Enhancement of IEEE 802.11 Distributed Coordination Function with Exponential Increase Exponential Decrease Backoff Algorithm

Nah-Oak Song, Byung-Jae Kwak, Jabin Song, Leonard E. Miller
Advanced Network Technologies Division
National Institute of Standards and Technology, MD, USA
Emial:{nsong, bjkwak, jabin, lmiller}@antd.nist.gov

***Abstract*— A new backoff algorithm is proposed to enhance the performance of the IEEE 802.11 Distributed Coordination Function (DCF) which employs Binary Exponential Backoff (BEB) algorithm. The proposed algorithm, called the Exponential Increase Exponential Decrease (EIED) backoff algorithm, is quite simple to implement while significantly improving the network performance over BEB. Another backoff algorithm called Multiple Increase Linear Decrease (MILD) backoff algorithm is considered for performance comparison. The simulation results show that EIED outperforms BEB and MILD in terms of both throughput and delay. The performance gain of EIED comes from successfully balancing the two extreme backoff policies of BEB and MILD.**

***Index Terms*— Wireless LAN, DCF, Binary Exponential Backoff, EIED, MILD.**

I. Introduction

Combined with wireless communication technologies such as Wireless LAN (IEEE 802.11), Bluetooth, and HIPERLAN, powerful notebook computers and PDAs have created a new mobile computing environment. Because of its already well established market acceptance, IEEE 802.11 is the most successful among the above mentioned wireless communication standards. The Distributed Coordination Function (DCF) is the fundamental access mechanism in IEEE 802.11 Medium Access Control (MAC) while the Point Coordination Function (PCF) is used optionally [1]. In DCF, Binary Exponential Backoff (BEB)[1] is employed as a stability strategy to share the medium. At the first transmission attempt of a packet, BEB selects a random slot from the next $\mathrm{CW} = \mathrm{CW}_{\min}$ slots with equal probability for transmission, where $\mathrm{CW}_{\min}$ is the minimum contention window size. Every time a node's packet is involved in a collision, the contention window size for that node is doubled up to its maximum $\mathrm{CW}_{\max}$, that is,

$$\mathrm{CW} = \min[2 \cdot \mathrm{CW}, \mathrm{CW}_{\max}] \quad (1)$$

and the new contention window is used for the following transmission attempt. A node resets its contention window to the minimum after a successful transmission, or when the total number of transmission attempts for a packet reaches the limit m ($m = 7$ for basic access mechanism and $m = 4$ for the Request-To-Send/Clear-To-Send (RTS/CTS) exchange mechanism). However, the contention window resetting mechanism causes a very large variation of the contention window size, and degrades the performance of a network when it is heavily loaded since each new packet starts with the *minimum* contention window, which can be too small for the heavy network load. Fig. 1 illustrates the backoff mechanism of BEB, where $\mathrm{CW}_{\min} = 16$ and $\mathrm{CW}_{\max} = 1024$ ($m = 7$). To resolve the problem of BEB, [2] proposed a backoff algorithm known as MILD (Multiple Increase Linear Decrease), where the contention window size is multiplied by 1.5 on a collision but decreased by 1 on a successful transmission as follows:

$$\mathrm{CW} = \min[1.5 \cdot \mathrm{CW}, \mathrm{CW}_{\max}] \quad \text{on a collision,} \quad (2)$$

$$\mathrm{CW} = \max[\mathrm{CW} - 1, \mathrm{CW}_{\min}] \quad \text{on a success.} \quad (3)$$

MILD performs well when the network load is steadily heavy. However, this extremely conservative transmission policy has its shortcomings: MILD does not perform well when the network load is light because it takes quite long time to recover from the backoff caused by occasional collisions. Furthermore, when the number of active nodes changes sharply from high to low, MILD cannot adjust its CW fast enough because its "linear decrease" mechanism. For

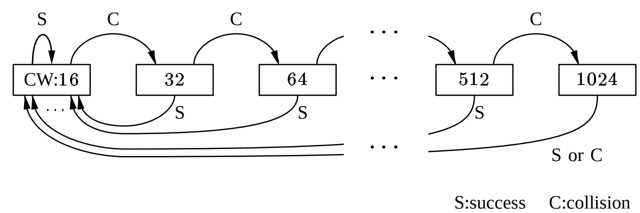


Fig. 1. Backoff mechanism of BEB: $\mathrm{CW}_{\min} = 16$, $\mathrm{CW}_{\max} = 1024$, $m = 7$.

[1] In IEEE 802.11, a truncated BEB is used. Many papers refer to this truncated version as BEB. We follow the convention in this paper.

example, when $\mathrm{CW}_{\min} = 16$ and $\mathrm{CW}_{\max} = 1024$ (IEEE 802.11 using Frequency-Hopping spread spectrum (FHSS) physical layer (PHY)), it takes a maximum of 1008 successful transmissions for MILD to reach $\mathrm{CW}_{\min}$. Another extreme is BEB, which takes only one successful transmission to reach $\mathrm{CW}_{\min}$.

There are also other contention resolution mechanisms proposed to improve the network performance of IEEE 802.11 DCF. However, most of them require exchange of information between nodes and complicated computation [3], [4], [5]. Those algorithms are not considered and we consider only acknowledgment based backoff algorithms [6]. In this paper, an exponential increase exponential decrease (EIED) backoff algorithm is proposed to enhance the the performance of the IEEE 802.11 DCF. EIED is as simple as BEB to implement while significantly improving the performance of IEEE 802.11 DCF.

This paper is organized as follows. First, we briefly describe the DCF of the IEEE 802.11 MAC in Section II. The proposed backoff algorithm, EIED, is presented in Section III. Then, in Section IV the performance of EIED is evaluated through simulation and compared with BEB and MILD. Finally, we conclude this paper in Section V.

II. IEEE 802.11 DCF

DCF is the fundamental access mechanism in the IEEE 802.11 MAC. In this section we will briefly describe the basic access mechanism of DCF.

When a node (station) receives a packet to transmit, if the node senses the medium has been idle for a period of time longer than or equal to a Distributed InterFrame Space (DIFS), the packet transmission may begin at the beginning of the immediately following slot. Otherwise, the node should defer the packet transmission as follows. The node waits until the medium is idle for a DIFS and then sets its backoff timer. The backoff timer is set to a value which is randomly selected from $0, 1, \cdots, \mathrm{CW}-1$ with equal probability, where CW represents contention window size. Initially, contention window size is set to its minimum $\mathrm{CW}_{\min}$ for the first transmission attempt of a packet. Every time the packet is involved in a collision, contention window size is doubled for the next transmission attempt. However, the contention window size cannot exceed its maximum $\mathrm{CW}_{\max}$. The backoff timer is decreased by 1 every slot time (50 μsec for FHSS PHY) after the medium has been idle for a DIFS, but is frozen when the medium becomes busy. When the backoff timer becomes zero, the station transmits the packet. If the destination node receives the packet correctly, it sends a positive acknowledgment (ACK) packet after a Short InterFrame Space (SIFS). When the source node does not receive an ACK, it assumes the packet has experienced a collision and updates the contention window size CW according to BEB algorithm as described above, then sets its backoff timer to a newly selected backoff values after a Extended InterFrame Space (EIFS). Since the number of transmission retries is bounded by m, a packet must be dropped after m transmission retries, that is, after experiencing m times of packet collision.

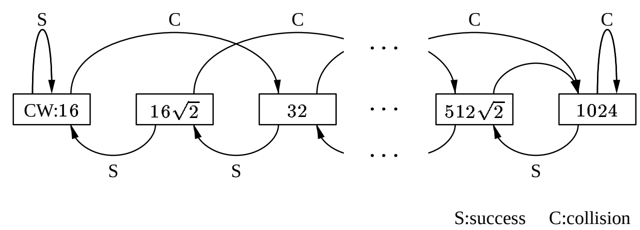


Fig. 2. Backoff mechanism of EIED: $\mathrm{CW}_{\min} = 16$, $\mathrm{CW}_{\max} = 1024$, $r_I = 2$, $r_D = \sqrt{2}$.

III. EIED, THE PROPOSED ALGORITHM

As explained in Section II, the IEEE 802.11 DCF employs BEB as a stability strategy to share the medium. But its contention window resetting mechanism degrades the performance of a network. In this section, we propose EIED backoff algorithm, where the contention window size is increased and decreased exponentially on collision and successful transmission, respectively, to enhance the performance of the IEEE 802.11 DCF.

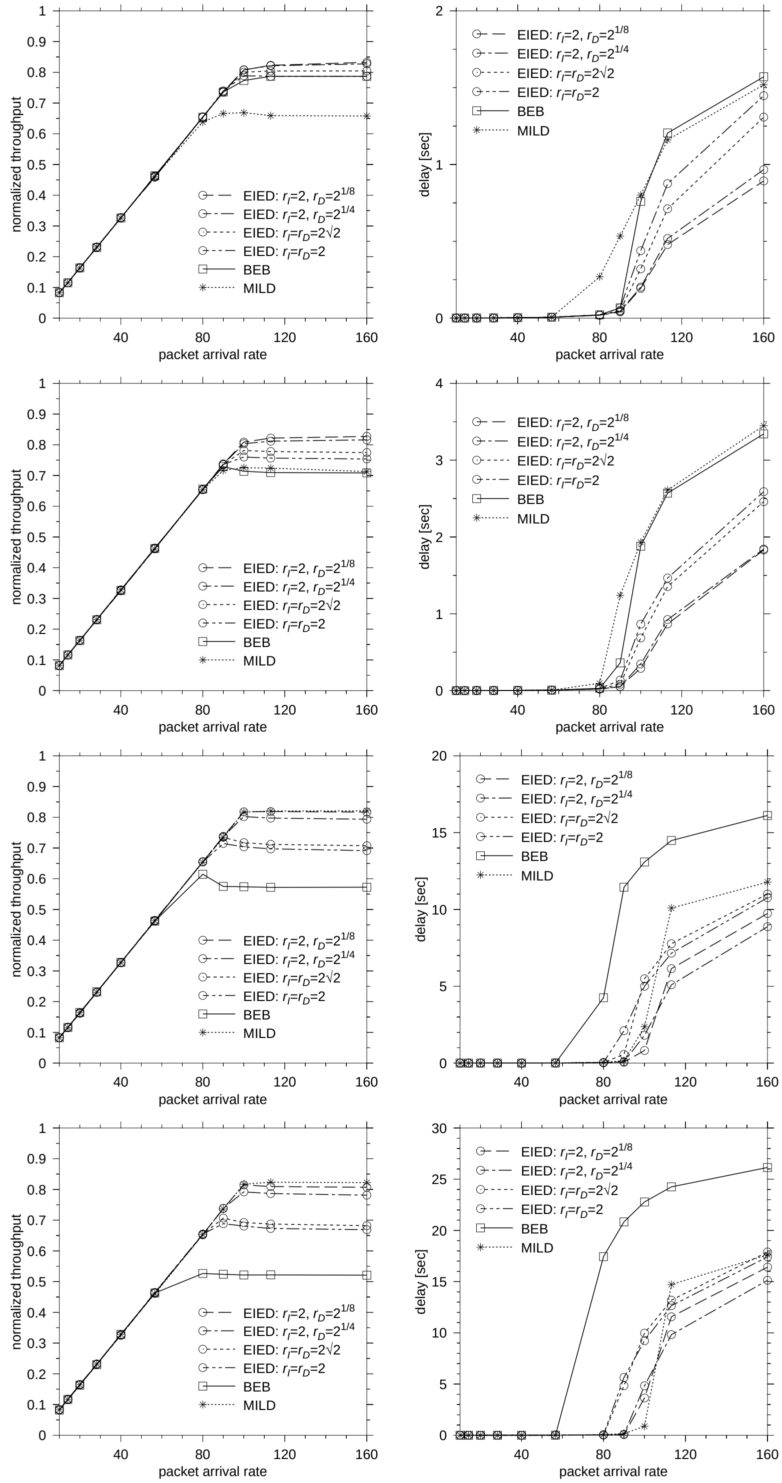
In EIED, whenever a packet transmitted from a node is involved in a collision, the contention window size for the node is increased by backoff factor r_I, and the contention window for the node is decreased by backoff factor r_D if the node transmits a packet successfully. The EIED backoff algorithm can be represented as follows.

$$\begin{aligned} \mathrm{CW} &= \min[r_I \cdot \mathrm{CW}, \mathrm{CW}_{\max}] \quad \text{on a collision,} \\ \mathrm{CW} &= \max[\mathrm{CW}/r_D, \mathrm{CW}_{\min}] \quad \text{on a success.} \end{aligned}$$

As shown in the simulation results below, the performance of EIED is affected by the choice of the values of r_I and r_D. In this paper, we fully exploit the degrees of freedom of EIED to obtain a better performance. Fig. 2 illustrates the backoff mechanism of EIED with $r_I = 2$ and $r_D = \sqrt{2}$. A special case of our proposed scheme with $r_I = r_D = 2$ was presented in [7], where the throughput was compared with BEB in IEEE 802.11 DCF under saturation condition. Note that it takes maximum 12 successful transmission for EIED with $r_I = 2$ and $r_D = \sqrt{2}$ to reach $\mathrm{CW}_{\min}$ in the above example.

IV. SIMULATION

The Wireless LAN model of the network simulator OPNET 8.1.A was used for the performance comparison of BEB, MILD, and EIED. The normalized throughput with respect to the channel capacity, and delay defined as the time from the moment a packet is placed in a queue until



(a) Saturation Throughput (b) Delay

Fig. 3. Simulation results: normalized throughput and delay with respect to packet arrival rate [packets/sec]. $N = 5, 10, 40, 60$.

the beginning of its successful transmission were used as the performance measures. We compare the performance when the basic access mechanism with FHSS PHY was used, where $\mathrm{CW}_{\min} = 16$, $\mathrm{CW}_{\max} = 1024$, $m = 7$. Fig. 3 shows the simulation results for number of nodes $N = 5$, 10, 40, and 60 for various system wide packet arrival rates from 10 to 160 packets/sec. Thus the number of nodes combined with the packet arrival rate is defined as the offered load. We assumed that all packets are 1024 bytes long and the arrival process is Poisson. BEB and MILD are compared with four different cases of EIED:

(1) $r_I = 2$, $r_D = 2^{1/8}$
(2) $r_I = 2$, $r_D = 2^{1/4}$
(3) $r_I = r_D = 2\sqrt{2}$
(4) $r_I = r_D = 2$

The figure shows that when the packet arrival rate is low (approximately < 80 packets/sec), all three backoff mechanisms have almost the same throughput which is proportional to the arrival rate, regardless of the number of nodes. The four cases of EIED always give higher throughput than BEB. When the number of nodes is small, the performance of BEB is almost as good as that of EIED, but as the number of nodes increases the performance differences also increase. As a result, the throughput of BEB is only about $2/3$ of that of the first two cases of EIED for $N = 60$. The throughput of MILD is very low when the network load is light ($N = 5$) as expected. However, it becomes higher as the number of nodes increases and its performance is on a par with EIED with $r_I = 2, r_D = 2^{1/8}$ for $N = 40$. For even higher number of nodes ($N = 60$), MILD yields only slightly higher throughput than EIED.

As in the case of throughput, for all N, all EIEDs have smaller delays than BEB for *all* arrival rates, and outperforms MILD for most of the arrival rates. The delay performance of MILD is especially poor when the number of nodes is small. The poor delay performances of BEB and MILD occur for different reasons. The delay performance of BEB suffers from packet collisions which cause more retransmissions. Thus, the delay performance of BEB is worse when there are more contending nodes (more collisions). On the other hand, the delay performance of MILD suffers from the excessive backoff, and thus the performance of MILD is worse when there are smaller number of nodes where even occasional collisions could cause unnecessarily large backoff.

V. CONCLUSION

In this paper, we proposed a new backoff algorithm (EIED) to enhance the performance of IEEE 802.11 DCF. The performance of EIED was compared with BEB and MILD using OPNET network simulator. The simulation results show that EIED outperforms BEB and MILD in terms of both throughput and delay. The performance gain of EIED comes from successfully balancing the two extreme backoff policies of BEB and MILD. BEB does not use the collision history of the previous packets and reduces CW too fast making it not suitable for network under heavy load (large N). On the other hand, MILD's linear decrease policy is too conservative especially when N is small. EIED is highly customizable by parameters r_I and r_D. Simulation results show that EIED with relatively smaller value of r_D compared to the value of r_I has higher performance gain.

REFERENCES

[1] *IEEE 802 Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*, IEEE Std., 1999.

[2] V. Bharghavan, A. Demers, S. Shenker, and L. Zhang, "MACAW: A Media Access Protocol for Wireless LAN's," in *Proc. ACM SIGCOMM'94*, London, England, 1994, pp. 212–225.

[3] G. Bianchi, L. Fratta, and M. Oliveri, "Performance Evaluation and Enhancement of the CSMA/CA MAC Protocol for 802.11 Wireless LANs," in *Proc. PIMRC'96*, Taipei, Taiwan, Oct. 1996, pp. 392–396.

[4] F. Calì, M. Conti, and E. Gregori, "Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Theoretical Throughput Limit," *IEEE/ACM Trans. Networking*, vol. 8, no. 6, pp. 785–799, Dec. 2000.

[5] D. Qiao and K. G. Shin, "UMAV: A Simple Enhancement to the IEEE 802.11 DCF," in *Proc. the 36th Hawaii International Conference on System Sciences (HICSS-36)*, Hawaii, Jan. 2003.

[6] F. P. Kelly and I. M. McPhee, "The Number of Packets Transmitted by Collision Detect Random Access Schemes," *Annals of Probability*, vol. 15, pp. 1557—1568, 1987.

[7] H. Wu, S. Cheng, Y. Peng, K. Long, and J. Ma, "IEEE 802.11 Distributed Coordination Function (DCF): Analysis and Enhancement," in *Proc. ICC2002*, New York, 2002, pp. 605–609.