Fractional Backoff Algorithm for the Next Generation WLAN

Xuewei Cai[1], Bo Li[1], Mao Yang[1(✉)], Zhongjiang Yan[1], Bo Yang[1], Yi Jin[2], and Xiaobo Li[2]

[1] School of Electronics and Information, Northwestern Polytechnical University, Xi'an, China
caixuewei@mail.nwpu.edu.cn, {libo.npu,yangmao,zhjyan}@nwpu.edu.cn
[2] China Academy of Space Technology, Xi'an, China

Abstract. With the rapid popularization of wireless communication devices, wireless local area network (WLAN) is ubiquitous in daily life. However, the demand for wireless communication services is growing rapidly and brings new challenges to WLAN technology. The problem of performance degradation under dense deployment network scenarios is an important topic in the next generation WLAN (NGW). This paper proposes fractional backoff algorithm, named eat-B, to enhance area throughput. Eat-B introduces fractional backoff and enables the nodes who provide more contributions for the area throughput to finish their backoff process faster. Simulation results indicate that the area throughput of the eat-B algorithm outperforms the binary exponential backoff (BEB) algorithm adopted by the traditional IEEE 802.11, especially under dense deployment scenarios.

Keywords: WLAN · IEEE 802.11 DCF · Binary exponential backoff · Dense deployment · Next generation WLAN

1 Introduction

With the development of information technology and wireless communication devices, the demand for wireless communication, especially transmission data rates, has keep rising. To meet the growing requirements, academia and industry are working on next-generation WLAN (NGW) standard amendment: IEEE 802.11ax towards high area throughput [1]. Highly dense deployment network [2] such as residential areas or offices is the target scenarios of 802.11ax [3], where many access points (APs) and non-AP stations (STAs) are distributed in geographically limited areas. IEEE 802.11ax modifies the physical layer (PHY) and the medium access control layer (MAC) [4] to improve the average throughput per station in dense deployment scenarios.

J.-L. Chen et al. (Eds.): WiCON 2018, LNICST 264, pp. 24–31, 2019.
https://doi.org/10.1007/978-3-030-06158-6_3

The distributed coordination function (DCF) protocol can be used to achieve fair access performance for multiple stations in IEEE 802.11 [5], but it also causes performance anomaly under multi-rate station conditions [6] (e.g., 802.11b supports four kinds of data rates [7]; 802.11a supports eight [8]) in which wireless channel are used by low-rate stations for a longer time than high-rate stations. This circumstance can inhibit network performance, especially in cases of dense deployment. Additionally, dense deployment poses great challenges for distributed channel access control due to fierce competition among a large number of stations.

The binary exponential backoff (BEB) algorithm is an important part of DCF to avoid simultaneous transmission and minimize interference. Each node needs to complete backoff process before accessing a channel. The backoff timer decreases when the clear channel assessment (CCA) and network allocation vector (NAV) indicate that the medium has been sensed to be idle for a DCF interframe space (DIFS) interval. The sensation granularity of the channel state in the BEB process is too coarse in dense deployment scenarios in which the channel state is complicated, only busy or idle. Similarly, the backoff action is also quite simple such that the backoff timer decreases by one when idle and hangs up when busy in one timeslot. Given these drawbacks of the BEB algorithm, Some researchers modified the minimum collision window to increase area throughput [9,10], but these method lacks efficiency in dealing with data frames of unequal length. A spatial reuse scheme proposed by Liu *et al.* [11] to enhance the average throughput, but falls short of setting backoff granularity reasonably.

To enhance area throughput, this paper proposes a fractional backoff algorithm called eat-B, in which the backoff process of each communication link dynamically adapts the channel state information (CSI) by refining the backoff granularity. It means the backoff counter of the node who may provide more contributions for the area throughput is probably decreased by a larger value, while that of the node who may provide less contributions for the area throughput is probably decreased by a smaller value. In other word, the nodes who provide more contributions for the area throughput will finish their backoff process faster. The simulation results confirm the performance advantages in area throughput.

The contribution of this research is as follows.

- To the best of our knowledge, this study is the first attempt to introduce a fractional backoff algorithm dynamically.
- This paper compares the eat-B and BEB algorithms through simulations, and the results indicate that the area throughput of the eat-B algorithm outperforms BEB, especially under dense deployment scenarios.

The reminder of this paper is as follows: Sect. 2 illustrates the motivation and key idea of backoff algorithm. Sect. 3 details the eat-B algorithm. Sec. 4 deploys several simulations and verifies the performance. Finally, Sect. 5 concludes the paper.

2 Motivation and Key Idea

2.1 Introduction to Backoff Mechanism and Analysis of Existing Problems

Two main problems plague the existing BEB mechanism. The first is that BEB has no unique ability to address the high collision probability resulting from fierce channel contention in dense deployment scenarios; reducing channel contention must be solved by NGWs in dense deployment circumstances. The second problem is that some parts of the BEB can inhibit area throughput for two reasons. First, WLANs contain multi-rate stations, but the probability of accessing the channels for each station is identical regardless of the station rate. The transmission time for a packet in a lower-rate station is longer than in a higher-rate station; thus, lower-rate stations occupy the channel for longer, limiting network performance and preventing proportional fairness. To solve this problem and improve channel utilization, an unfair channel access mechanism must be implemented to increase channel access opportunities for higher-rate stations. Second, even if the channel states across stations are similar, the contributions of communication link to area throughput may be different due to different link qualities.

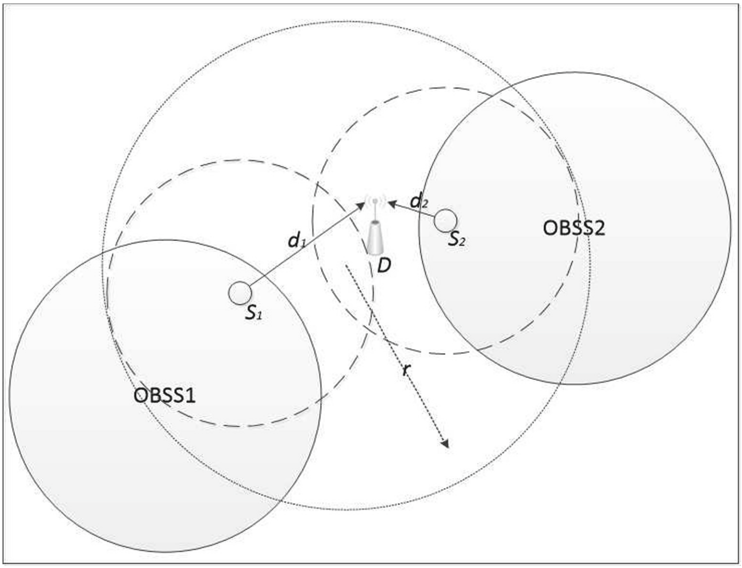

Fig. 1. Illustration of sample scenario.

As shown in Fig. 1, node S_1 and node S_2 have similar channel states, but the link quality of S_2 can be better than that of S_1 due to different transmission distances, which contributes more to area throughput. However, under the BEB mechanism, these nodes will have the same backoff speed and identical channel access opportunities, which cannot fully leverage good-quality links. Therefore, channel access opportunities should be adjustable depending on link quality so good-quality links have more opportunities to access the channel and thus improve area throughput.

2.2 Key Idea

The eat-B algorithm is assumed to solve problems related to performance degradation given dense deployment and performance anomalies under multi-rate station circumstances. The backoff granularity of each timeslot is not fixed at 1; rather, a fractional number in the eat-B algorithm can refine granularity, alleviate channel competition, and reduce the collision probability. The backoff granularity is determined by the contribution of the communication link to area throughput of each node, so stations making greater contributions can be provided more frequent channel access to make sufficient use of the wireless channel. For example, as shown in Fig. 1, S_2 has larger granularity than S_1 because the signal transmitted by S_2 can be received by D at a higher signal to interference plus noise ratio (SINR) in which S_1 and S_2 have equal transmission power. Additionally, AP can adjust the backoff granularity factor to ensure fairness.

3 Description of Eat-B Algorithm

3.1 Overview

The most important question in the eat-B algorithm is how to apply the backoff granularity algorithm for each node. In each timeslot, the current channel state (e.g., interference power and communication link distance) is used to calculate the contribution of the link to the area throughput. Then, the backoff granularity of the current timeslot can be obtained, and the backoff process can be paused within this timeslot if necessary.

3.2 Specifications

The proposed eat-B algorithm is described as follows.

Step 1. The source node (denoted as S), which requires access to the channel and wants to send a data frame to the destination node (denoted as D), must query the maintained CCA range first; that is, $[-82dBm, CCA_{th}]$, where CCA_{th} is the CCA threshold of each communication link; it may be a unique threshold for the whole network, or it could be obtained by the receiving node D during the last transmission, in which case the CCA_{th} of each node pair may be different.

Step 2. In each timeslot, S detects the interference power of the channel, denoted as I. If $I > CCA_{th}$, then the backoff process becomes hung up within this timeslot. If so, Step 2 is repeated in the next timeslot; otherwise, proceed to Step 3.

Step 3. Calculate the estimated signal to interference ratio (SIR) as $SIR_e = Pr - I(dB)$, where Pr is the receiving power of the last transmission from S to D, such as the power of the RTS frame. Then, the corresponding data transmission rate R_e can be obtained via mapping.

Step 4. The backoff granularity ω of the current timeslot can be calculated according to $\omega : \omega_{max} = \eta : \eta_{max}$, ω_{max} represents the maximum backoff granularity (the value can be either 1 or another positive number), η represents the contribution of the communication link to the area throughput, and η_{max} is the maximum value. Given a minimum interference area $\mathscr{A}_{min}$ and a maximum data rate R_{max}, then we have $\eta_{max} = \frac{R_{max}}{\mathscr{A}_{min}}$, similarly we have $\eta = \frac{R}{\mathscr{A}}$, where $\mathscr{A}$ represents the union of interference area of S and D.

Step 5. The backoff timer counts down the value of ω , and S transmits the frame when the backoff timer reaches 0; otherwise, return to Step 2 in the next timeslot.

3.3 Use Case

This section emulates the process of the eat-B algorithm using the scenario in Fig. 1.

Step 1. S_1 and S_2 each want to send a data frame to D. They have five and nine backoff timeslots at a CCA threshold of $-62dBm$ and $-60dBm$, respectively.

Step 2. Detect the interference power on the channel. Even if S_1 and S_2 have similar channel states, the backoff action may be different due to different CCA thresholds; for example, the backoff process of S_1 may get hung up when $I = -61dBm$, whereas that of S_2 continues.

Step 3. Calculate the corresponding data transmission rate R_e.

Step 4. The link quality of S_2 is better than that of S_1; thus, the backoff granularity of S_2 is assumed to be twice that of S_1.

Step 5. The backoff timer counts down, and the frame is sent if the timer reaches 0.

As indicated in this case, even if S_2 has twice as many backoff timeslots as S_1, S_2 which has a better channel state will still transmit the frame before S_1 due to having a larger backoff granularity and higher CCA threshold; therefore, resource utilization is enhanced.

4 Simulation

4.1 Simulation Environment

This section tests and compares the performance of the eat-B algorithm and BEB algorithm through simulations of the eat-B algorithm based on the NS-2 simulation platform developed for IEEE 802.11ax [12].

We deploy a multi-BSS network in which one AP and several STAs are served in each BSS and only the uplink traffic scenario is considered. We assume that the APs are deployed within a square area of with $120\,m \times 120\,m$. The STAs in each BSS are randomly deployed in an annular area with the AP as centre, an inner radius r_a and outer radius r_b. We assume that $r_a = 10\,m$ and $r_b = 60\,m$ based on the condition of $r_a < r_b$ [13]. The path loss exponent α is set to 6 in the simulation. In the proposed eat-B algorithm, $\omega_{max} = 1$, $CCA_{th} = -62dBm$. The mapping relations between the SIR and transmission rate can be refereed as [14]. Performance is compared by testing the area throughput, collision probability, and average latency between the eat-B and BEB algorithms.

4.2 Performance Evaluation

Figure 2 illustrates that the area throughput of the proposed eat-B algorithm hardly changed with different numbers of STAs, and larger granularity avoided a high collision probability as the number of STAs in each BSS increased.

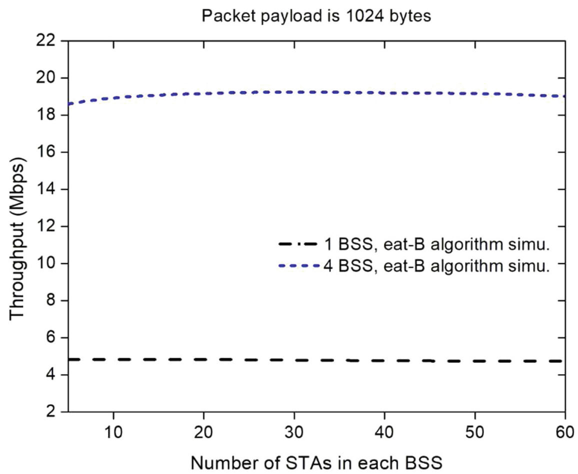

Fig. 2. Performance of eat-B algorithm with different numbers of STAs.

Figure 3 compares the area throughput and collision probability of the eat-B and BEB algorithms. As the number of BSS increased, the area throughput of the BEB algorithm was not perfectly linear because the collision probability also increased; the performance of the eat-B algorithm improved substantially with 24 BSS because the channel state for each station changed from simple to complex in this range and barely changed thereafter. The performance of eat-B and BEB followed the same trend with BSS above 4. Generally, the gap in area throughput and collision probability between the two algorithms was nearly 100% and 60%, respectively.

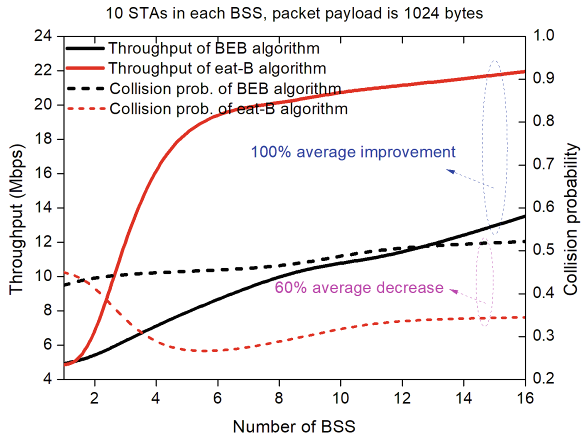

Fig. 3. Performance of eat-B algorithm with different numbers of BSS.

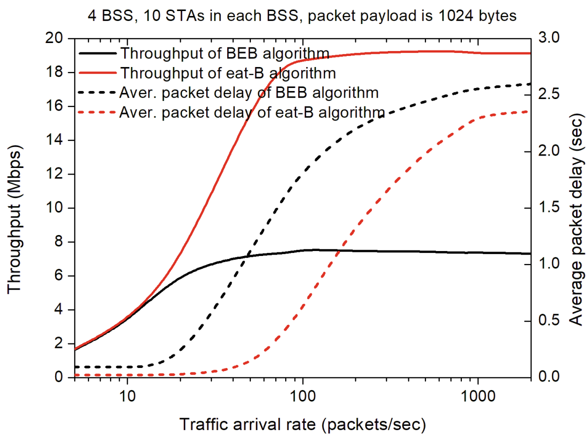

Fig. 4. Performance of eat-B algorithm at different traffic rates.

Fig. 4 compares the area throughput and average latency of the eat-B and BEB algorithms based on traffic rate. The latency of the eat-B algorithm declined by 15% compared to BEB, and the area throughput gain of eat-B became apparent at a traffic arrival rate exceeding channel capacity due to the gain is from its high channel utilization.

5 Conclusions and Future Work

This paper proposes fractional backoff algorithm called eat-B for dense deployment scenarios to improve NGW performance. Comparative simulations indicate this algorithm substantially enhanced area throughput by dynamically adapting the backoff granularity of each communication link. In the future, we plan to research the eat-B system model to enrich its theoretical foundation and extend it to multi-channel wireless networks [15].

Acknowledgement. This work was supported in part by the National Natural Science Foundations of CHINA (Grant No. 61771390, No. 61501373, No. 61771392, and No. 61271279), the National Science and Technology Major Project (Grant No. 2016ZX03001018-004, and No. 2015ZX03002006-004), and the Fundamental Research Funds for the Central Universities (Grant No. 3102017ZY018).

References

1. IEEE 802.11 Wireless LANs: Proposed TGax draft specification. IEEE 802.11-16/002 4r1, March 2016
2. Kamel, M., Hamouda, W., Youssef, A.: Ultra-dense networks: a survey. IEEE Commun. Surv. Tutor. **18**(4), 25222545, Fourth quarter (2016)
3. IEEE: 802.11 HEW SQ Proposed PAR. IEEE, doc. IEEE 802.11-14/0165r1 (2014)
4. Bellalta, B.: IEEE 802.11ax: high-efficiency WLANs. IEEE Wirel. Commun. **23**(1), 38–46 (2016)
5. IEEE STD. 802.11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (1999)
6. Heusse, M., Rousseau, F., Berger-Sabbatel, G., Duda, A.: Performance anomaly of 802.11b. In: IEEE INFOCOM 2003 Twenty-Second Annual Joint Conference of the IEEE Computer and Communications Societies (IEEE Cat. No.03CH37428), vol. 2, pp. 836–843 (2003)
7. IEEE W.G.: Supplement to part 11 : wireless LAN medium access control (MAC) and physical layer specifications: high-speed physical layer extension in the 2.4 GHz band. IEEE Std (1999)
8. IEEE. W.G.: Supplement to part 11 : wireless LAN medium access control (MAC) and physical layer specifications : high-speed physical layer extension in the 5 GHz band. IEEE Stda (1999)
9. Aad, I., Castelluccia, C.: Differentiation mechanism for IEEE 802.11. IEEE Infocom. Anchorage, AK **1**, 209–218 (2001)
10. Kim, H., Yun, S., Kang, I., Bahk, S.: Resolving 802.11 performance anomalies through QoS differentiation. IEEE Commun. Lett. **9**(7), 655–657 (2005)
11. Liu, J., Wu, T., Huang, R., Wang, J.: Prioritized channel access schemes with spatial reuse consideration. US 2016/0066257 A1, 3 March 2016
12. Lin, W., et al.: Integrated link-system level simulation platform for the next generation WLANIEEE 802.11 ax. IEEE GLOBECOM, pp. 1–7, December 2016
13. Liu, Y., Ding, Z., Elkashlan, M., Poor, H.V.: Cooperative non-orthogonal multiple access with simultaneous wireless information and power transfer. IEEE J. Sel. Areas Commun. **34**(4), 938–953 (2016)
14. Qiao, D., Choi, S., Shin, K.G.: Goodput analysis and link adaptation for IEEE 802.11a wireless LANs. IEEE Trans. Mobile Comput. **1**(4), 278–292 (2002)
15. Yang, B., Li, B., Yan, Z., Yang, M.: A distributed multi-channel MAC protocol with Parallel cooperation for the next generation WLAN. In: IEEE Wireless Communications and Networking Conference Workshops (WCNCW), pp. 327–332 (2016)