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E-BEB: Enhanced Binary Exponential Backoff Algorithm for Multi-hop Wireless Ad-hoc Networks

Hui-Hsin Chin · Chun-Cheng Lin · Der-Jiunn Deng

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Abstract Binary exponential backoff algorithm is the de-facto medium access control protocol for wireless local area networks, and it has been employed as the standard contention resolution algorithm in multi-hop wireless ad-hoc networks. However, this algorithm does not function well in multi-hop wireless environments due to its several performance issues and technical limitations. In this paper, we propose a simple, efficient, priority provision, and well performed contention resolution algorithm called enhanced binary exponential backoff (E-BEB) algorithm for impartial channel access in multi-hop wireless ad-hoc networks. We also provide a simple and accurate analytical model to study the system saturation throughput of the proposed scheme. Simulations are conducted to evaluate the performance of E-BEB algorithm. The results show that the E-BEB algorithm can alleviate the fairness problem and support multimedia transmission in multi-hop wireless environments.

Keywords MAC · Ad-hoc networks · Fairness problem · BEB · Multi-hop

1 Introduction

Recently, multi-hop wireless ad-hoc network is an emerging field due to its dynamic topology, better targeting, and convenient usage. For the majority of multi-hop wireless networks, binary exponential backoff (BEB) [1] algorithm has been widely accepted and employed as

H.-H. Chin · C.-C. Lin
Department of Industrial Engineering and Management, National Chiao Tung University, Hsin-chu, Taiwan
e-mail: huihsinchin@gmail.com

C.-C. Lin
e-mail: cclin321@nctu.edu.tw

D.-J. Deng (✉)
Department of Computer Science and Information Engineering, National Changhua University of Education, Changhua, Taiwan
e-mail: djdeng@cc.ncue.edu.tw

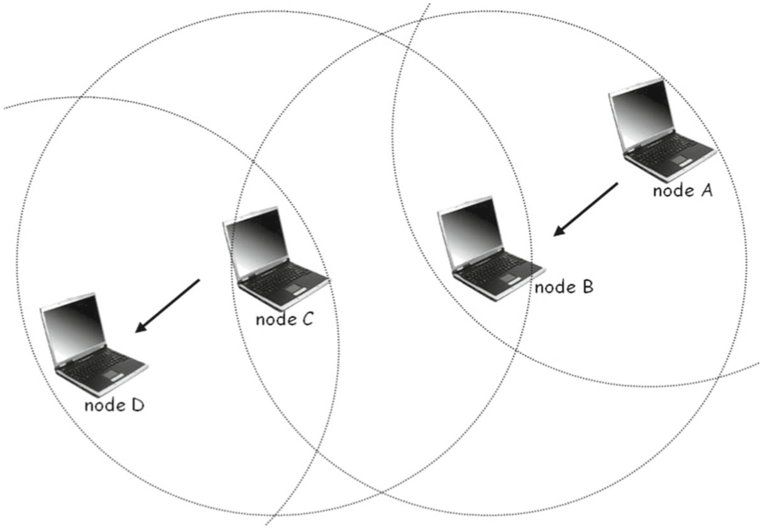

Fig. 1 Multi-hop wireless ad-hoc networks

the mandatory medium access control (MAC) protocol to share the wireless channel. However, BEB algorithm is not designed for multi-hop wireless environments and poses several performance issues and technical limitations, such as intensive packet collision probability, unfair channel access, and lack of priority mechanism.

To begin with, BEB algorithm could incur high collision probability in congested environments and this might seriously degrade the overall system performance since BEB algorithm always selects a small initial contention window size due to a naive assumption of light load environments.

Besides, the BEB algorithm might lead to an unfair channel access in multi-hop wireless environments because BEB algorithm always favors the last successfully transmitted node and this could cause starvation problem since some nodes could "grab" the channel. For example, considering the network topology shown in Fig. 1, two connections established from node A to node B and from node C to node D respectively. Compare with Node C, Node A will get less chance to access the channel since Node C will "grab" the channel by using a smaller contention window size.

In order to observe the effect of fairness problem in BEB algorithm, we use our custom event-driven C++ simulator to run an experiment in traditional 802.11 multi-hop wireless ad-hoc networks. The result has presented in Fig. 2 and random topology we used is provided in Fig. 3. As pervious works [2–5] has shown, we can find the number of packets blocked is quite unbalanced. This result verified due to the spatial factor and employing BEB algorithm, the IEEE 802.11 MAC protocol may face severe fairness problem which result in the degradation of system throughput. Finally, BEB algorithm does not support priority and there is no other mechanism to guarantee a lower access delay bound for real-time nodes. Hence, multimedia traffic like voice and live video transmission may suffer with this protocol.

Since the wireless network performance is greatly dependent on the adopted MAC protocol, there have been adequate discussions on the issue on variant BEB algorithms and their performance analysis [6–8].

In Song et al. [9] proposed exponential increase exponential decrease (EIED) algorithm for channel access in wireless local area networks (WLANs). This protocol provides better

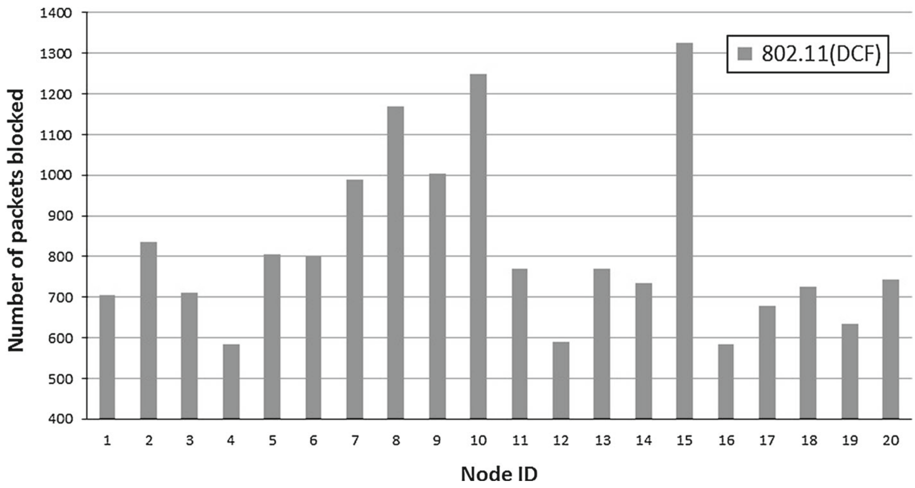

Fig. 2 Simulation result

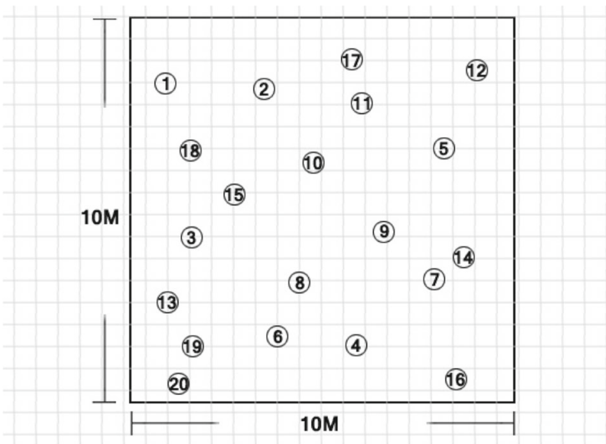

Fig. 3 Topology used in simulation

performance than BEB in dense environments since it double its contention window size after a collision but only halve its contention window size after a successful transmission.

Another approach, linear increase linear decrease (LILD) algorithm which proposed by Bharghavan et al. [10], adopts an even retarded contention window control mechanism than EIED since the size of contention window increases linearly after collision and also decreases linearly after a successful transmission. Hence, LILD can provide a slightly better performance than EIED in extremely congested but stable wireless environments.

Except EIED and LILD algorithms, in the literatures there also has been a great deal of excellent efforts on enhancing the performance of BEB algorithms [11–13]. In [14] and [15], the authors pointed out that the fairness problem is caused due to unequally channel access among nodes. Hidden or exposed terminal problems are two special cases of fairness problem.

All of the aforementioned schemes did not address the fairness problem and they did not provide any priority mechanisms to support multimedia traffic either. Accordingly, the IEEE 802.11 working group proposed a new MAC protocol to support multimedia traffic in WLANs. They proposed EDCA (enhanced distributed channel access) to enhance the original 802.11 to support applications with QoS requirements. However, EDCA did not take into account the fairness problem.

In [16], the authors also proposed a so called enhanced BEB algorithm to improve the quality-of-service (QoS) on wireless ad-hoc networks. However, our proposed algorithm focuses on the improvement of overall network performance.

Based on the above observations, we proposed a pragmatic backoff algorithm, called enhanced binary exponential backoff (E-BEB) algorithm, to improve the system throughput and impartial channel access in multi-hop wireless ad-hoc networks. E-BEB can mitigate intensive collision among nodes and effectively increase the overall network throughput in congested environments and it can also alleviate the fairness problem in partially connected network topology. Besides, E-BEB includes multi-level priority schemes so that multimedia communication can be supported. Compare with the BEB and other backoff algorithms, E-BEB can provide better system performance over a wider range of channel condition.

An analytical analysis is carried out to study the system saturation throughput of the proposed scheme. In addition, we have carried out comprehensive simulations implemented by a customized simulation program to evaluate the proposed E-BEB algorithm. The results confirm that the E-BEB algorithm not only alleviate the fairness problem in multi-hop wireless environments but also mitigate the intensive packet collision rate in congested scenario.

The remainder of this paper is organized as follows. In Sect. 2 we describe the proposed B-BEB algorithm and its numerical analysis. Section 3 provides simulation results. Finally, in Sect. 4 we conclude this paper.

2 E-BEB Algorithm and its Numerical Analysis

In this section, we describe proposed scheme in detail as an effort to improve the previous schemes. Besides, we also provide the system saturation throughput analysis.

2.1 Proposed Scheme

E-BEB algorithm is similar to the BEB algorithm except we add a variable, persistent probability, to decide whether one should double its contention window size or not after a successful transmission.

At first, E-BEB chooses the value of persistent probability. After the value is determined, corresponding to the start-up phase, the contention window increase exponential after a transmission failure to quickly tune its size according to the current channel status, just like the traditional BEB algorithm. Nevertheless, after a successful transmission, E-BEB algorithm will use the persistent probability to decide whether this node should double its contention window size or not. By using the persistent probability, we can let successful transmitted node releases channel resources and keeps few number of nodes having relatively smaller contention window to reduce collision rate.

Compare with the BEB algorithm, E-BEB provides better performance in terms of lower packet collision probability, shorter average channel access delay, and fair channel access. Please note that the performance of the E-BEB algorithm strongly depends on the parameter of persistent probability. In other words, the value of persistent probability should be dynam-

Algorithm 1 Function E-BEB contention window handler

```
Initialization
   Contention window size := W_0
   Priority classes S_x :={x_1, x_2, ..., x_n}
   Persistent probability :=x
   Persistent Number := X

Repeat
   x:= ResolvePriority( DateType , S_x )
   X:=⌊100 · x⌋
    if ACK frame received then
    // successful transmission
    /* RND is a random number between 1 and 100*/
    RND:= rand() mod 100 +1
    if RND < X then
    /* enlarge contention window after successful transmission */
     Contention window size
     := Contention window size *2
    else
     Contention window size:=W_0
   else
   // failed transmission
    if Current backoff window size < W_m then
     Contention window size
     :=Contention window size *2
    else
     Contention window size=W_m
until no more frame to transmit
end
```

ically adjusted according the channel status, and a proper choice of the value of persistent probability based on current environment has a great influence on overall system performance. Based on above reasoning, the proposed scheme also can extend to support priority transmission by setting different persistent probability. The high priority nodes should be given lower value of persistent probability to increase the choice of selecting a small backoff number and vice versa.

The discrete-time Markov chain with two-dimensional parameters of E-BEB is showing in Fig. 4 and the following pseudo-code describes how the E-BEB enable node to decide its contention window. Besides, the following pseudo-code is a handler performed how E-BEB scheme count down and decide accurate backoff number.

2.2 Saturation Throughput Analysis

In this section, we present an analytical model that accurately evaluates the saturation throughput of proposed scheme. Before we start to present our analysis, important notations and variables are define in Table 1, and they will be used throughout this paper.

Assume $s(t)$ and $b(t)$ be the stochastic processes representing the backoff stage and the backoff time counter respectively for a given station at time slot. The bidirectional process $\{s(t), b(t)\}$ can be modeled by a Markov chain as shown in Fig. 4.

Let $b_{i,k} = \lim_{t\to\infty} p\{s(t) = i, b(t) = k\}$ be the stationary distribution of the Markov chain for $i \in [0, n-1]$ and $k \in [0, W_i - 1]$. Now we try to calculate the average contention window size. As defined in Sect. 2, we use the persistent probability X to control the

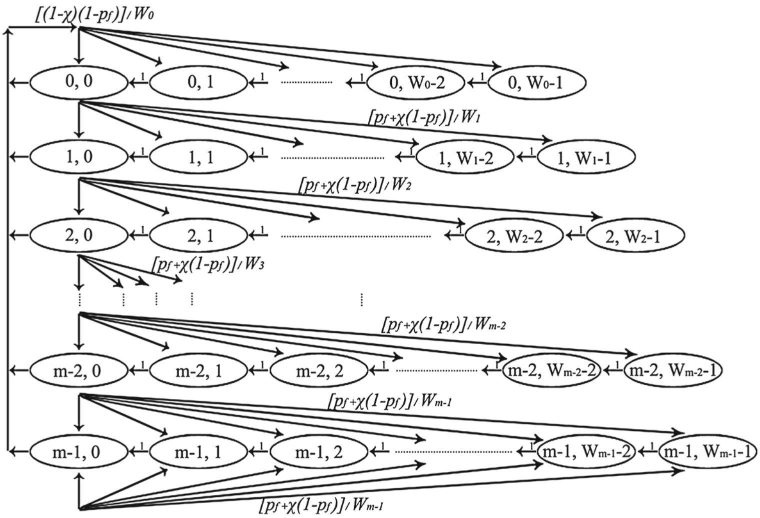

Fig. 4 Markov Chain model for the proposed backoff algorithm

Table 1 Variables used in analytical analysis

Variables	Meaning and explanation
β	Channel bandwidth
$\bar{W}$	Average contention window size
x	Persistent probability
m	Maximum number of backoff stages
n	Number of nodes
p_f	Probability of transmission failure
p	Transmission probability
L_{data}	Data packet size
L_{ack}	ACK packet size
P_s	Probability of a successful transmission
P_I	Probability of idle channel
P_c	Probability of a collided transmission
P_{err}	Probability of a transmission errors
T_s	Duration of a success transmission time
T_I	Duration of idle channel time
T_c	Duration of a collided transmission time
T_{err}	Duration of a transmission error time
T_{frame}	Length of time frame
BER	Cannel bit error rate
σ	Duration of time slot
δ	Propagation delay

Algorithm 2 Function E-BEB Backoff handler

```
Initialization
    /* W0 is set by Function E-BEB handle contention window size */
    Node's contention window size :=W0
    Current backoff number := bf
    An array with increasing number {0, 1, 2,··· , W0-1} :=s[W0]

if Select new backoff number then
   // Here need to choose a contention window size
   // from the set {0, 1, 2, 3,··· , W0-1}
   // Let the device count down contention window
   // PIVOT is a random number between 0 and W0-1
   PIVOT := rand mod W0
   bf := s[PIVOT]
else if Continue countdown process then
   Repeat
if bf > 0 then
     //continue countdown
     bf:=bf-1
else
     break and Send Packet
   until end of backoff
end
```

contention window size. Thus, we have:

$$\begin{aligned}\tilde{W} &= x(1-p_f)2W + xp_f(1-p_f)2^2W + xp_f^2(1-p_f)2^3W \\ &\quad + \cdots + xp_f^m(1-p_f)2^{m+1}W + (1-x)(1-p_f)W + (1-x)p_f(1-p_f)2W \\ &\quad + (1-x)p_f^2(1-p_f)2^2W + \cdots + (1-x)p_f^m(1-p_f)2^mW \end{aligned} \tag{1}$$

By solving the above equation, we get

$$\bar{W} = \frac{\tilde{W}}{1-p_f^{m+1}} \tag{2}$$

Substituting $\tilde{W}$ express in Eq. (1) into Eq. (2), we obtain:

$$\bar{W} = \frac{[2x+(1-x)]\cdot(1-p_f)\cdot\left(\frac{1-(2p_f)^{m+1}}{1-2p_f}\right)W}{1-p_f^{m+1}} = \frac{(1+x)(1-p_f)\left[1-(2p_f)^{m+1}\right]}{\left(1-p_f^{m+1}\right)(1-2p_f)}W \tag{3}$$

Since, in the beginning, a node starts to transmit a frame with probability p, and defers the transmission with probability $1-p$. According to probability theory, we get:

$$P(X=x) = (1-p)^{x-1}p, \quad 1 \le x \le \infty \tag{4}$$

Hence, the average contention window size, $\bar{W}$, is completely identified by the value of p, and thus we have

$$\frac{\bar{W}+1}{2} = \sum_{x=1}^{\infty} xp(1-p)^{x-1} = \frac{p}{1-p}\sum_{x=1}^{\infty} x(1-p)^{x-1} = \frac{1}{p} \tag{5}$$

By solving the above equation, we get:

$$p = \frac{2}{\bar{W} + 1} \tag{6}$$

Then, substituting $\bar{W}$ in (2) into (6), we obtain:

$$\bar{W} \tag{7}$$

However, the value of probability p_f is still unknown. Since the probability of transmission failure is defined as the probability that a transmitted frame collided or received with error, we have

$$p_f = 1 - (1-p)^{n-1} * \left(1 - p_e^{data}\right) * \left(1 - p_e^{ack}\right) \tag{8}$$

Here P_e^{data} and P_e^{ack} stand for the probability of data frame received with error and the probability of ACK frame received with error. Thus, we have:

$$P_e^{data} = 1 - (1 - BER)^{L_{data}} \tag{9}$$

$$P_e^{ack} = 1 - (1 - BER)^{L_{ack}} \tag{10}$$

Since the saturation throughput is defined as a relation of successfully transmitted payload size over a randomly chosen time slot in the active stage, the system saturation throughput can be defined as follows:

$$S = \frac{P_s * L_{DATA}}{\left(P_e^{DATA} + P_e^{ACK} + P_c + P_s\right) * T + P_I * \sigma} \tag{11}$$

Where $T = T_{DIFS} + T_{SIFS} + \frac{L_{DATA}+L_{ACK}}{\beta} + 2\delta$. According to the equation above, the successful transmission probability, P_s, is defined as the system transmitted a data frame without collision or bit error. Hence, we can express P_s as

$$P_s = np(1-p)^{n-1}(1-p_e) \tag{12}$$

Let P_I denote the probability that there is no node try to send packet in a randomly chosen time slot, and P_c denote the probability that a collision occurs in a randomly chosen time slot. Hence, they can be express as:

$$P_I = (1-p)^n \tag{13}$$

$$P_c = 1 - (1-p)^n - np(1-p)^{n-1} \tag{14}$$

2.3 How to Find an Optimal X

We attempt to find out the optimal persistent probability x. However, we discover that our persistent probability x is depended on the throughput so that we need find out the maximum throughput first. From above evaluation, it is clear that in Eq. (11), the system throughput depends on the contention window size via p. Therefore, taking derivative of Eq. (12) with respect to p, and imposing it to zero, we can calculate an optimal contention window size that effects whole system maximum throughput by solving the equation as below:

$$\frac{\partial S}{\partial p} = 0 \tag{15}$$

Under the condition that $p \ll 1$, we have

$$(1-p)^n \cong 1 - np \tag{16}$$

Therefore, we can get approximate solution, Opt_p, from the following equation.

$$p = Opt_p = \frac{Tn + 2T - \sigma + \sqrt{Tn^2 + 2T(T-\sigma)n - 2T^2 - 2T\sigma + \sigma^2}}{4(T-\sigma+1)n} \tag{17}$$

In the following, we try to find an optimal contention window size. From Eq. (6), we substituting p by Opt_p, and thus we have

$$Opt_p = \frac{2}{\bar{W} + 1} \tag{18}$$

Since $p_f \ll m,\ 0 \le p_f \le 1$,and $m \succ 1$, we can simplify the Eq. (18). By substituting $\bar{W}$ in (18), finally, we have

$$X = 1 + \frac{\left[\left(p_f^{m+1} - p_f^m\right)2^m + (1-p_f)\right] \cdot Opt_p \cdot W + 4 \cdot p_f}{\left[\left(p_f^{m+1} - p_f^m\right)2^{m+1} - (1-p_f)\right] \cdot Opt_p \cdot W} \tag{19}$$

3 Simulations and Performance Evaluation

In this section we evaluate the performance of proposed scheme and provide comprehensive comparison with other well known backoff algorithms.

3.1 Simulation Environment

Our simulation model is built using the custom event-driven C++ program, and each simulation runs at least for 1,000 simulation seconds. We assume all nodes are in a saturated network condition, and use static routing and random topology so as to focus on MAC layer performance analysis issues. All the simulations are conducted on Ubuntu 10.04 on an Intel Core i5 1.3 GHz Notebook with 4 GB memory.

Table 2 Default attribute values used in the simulation with explanation

Attribute	Meaning and Explanation	Value
$L_{MAC-HEANDER}$	Length of MAC header	160 bits
L_{phy}	PHY header	192 bits
$L_{PAYLOAD}$	MAC layer payload size	1,000 bytes
L_{ACK}	MAC layer ACK size	112 bits
CW_{min}	Initial Contention window	32
CW_{max}	Maximum Contention window	1024
m	Maximum backoff state	5
β	Channel bit rate	1 Mbps
T_{slot}	Duration of time slot	20 μs
T_{DIFS}	DIFS time interval	50 μs
T_{SIFS}	SIFS time interval	10 μs
δ	Propagation delay	1 μs

The evaluation was made with respect to the system saturation throughput, collision rate, fairness index and average end-to-end delay under different value of persistent probability X or number of nodes. The default parameters used in the simulation are list in Table 2. These values are chosen carefully to make simulation reasonable and feasible and reflect a realistic wireless environment.

3.2 Simulations Result

Figure 5 compares the system throughput with other backoff algorithm. The value of persistent probability is set to be 0.9. As shown in figure, the proposed scheme obtains much higher performance in both high and low density networks.

Figure 6 depicts the packet collision rate versus the number of nodes. Compare with other backoff algorithms, the proposed scheme achieves a lower collision ratio in congested environments.

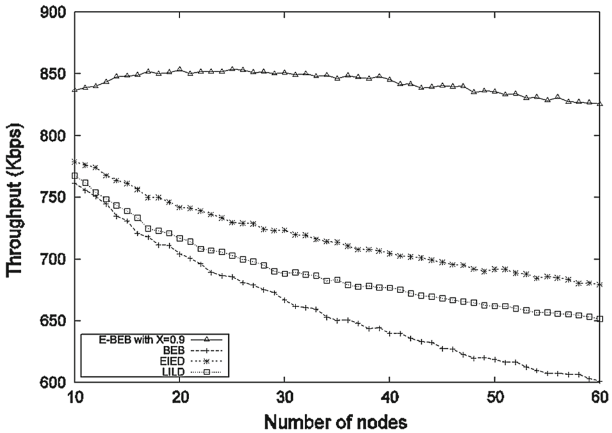

Fig. 5 Throughput versus number of nodes

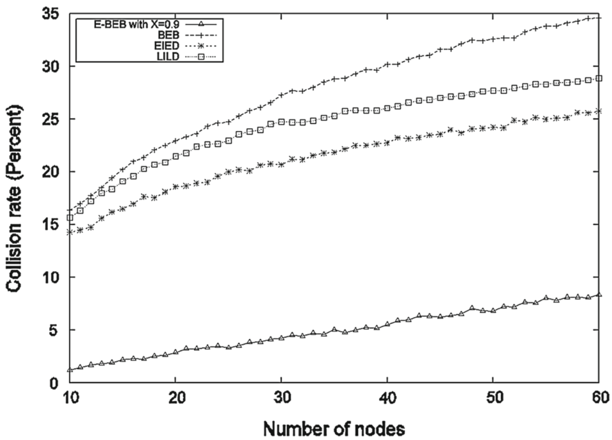

Fig. 6 Collision rate versus number of nodes

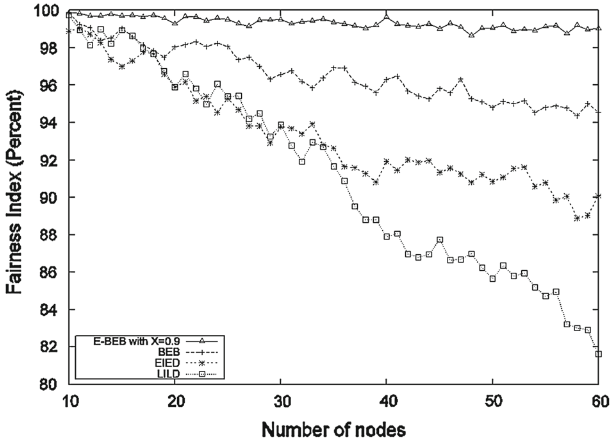

Fig. 7 Fairness Index versus number of nodes

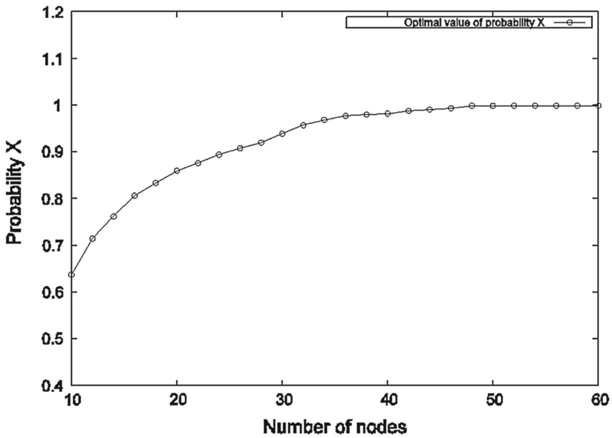

Fig. 8 Optimal value of probability X versus number of nodes

Since fairness problem is an important metric when we evaluate the performance of wireless MAC protocol, in Fig. 7 we calculate the fairness index defined by Jain [17] to evaluate how fair the proposed scheme is. The fairness index is defined as

$$Fairness\ Index = \frac{\left(\sum_{i=1}^{n} T_i\right)^2}{n * \sum_{i=1}^{n} T_i^2}$$

Where n is the number of connections, and T_i is the throughput of node i. We can see the proposed scheme can achieve approximate 0.99, and this result shows that our scheme can achieve both efficiency and fairness.

Figure 8 shows the optimal value of persistent probability X. As mentioned in Sect. 2, we can get an optimal value of X by solving Eq. (18). As shown in Fig. 8, the optimal value of X approximates 1 when the network becomes congested. This is reasonable because a high probability X implicitly increases the average contention windows size.

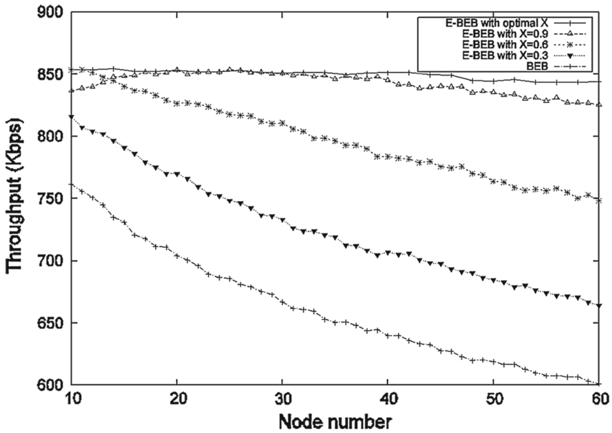

Fig. 9 Probability X versus number of nodes

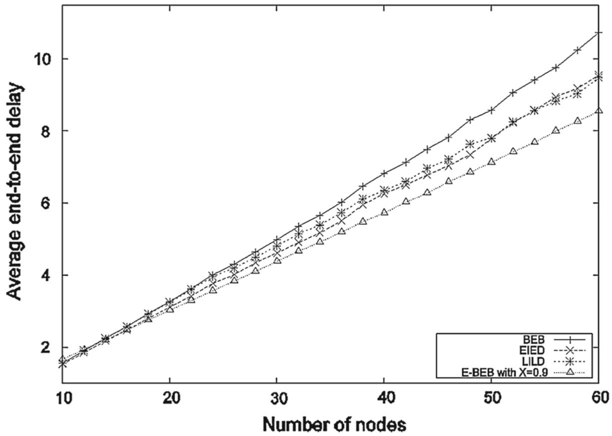

Fig. 10 Average end-to-end delay versus number of nodes

Figure 9 shows the value of persistent probability X in our proposed scheme is optimal. As shown in the figure, an optimal X can always achieve higher system throughout in both high load and low load environments.

In Fig. 10, we evaluate the average end-to-end delay of the proposed scheme and other backoff algorithms. As shown in figure, the proposed scheme can always keep lower delay, especially in congested scenario.

Figure 11 depicts the end-to-end delay of different priority traffic. The simulation result shows that the proposed scheme can easily support the prioritized channel access.

4 Conclusions

In this paper, we introduce an E-BEB algorithm for multi-hop wireless ad-hoc networks which employs a distributed contention window control mechanism to alleviate intensive collisions, mitigate the fairness problem, and to support multimedia traffic. Our method

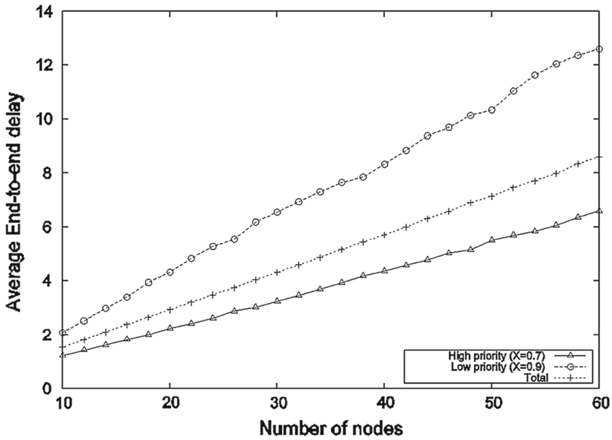

Fig. 11 Average end-to-end delay versus number of nodes for different priority traffic

is simple and efficient. An accurate system saturated analytical model is also present in this paper to study the system throughput. Furthermore, the given results also show that the optimal value of persistent probability X has a significant impact on the system performance. Through extensive simulations, we have demonstrated quantitatively the effectiveness of the proposed E-BEB algorithm. As perspective to this work, we will calculate the optimal persistent probability for E-BEB algorithm based on the analytical model provided in this paper.

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References

1. Bianchi, G. (2000). Performance analysis of the IEEE 802.11 distributed coordination function. *IEEE Journal on Selected Area of Communications*, *18*(3), 535–547.
2. Nandagopal, T., Kim, T. E., Gao, X., & Bharghavan, V. (2000). Achieving MAC layer fairness in wireless packet networks. In *Proceedings of the 6th annual international conference on Mobile computing and networking—MobiCom '00*, (pp. 87–98).
3. Ozugur, T., Naghshineh, M., Kermani, P., & Copeland, J. A. (1999). Fair media access for wireless LANs. In *Seamless Interconnection for Universal Services. Global Telecommunications Conference. GLOBECOM99. (Cat. No.99CH37042)*, (pp. 570–579).
4. Bensaou, B. (2000). Fair medium access in 802.11 based wireless ad-hoc networks. In *2000 First Annual Workshop on Mobile and Ad Hoc Networking and Computing. MobiHOC (Cat. No.00EX444)*, (pp. 99–106).
5. Koh, E. B., & Kim, C. K. (2006). Mitigating starvation in CSMA-based wireless ad hoc networks using carrier sense threshold. In *Software, Telecommunications and Computer Networks, 2007. SoftCOM 2007. 15th International Conference on, IEEE*, (pp. 1–6).
6. Ni, Q., Li, T., Turletti, T., & Xiao, Y. (2005). Saturation throughput analysis of error-prone 802.11 wireless networks. *Wireless Communications and Mobile Computing*, *5*(8), 945–956.
7. Deng, D. J., Li, B., Huang, L., Ke, C. H., & Huang, Y. M. (2009). Saturation throughput analysis of multi-rate IEEE 802.11 wireless networks. *Wireless Communications and Mobile Computing*, *9*(8), 1102–1112.
8. Li, C. S., Tsuei, T. G., & Chao, H. C. (2004). Evaluation of contention-based EDCA for IEEE 802.11e wireless LAN. *Journal of Internet Technology*, *35*(4), 429–434.
9. Song, N. O., Kwak, B. J., Song, J., & Miller, L. E. (2003). Enhancement of IEEE 802.11 distributed coordination function with exponential increase exponential decrease backoff algorithm. In *The 57th IEEE Semiannual Spring VTC*, (p. 4).

10. Bharghavan V., Demers, A., Shenker, S., & Zhang, L. (1994). MACAW: A media access protocol for wireless LAN's. In *Proceeding ACK SIGCOMM'94*, (pp. 212–255).
11. Wang, C., Li, B., & Li, L. (2004). A new collision resolution mechanism to enhance the performance of IEEE 802.11 DCF. *IEEE Transactions on Vehicular Technology*, *53*(4), 1235–1246.
12. Sakakibara, K., & Yamakita, J. (2004). Backoff algorithm with release delay after successful transmissions. In *TENCON 2004. 2004 IEEE Region 10 Conference*, 3, (pp. 5–8).
13. Wu, H., Cheng, S., Peng, Y., Long, K., & Ma, Jian (2002). IEEE 802.11 distributed coordination function (DCF): analysis and enhancement. In *Communications, 2002. ICC 2002. IEEE International Conference on*, 1, (pp. 605–609).
14. Ozugur, T., Naghshineh, M., Kermani, P., & Copeland, J. A. (1999). Fair media access for wireless LANs. In *Global Telecommunications Conference*, 1b, (pp. 570–579).
15. Bensaou, B., Wang, Y., & Ko, C. C. (2000). Fair medium access in 802.11 based wireless ad-hoc networks. MobiHOC. In *2000 First Annual Workshop on Mobile and Ad Hoc Networking and Computing*, (pp. 99–106).
16. Al-Hubaishi, M., Abdullah, T., Alsaqour, R., & Berqia, A. (2012). E-BEB algorithm to improve quality of service on wireless ad-hoc networks. *Research Journal of Applied Science, Engineering and Technology*, *6*(7), 807–812.
17. Jain, R., Durresi, A., & Babic, G. (1999). Throughput fairness index: an explanation. In *Proceedings of ATM Forum/99-0045*.

Hui-Hsin Chin received the M.S. degree the Department of Computer Science and Information Engineering, National Changhua University of Education in 2013. She is currently pursuing the Ph.D. degree in the Department of Industrial Engineering and Management, National Chiao Tung University, Hsinchu, Taiwan. Her main interests include mobile ad-hoc networks and wireless local area networks. She is a student member of the IEEE.

Chun-Cheng Lin received his B.S. degree in Mathematics, M.B.A. degree in Business Administration, and Ph.D. degree in Electrical Engineering from National Taiwan University, Taiwan, in 2000, 2007, and 2009, respectively. Since February 2011, he has been an Assistant Professor at National Chiao Tung University, Taiwan. He was an Assistant Professor at Taipei Municipal University of Education (2010–2011) and National Kaohsiung University of Applied Sciences (2009–2010). His main research interests include graph drawing and information visualization, wireless networks, design and analysis of algorithms, as well as computational management science. He is a member of the IEEE.

Der-Jiunn Deng received the Ph.D. degree in electrical engineering from the National Taiwan University in 2005. He joined the National Changhua University of Education as an assistant professor in the Department of Computer Science and Information Engineering in August 2005 and then became a full professor in February 2012. His research interests include multimedia communication, quality-of-service, and wireless networks. In 2010, 2011, and 2012, he received the Research Excellency Award of National Changhua University of Education. In 2012, he also received the Outstanding Faculty Research Award of National Changhua University of Education. Dr. Deng served or is serving as an editor and guest editor for several technical journals. He also served or is serving on several symposium chairs and technical program committees for IEEE and other international conferences. Dr. Deng is a member of the IEEE.