. Saturated throughput in IEEE802.11a standard

Figure 7 shows the behavior of saturated throughput as a function of the number of contending stations based on IEEE802.11b standard, and we fixed the data speed at 11 Mbps. The results guarantee that the performance of BEIHD backoff algorithm is still better than the BEB, EBB and DIRD backoff algorithms. Similarly, Fig. 8 also shows the theoretical saturated throughput efficiency in IEEE802.11g standard at data speed 54 mbps. All the results guarantee that the performance of BEIHD backoff algorithm is still higher than the BEB, EBB and DIRD backoff algorithms. However, when the contending station is too small (1 station) the performance of EBB backoff algorithm seem to be better than the DIRD and BEB backoff algorithms. From Fig. 6, 7 and 8, we can summarize that the incrementing and decrementing contention window scheme of BEIHD backoff algorithm has the best saturated throughput performance.
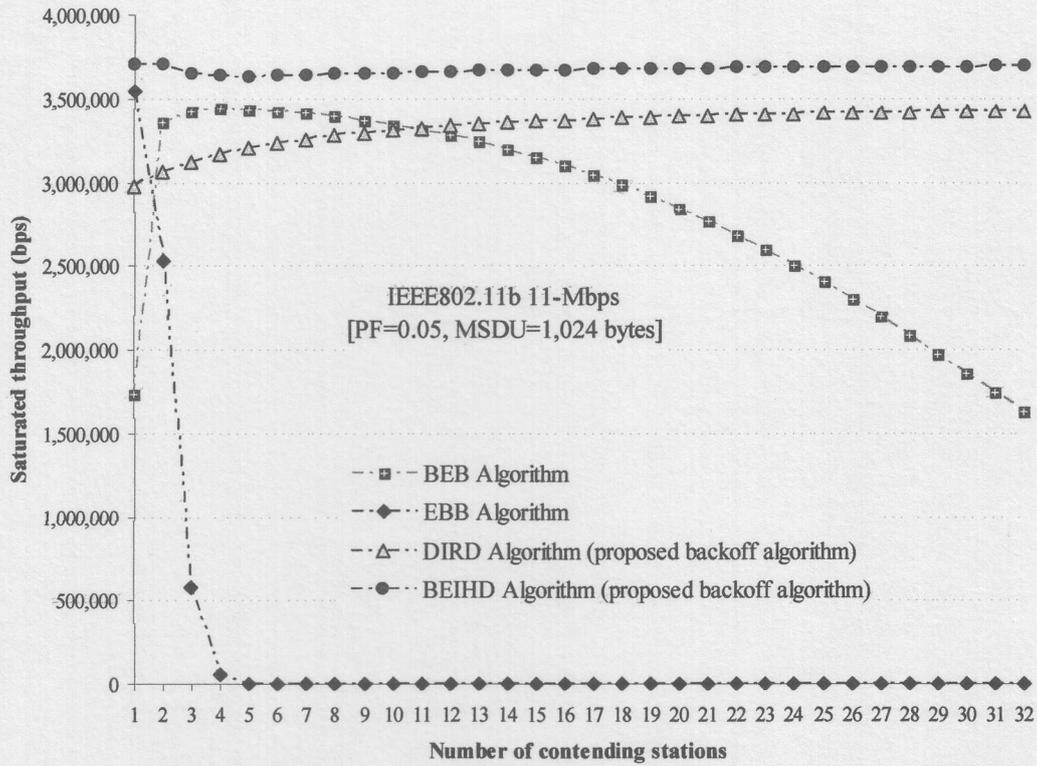
Figure 7. Saturated throughput in IEEE802.11b standard
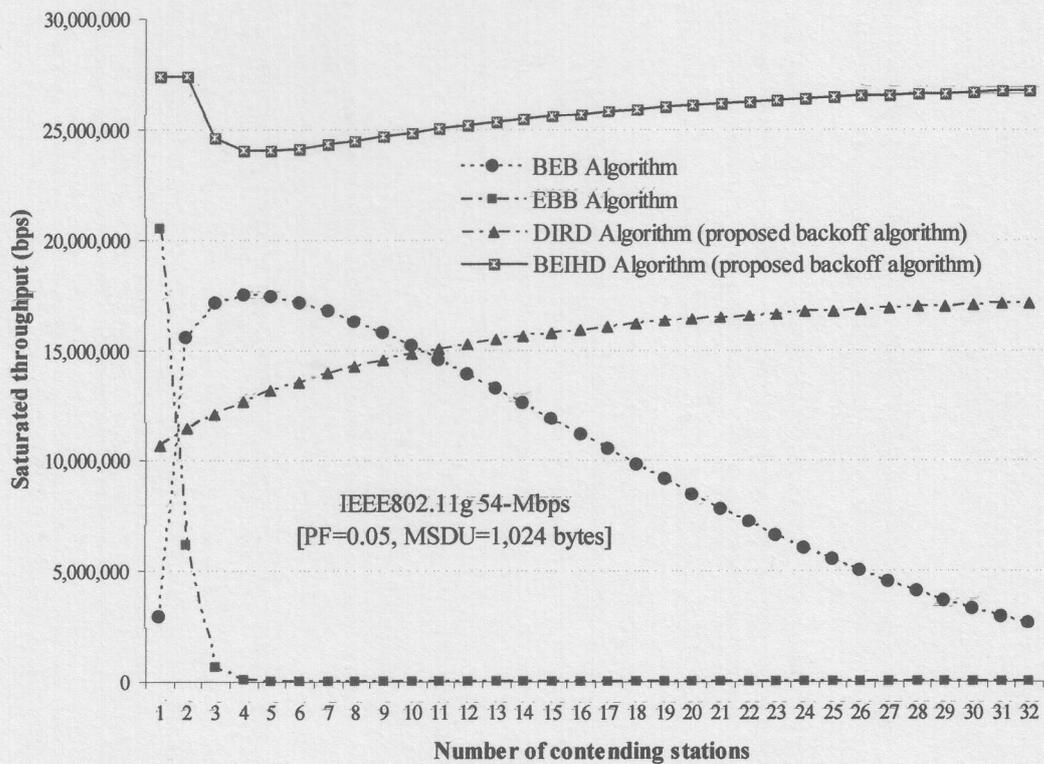
Figure 8. Saturated throughput in IEEE802.11g standard
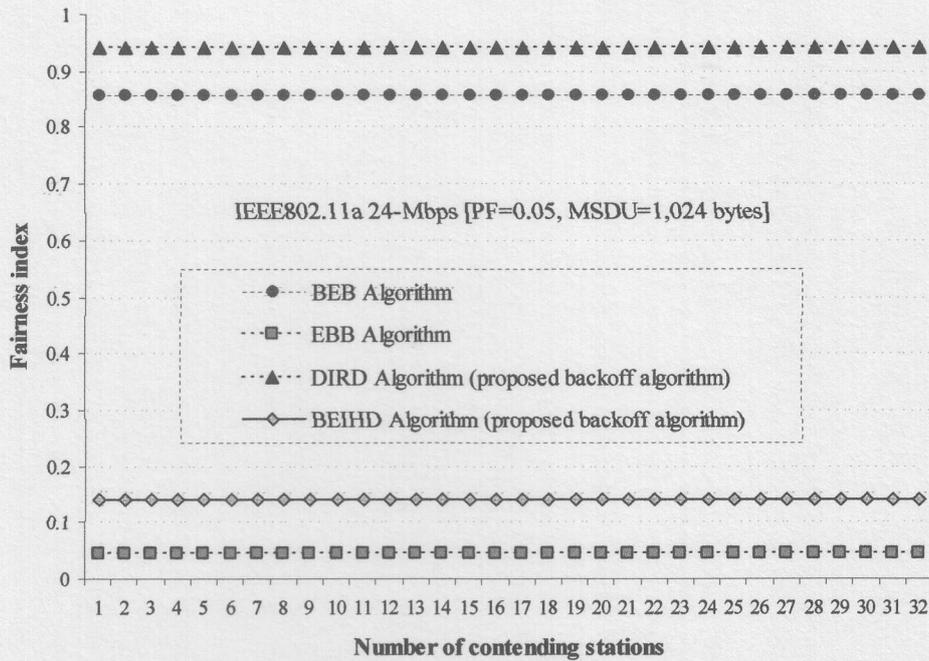
Figure 9. The fairness index performance of BEB and DIRD backoff algorithms

Figure 9 shows the fairness indices of all backoff algorithms under saturated condition based on IEEE802.11a standard. The results on the graph illustrate that the fairness index of BEB, EBB, DIRD and BEIHD backoff algorithms are about 0.86, 0.05, 0.94 and 0.15, respectively. Noticeably, the performance of DIRD backoff algorithm is fairer than the other algorithms.
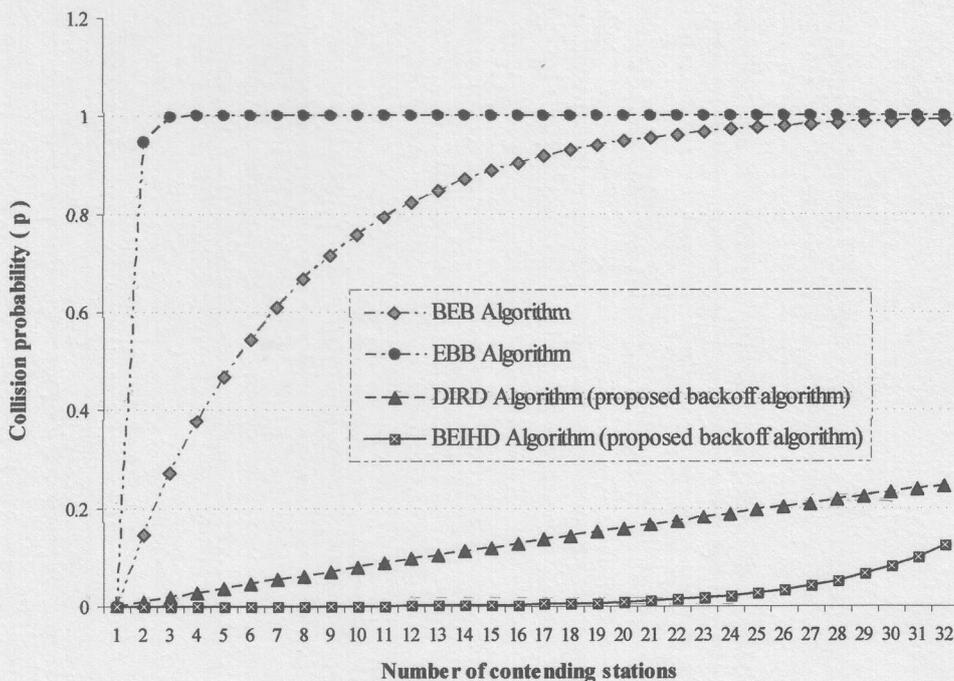
Figure 10. Collision probability of all backoff algorithms under saturated condition

Finally, the collision probabilities of all backoff algorithms are shown in Fig.10. From the results, we can see that the collision probabilities are increased when the number of contending stations varies from 1 to 32 stations. However, the collision probability of

BEIHD and DIRD backoff algorithms increase slowly, but the collision probability of BEB and EBB backoff algorithms seem to increase quickly.

Section 6: Conclusion

In this research paper, we have introduced a new discrete Markov chain model to derive the transmission probability by applying the Fixed Backoff stages and Fixed Contention windows (FBFC) technique. Moreover, we proposed two new backoff algorithms for improving the saturated throughput and fairness index efficiency. The proposed backoff schemes are named the Binary Exponential Increment Half Decrement (BEIHD) and Double Increment Random Decrement (DIRD) backoff algorithms. Our numerical results present that not only the saturated throughput of BEIHD and DIRD backoff algorithms are higher than the BEB and EBB backoff algorithms, but also the fairness index of DIRD backoff algorithm is better than the BEIHD, BEB and EBB backoff algorithms. In addition, the BEIHD and DIRD backoff algorithms are stable under high traffic load conditions for wireless local area network system. The distinction of BEIHD and DIRD backoff algorithms can be implemented without modifying the hardware in physical layer. In future work, we will evaluate the performance of BEIHD and DIRD backoff algorithms under non-saturation channel, and we will investigate and design the optimum backoff algorithm for wireless local area networks as well.

Acknowledgments

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