IEICE TRANS. COMMUN., VOL.E99–B, NO.11 NOVEMBER 2016

PAPER

A Novel Collision Avoidance Scheme Using Optimized Contention Window in Dense Wireless LAN Environments*

Yoshiaki MORINO†a), ***Student Member***, **Takefumi HIRAGURI**†, ***Senior Member***, **Hideaki YOSHINO**†, ***Fellow***, **Kentaro NISHIMORI**††, ***and*** **Takahiro MATSUDA**†††, ***Senior Members***

SUMMARY In IEEE 802.11 wireless local area networks (WLANs), contention window (CW) in carrier sense multiple access with collision avoidance (CSMA/CA) is one of the most important techniques determining throughput performance. In this paper, we propose a novel CW control scheme to achieve high transmission efficiency in dense user environments. Whereas the standard CSMA/CA mechanism. Employs an adaptive CW control scheme that responds to the number of retransmissions, the proposed scheme uses the optimum CW size, which is shown to be a function of the number of terminal stations. In the proposed scheme, the number of terminal stations are estimated from the probability of packet collision measured at an access point (AP). The optimum CW size is then derived from a theoretical analysis based on a Markov chain model. We evaluate the performance of the proposed scheme with simulation experiments and show that it significantly improves the throughput performance.

key words: *IEEE802.11 MAC, contention window, transmission efficiency*

1. Introduction

In IEEE 802.11 wireless local area network (WLAN) [1], the number of WLAN devices such as laptops and smartphones has increased drastically in recent years. In dense user environments, the network design of WLANs must be reconsidered because the medium access control (MAC) protocol in the traditional IEEE 802.11 is not designed for such environments. Therefore, in the new IEEE 802.11ax standard [2], packet-transmission techniques for dense environments are being discussed.

In the IEEE 802.11 MAC based on distributed coordinate function (DCF), packets are transmitted with carrier sense multiple access with collision avoidance (CSMA/CA), where each terminal station (STA) transmits a packet by randomly choosing a time slot within the contention window (CW). Packets collide when the same time slot is chosen by several STAs. The size of the CW increases with the number of packet retransmissions in order to reduce packet collisions. This mechanism is called the *backoff algorithm*.

We consider that the traditional backoff algorithm has two critical problems. These problems are critical especially in dense environments and cause throughput degradation. One is that the minimum CW ($CW_{\min}$), which is the initial CW size, is assigned a small value. This means that the CW size is not optimized. Namely, when $CW_{\min}$ is small, packets collide with high probability. On the other hand, when $CW_{\min}$ is excessively large, some packets may have to wait a long time until the backoff timer expires. Therefore, there is an optimal $CW_{\min}$ that maximizes the throughput performance. The other critical problem is that several retransmission trials are required before the CW reaches an adequate size.

In this paper, we propose a novel CW control scheme to solve these problems. In the proposed scheme, an access point (AP) computes the optimum $CW_{\min}$ and each STA transmits packets with the $CW_{\min}$ notified from the AP. To compute the optimum $CW_{\min}$, we utilize the fact that the optimum $CW_{\min}$ is a function of the number of STAs in the WLAN. Under an unsaturated traffic condition, an AP counts the number of STAs connecting the AP, where we call it *the number of connected STAs*. On the other hand, under the traffic saturated condition, where collisions frequently occur, it is difficult to correctly count the active number of connected STAs. Therefore, we utilize *the number of contending STAs*, which can be estimated from the collision probability measured at the AP.

The proposed scheme offers two advantages. One is that the optimum CW size is computed from a simple closed formula, which is obtained by a theoretical throughput analysis based on a Markov chain model [4], [5]. The other is that no modifications are required to the transmission procedure of STAs. Therefore, the proposed scheme can be implemented exclusively by modifying the AP.

The remainder of this paper is organized as follows. Section 2 discusses the conventional binary backoff algorithm and explains the basic idea of the proposed scheme. Section 3 describes the proposed scheme in detail. Section 4 evaluates the performance of the proposed scheme with simulation experiments and theoretical analysis. Finally, Sect. 5 concludes this paper.

Manuscript received February 8, 2016.
Manuscript revised April 19, 2016.
Manuscript publicized May 19, 2016.

†The authors are with the Faculty of Engineering, Nippon Institute of Technology, Misato-shi, 345-8501 Japan.
††The author is with the Faculty of Engineering, Niigata University, Niigata-shi, 950-2181 Japan.
†††The author is with the Graduate School of Engineering, Osaka University, Suita-shi, 565-0871 Japan.

*This paper is presented in part at the 3rd International Conference on Artificial Intelligence, Modelling and Simulation (AIMS 2015) [3].

a) E-mail: e1102437@estu.nit.ac.jp

DOI: 10.1587/transcom.2016EBP3056

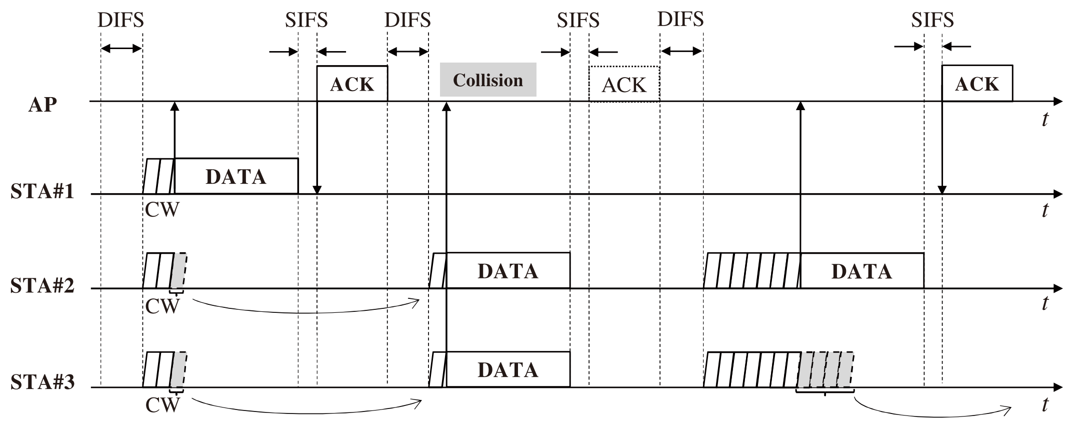


Fig. 1 Example of access control with the IEEE 802.11 standard.

2. Binary Exponential Backoff Algorithm and Problems with the Conventional Scheme

Figure 1 shows an example of packet transmissions with CSMA/CA in the IEEE 802.11 MAC. Interested readers can refer to the IEEE 802.11 standard for detailed descriptions of the packet-transmission procedure [1]. In the MAC protocol, a binary exponential backoff algorithm is used to implement the collision-avoidance function. In this paper, we focus on the CW size W, which affects the performance of the backoff algorithm. In the IEEE 802.11 MAC, parameters such as the minimum CW size $CW_{\min}$ are assigned different values, depending on the specifications of the physical layer. We use the parameter set in the IEEE 802.11a standard, where 15 is set to $CW_{\min}$.

During the first trial of a packet transmission, the backoff algorithm sets $CW_{\min}$ to W. Each STA randomly chooses a time slot from $[0, CW_{\min}]$, and transmits the packet in that slot. When a packet collision occurs, W is doubled before retransmitting the packet, in order to reduce the probability of collision. In the backoff algorithm, the CW size causes a tradeoff between the collision probability and the transmission efficiency. That is, whereas a small CW size increases the probability of collisions, an excessively large CW significantly delays transmissions. Therefore, an optimum CW size is needed to maximize the throughput performance.

Unfortunately, the backoff algorithm in the IEEE 802.11 standard does not optimize the CW size, because STAs and the AP do not have the number of STAs connected to the AP. This approach, however, is inappropriate to achieve a higher throughput performance, especially in a dense network environment, because $CW_{\min} = 15$ is adequate only for a smaller number of STAs. Indeed, the default size ($CW_{\min} = 15$) is insufficient in a dense WLAN environment. On the other hand, our proposed scheme aims at achieving higher throughput by optimizing the CW size. With our proposed scheme, we exploit the fact that the collision probability is a function of the number of STAs connected to the AP. The number of STAs is estimated from the collision probability measured by the AP, and the CW size is set to an optimum size based on this estimation.

In related work [4]–[14], schemes for optimum CW size control have been proposed. We compared related works to our proposed scheme and explain some papers. In [4] and [5], the throughput and optimum CW size are derived based on a Markov chain model. However, [4] and [5] merely provide a theoretical analysis. Consequently, they do not consider issues pertaining to implementation. In [6], the unique signals—i.e., Busy Idle (BI) signals—are transmitted from two or more APs to all STAs. Then, all STAs select the optimum CW size from BI signal information. Therefore, each respective STA derives the optimum CW size. By contrast, our proposed scheme is able to derive the optimum CW size from only AP information (i.e., the busy ratio). Therefore, the AP calculates and derives the optimum CW size. All STAs are notified of the derived optimum CW size in the AP. Thus, the STAs incur almost no processing load. Chun et al. [7] propose a scheme for estimating idle slot intervals using successful transmission events and collision events in the radio medium. Then, the transmission cycle in STAs is controlled by the fair transmission right. However, Chun et al. do not describe methods for collecting this event information. By contrast, our proposed scheme can select the optimum CW size without collecting from each STA, since an AP collects the busy ratio from the wireless network. Moreover, the proposed scheme ensures fair transmissions in each STA because an AP notifies the same CW size range for all STAs. Patel et al. [8] propose a simple control method, such that the CW size is modified according to the success or failure of the packet transmissions. However, because this method must set a new CW size range packet–by–packet for transmissions, the process is complicated, making real–time control difficult to implement. Because our proposed scheme calculates the optimum CW size from the statistic in the constant period and notifies the STAs, real–time processing is excluded. Therefore, our proposed scheme is easily implementable. In [9], the CW size range is gradually decreased or unchanged when transmissions succeed. For example, when the transmission of a packet succeeds, the CW size range is not changed to the CW size of the initial value. However, it is changed to the same CW size range, or to the CW size range based on the number of retransmissions minus one. Moreover, even though this technology is easy to implement, it is impossible to choose an optimum CW. Deng et al. [10] propose a method for judging packet collisions on the wireless MAC layer and transmission errors on the TCP networks. Their proposal selects the optimum transmission procedure. Such methods have recently been used as cross–layer technology. By contrast, our proposed scheme focuses only on the wireless MAC layer, and it is thus a different approach. Moreover, our scheme obtains higher throughput, regardless of the cause of the packet loss, and it can be implemented merely by remodeling the MAC layer. However, these related works should implement complex functions not only in the AP, but also in the STAs. Therefore, these schemes involve using computationally expensive functions in the AP and STAs. In the proposed scheme, the AP optimizes the CW size exclusively based on collision probability. As described in the next section, the optimum CW size is derived using a simple closed form of the collision probability. Therefore, the proposed scheme does not burden the AP or STAs with heavy computational complexity. Further, the proposed scheme does not require any additional modifications to the IEEE 802.11 MAC protocol, except regarding the assignment of the CW size and this can be easily implemented using the enhanced distributed channel access (EDCA) function in the IEEE 802.11e MAC protocol [15]–[17].

3. Contention Window Control Scheme Based on the Number of Contending STAs

In this section, we describe the proposed CW control scheme. In Sect. 3.1, we explain how the optimum CW size is obtained from the theoretical throughput analysis based on a Markov chain model. We derived the throughput and optimum CW size based on Bianchi [4], [5]. In Sect. 3.2, we explain how the number of contending STAs can be estimated based on the collision probability.

3.1 Optimal Contention Window Size Using a Markov Chain Model

Suppose that an STA attempts to transmit a packet to the AP. Let $\mathcal{T}$ denote the event that occurs when the STA transmits a packet in a time slot. We define state $s \in \{0, 1, \ldots, R\}$ for the STA as the number of retransmissions, where R denotes the maximum number of retransmission counts, and $s = 0$ corresponds to the first transmission trial of the packet. Using the binary exponential algorithm, we can obtain $\Pr(\mathcal{T} \mid s = i)$ and $\Pr(s = i \mid \mathcal{T})$ respectively as follows:

$$\Pr(\mathcal{T} \mid s = i) = \frac{1}{1 + \dfrac{2^i(CW_{\min} + 1) - 2}{2}},$$

$$\Pr(s = i \mid \mathcal{T}) = \frac{(1-p)p^i}{1 - p^{R+1}},$$

where p denotes the collision probability. Let $\tau = \Pr(\mathcal{T})$ denote the probability that the STA transmits the packet in the given time slot. From [5], τ is obtained as follows:

$$\begin{aligned}\tau &= \frac{1}{\displaystyle\sum_{i=0}^{R} \frac{\Pr(s = i \mid \mathcal{T})}{\Pr(\mathcal{T} \mid s = i)}} \\ &= \frac{1}{\displaystyle\sum_{i=0}^{R} \frac{(1-p)p^i}{1-p^{R+1}} \cdot \left(1 + \frac{2^i(CW_{\min}+1) - 2}{2}\right)}. \end{aligned} \tag{1}$$

By contrast, with the proposed scheme, the CW size is fixed at W. The probability $\tau^{(\text{prop})}$ that the STA will transmit the packet is calculated by

$$\tau^{(\text{prop})} = \frac{2}{1 + W}. \tag{2}$$

Let n ($n > 0$) denote the number of STAs. We define P_{tx} of conventional scheme and $P_{\text{tx}}^{(\text{prop})}$ of proposed scheme as the probability that at least one STA will transmit a packet to the AP, and it is calculated by

$$P_{\text{tx}} = 1 - (1 - \tau)^n, \tag{3}$$

$$P_{\text{tx}}^{(\text{prop})} = 1 - \left(1 - \tau^{(\text{prop})}\right)^n. \tag{4}$$

We also define P_{suc} as the probability that a transmitted packet will be successfully received at the AP. Here, P_{suc} and $P_{\text{suc}}^{(\text{prop})}$ are given by

$$P_{\text{suc}} = \frac{n\tau(1-\tau)^{n-1}}{P_{\text{tx}}}, \tag{5}$$

$$P_{\text{suc}}^{(\text{prop})} = \frac{n\tau^{(\text{prop})}\left(1 - \tau^{(\text{prop})}\right)^{n-1}}{P_{\text{tx}}^{(\text{prop})}}. \tag{6}$$

By using P_{tx} and P_{suc}, the throughput S is represented by

$$\begin{aligned} S &= \frac{P_{\text{suc}} P_{\text{tx}} L_{\text{pkt}}}{(1 - P_{\text{tx}})\sigma + P_{\text{suc}} P_{\text{tx}} T_{\text{suc}} + P_{\text{tx}}(1 - P_{\text{suc}}) T_{\text{fail}}} \\ &= \frac{L_{\text{pkt}}}{T_{\text{suc}} - T_{\text{fail}} + \dfrac{(1-P_{\text{tx}})\sigma / P_{\text{tx}} + T_{\text{fail}}}{P_{\text{suc}}}}. \end{aligned} \tag{7}$$

where σ denotes the length of the time slot, L_{pkt} denotes the payload size of the packets, T_{suc} denotes the transmission time for a packet that is received successfully at the AP, and T_{fail} denotes the transmission time for a packet that is not received at the AP. From

$$\frac{dS}{dW} = \frac{dS}{d\tau}\frac{d\tau}{dW} = 0,$$

we obtain

$$(1 - \tau^{(\text{prop})})^n - \frac{T_{\text{fail}}}{\sigma(n\tau^{(\text{prop})} - (1 - (1 - \tau^{(\text{prop})})^n))} = 0.$$

We assume that $\tau \ll 1$. We then obtain

$$\tau^{(\mathrm{prop})} = \frac{\sqrt{n(n+2(n-1)(T_{\mathrm{fail}}/\sigma-1))}-n}{n(n-1)(T_{\mathrm{fail}}/\sigma-1)} \approx \frac{\sqrt{2}}{n\sqrt{T_{\mathrm{fail}}/\sigma}}.$$

From Eq.(2), we obtain

$$W \approx n\sqrt{\frac{2T_{\mathrm{fail}}}{\sigma}}. \tag{8}$$

Equation (8) gives the optimal CW size for maximizing throughput as a function of the number of connected STAs.

3.2 Estimating the Number of Contending STAs

In this subsection, the proposed scheme is illustrated in terms of how it estimates the number of contending STAs. First, we define the collision probability P_{col} as the probability that a transmitted packet is not received at the AP. From Eqs. (1), (3), (5), P_{col} given by

$$P_{\mathrm{col}} = 1 - P_{\mathrm{suc}}. \tag{9}$$

And, from Eqs. (2), (4), (6), $P_{\mathrm{col}}^{(\mathrm{prop})}$ given by

$$\begin{aligned} P_{\mathrm{col}}^{(\mathrm{prop})} &= 1 - P_{\mathrm{suc}}^{(\mathrm{prop})} = 1 - \frac{2n(W-1)^{n-1}}{(1+W)^n-(W-1)^n} \\ &= 1 - \frac{2n(W-1)^{n-1}}{(1+W)^n-(W-1)^n} \\ &= 1 - \frac{\frac{2n}{W-1}}{\left(\frac{W+1}{W-1}\right)^n - 1} \\ &= 1 - \frac{\frac{2n}{W-1}}{\left(1+\frac{2}{W-1}\right)^n - 1}. \end{aligned} \tag{10}$$

The number n of contending STAs is derived from Eq. (10). Under the assumption that $W-1$ is significantly large, the following approximation using Eq. (11) for P_{col} is obtained with the binomial theorem from Eq. (10):

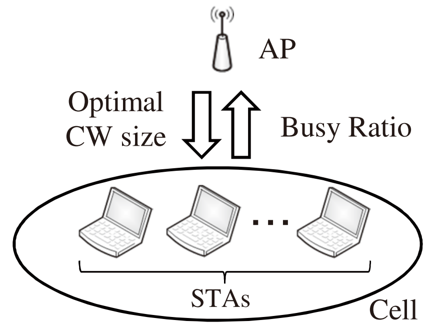
$$\begin{aligned} P_{\mathrm{col}}^{(\mathrm{prop})} &\approx 1 - \frac{\frac{2n}{W-1}}{1+n\frac{2}{W-1}+\frac{n(n-1)}{2}\left(\frac{2}{W-1}\right)^2-1}, \\ &\approx 1 - \frac{W-1}{W+n}. \end{aligned} \tag{11}$$

Therefore, we can estimate the number $\hat{n}$ of contending STAs as follows:

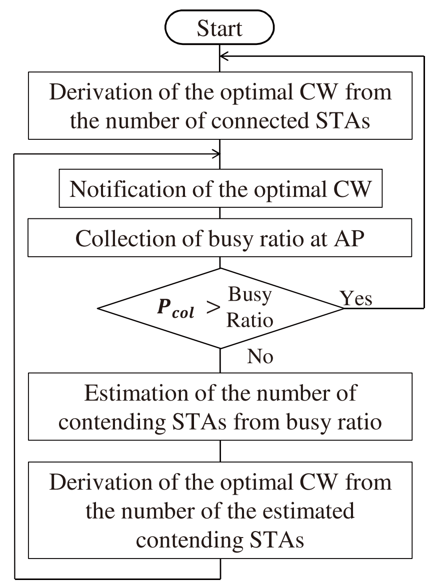
$$\hat{n} \approx \frac{P_{\mathrm{col}}^{(\mathrm{prop})}(W-1)}{1-P_{\mathrm{col}}^{(\mathrm{prop})}} + 1. \tag{12}$$

Figure 2 summarizes the procedure of the proposed scheme. First, the initial value for the optimal CW is derived from the number of connected STAs, because the AP cannot estimate the number of contending STAs yet. This initial value acts as a notification to the STAs from the AP. Next, the AP collects the *busy ratio* [3], which is defined as the ratio of the busy time to the busy time plus the idle time. Then, the AP compares this busy ratio with the calculated collision probability. If the busy ratio is close to the collision probability, the WLAN is considered saturated. The reason is that the collision probability is saturated when the wireless channel is congested. On the other hand, if the busy ratio is less than the collision probability, the WLAN is considered unsaturated.

When the WLAN is saturated, the AP can estimate the number of contending STAs using Eq. (12). On the other hand, when the WLAN is unsaturated, we set n to the number of connected STAs. The reason is that the optimal CW size is slightly different, decreased the throughput is small under unsaturated traffic. The value of optimized CW size is delivered from the AP to the STAs via control packets in the MAC procotol such as beacons. A similar procedure for



(a) Exchange of the optimal CW size and busy ratio



(b) Flowchart

Fig. 2 Control scheme for the AP.

delivering the CW size is used by the EDCA method in the IEEE802.11e standard.

4. Performance Evaluation

4.1 Throughput Performance under Saturated Environment

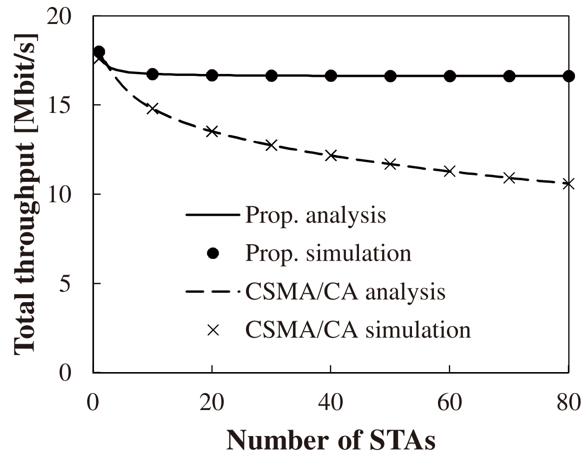
We evaluated the performance of the proposed scheme with simulation experiments [18] and the numerical results obtained from a theoretical analysis. To evaluate the performance, we set the transmission rate at 24 Mbits/s, L_{pkt} = 1500 bytes and $\sigma = 9\,\mu$s. In what follows, we consider uplink flows in a network with one AP and n ($1 \leq n \leq 80$) STAs. In this evaluation, we did not consider hidden STAs and propagation loss. Moreover, packet loss occurs only during simultaneous packet transmissions. In this subsection, we consider a saturated environment and make the environment by setting each STA always to have packets to transmit.

In order to evaluate the basic performance of the proposed scheme, we considered an ideal situation, where the number of STAs is perfectly estimated by the AP. Figure 3(a) shows the relationship between the total throughput and the number of STAs. In the figure, lines and plots correspond to numerical results and simulation results, respectively. The dashed line represents the performance of CSMA/CA in the IEEE 802.11 MAC (hereafter "CSMA/CA"). The solid line represents the performance of the proposed scheme. The proposed scheme showed higher throughput performance than CSMA/CA. The throughput performance of the latter decreased as the number of STAs increased. Moreover, the theoretical analysis agrees well with the simulation results, validating our approach based on throughput analysis using the Markov chain model. The effectiveness of the proposed scheme can be confirmed with Fig. 3(b), showing the relationship between the collision probability and the number of STAs from Eqs. (9)–(10). With CSMA/CA, the collision probability increased with the number of STAs. By contrast, the proposed scheme maintained a lower collision probability.

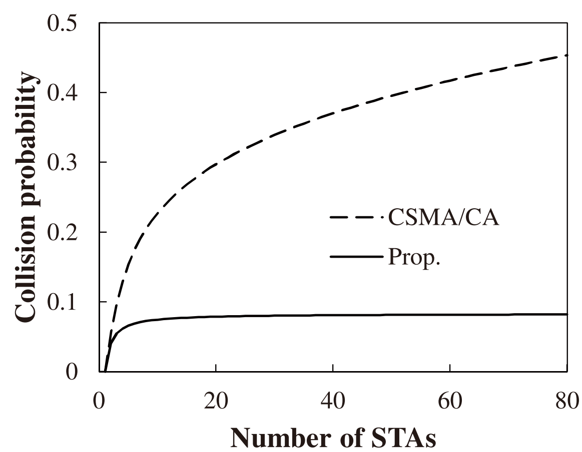
Figure 4 shows the relationship between throughput performance and the number of STAs. The solid line represents the throughput performance when the number of STAs is perfectly estimated. The plots represent the throughput performance when the number of STAs has been estimated based on the collision probability. Indeed, both results agree well with one another.

4.2 Modification of the Proposed Scheme

Because the IEEE 802.11 MAC protocol is based on the binary exponential backoff algorithm, the CW size increases exponentially with the number of retransmissions. When IEEE 802.11a is used as a physical–layer protocol, the CW size W is selected from $\{15, 31, 63, 127, 255, 511, 1023\}$, where $W = 1023$ corresponds to the maximum CW size.



(a) Throughput characterizations



(b) Collision probability characterizations

Fig. 3 Evaluation of the optimized CW size.

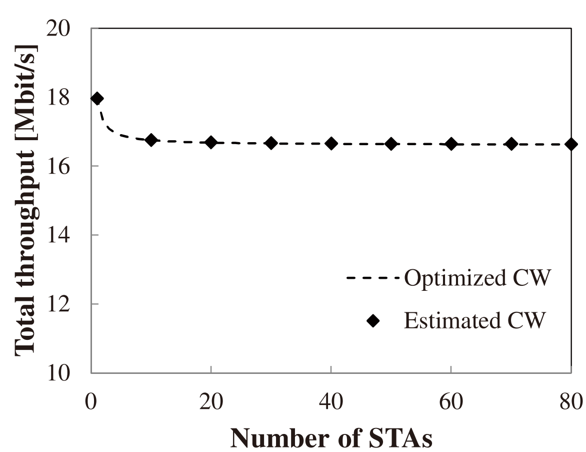


Fig. 4 Throughput characterizations of the estimated number of contending STAs.

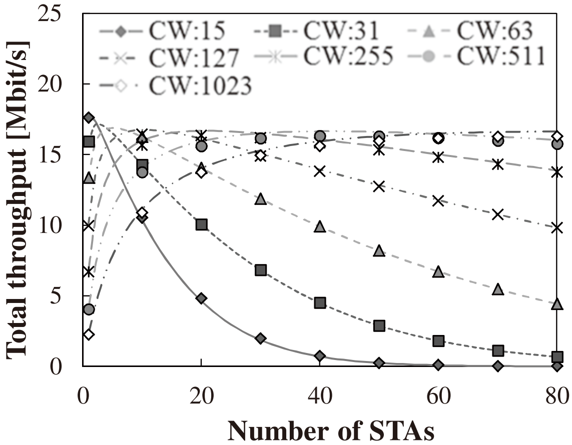


Fig. 5 Throughput characterizations with a binary CW size.

Table 1 Optimal binary CW size vs. the number of STAs.

Number of STAs	Optimal binary CW
1 – 2	15
3 – 4	31
5 – 8	63
9 – 15	127
16 – 29	255
30 – 59	511
60 –	1023

We refer to these CW sizes as *binary CW sizes*, hereafter. On the other hand, with the proposed scheme, an arbitrary integer is assigned to the CW size. This size is sometimes impractical, however, because each STA requires many states of the CW size. Therefore, we modified the proposed algorithm with binary CW sizes, hereafter referred to as the *modified scheme*. Figure 5 shows the relationship between the throughput performance of CSMA/CA and the number of STAs, where the lines and plots correspond to the theoretical analysis and simulation results, respectively. In this figure, the throughput performance was obtained by fixing the CW size. For example, "CW : 15" represents the throughput performance of CSMA/CA when the CW size was fixed at $W = 15$. Indeed, for each binary CW size, there is an optimum number of STAs to maximize the throughput performance. We can obtain the optimum binary CW size as a function of the number of STAs, as shown in Table 1. We thus implemented the modified algorithm with this table.

Figure 6 shows the relationship between the throughput performance and the number of STAs. In this figure, "Optimized CW," "Binary CW," and "Conventional CSMA/CA" represent the performance of the proposed scheme described in the previous section, the modified algorithm, and CSMA/CA in the IEEE 802.11 standard, respectively. From the figure, we can observe that the modification does not degrade the performance of the proposed scheme.

In order to investigate the behavior of the modified scheme, we evaluated the relationship between the collision probability and the number of STAs in Fig. 7, where "Binary CW_{opt}" corresponds to the performance of the modified scheme. With the modified scheme, the collision probability fluctuated between 0.05 and 0.1. As shown in Fig. 3(b), the proposed scheme aims to stabilize the collision probability based on the number of STAs. By contrast, the modified scheme aims to stabilize the collision probability within a certain range.

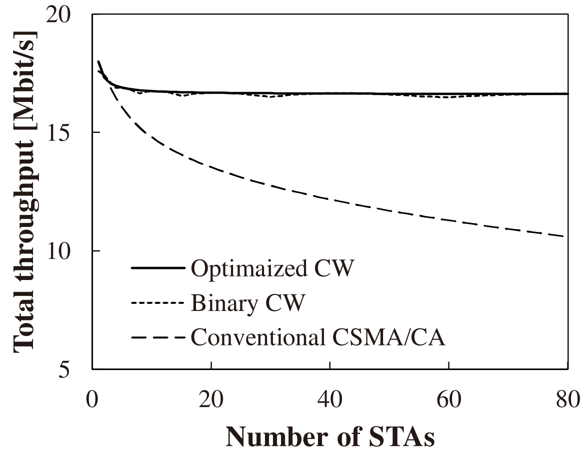


Fig. 6 Comparing the throughput of an optimized CW with that of a binary CW size.

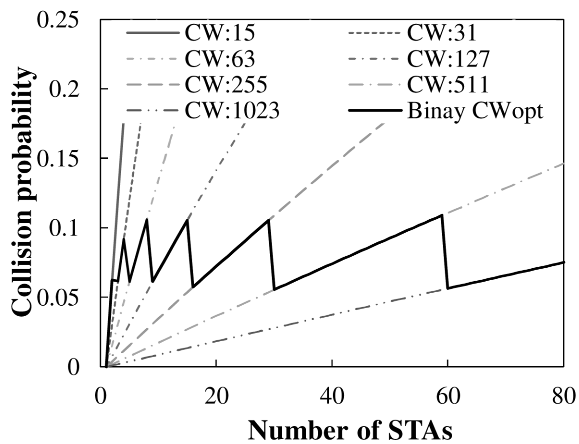
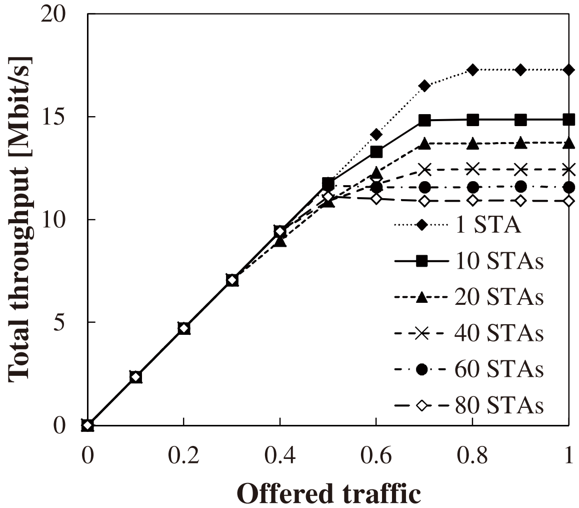


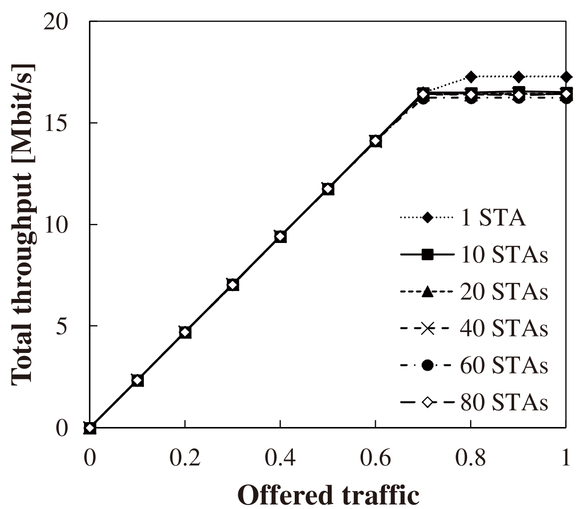
Fig. 7 Collision probability with a binary CW size.

These results show a more stable throughput with an optimized CW size that closely approximated the throughput with a fixed binary CW size. On the other hand, in terms of the collision probability, the binary CW variation range was wider than with an optimized CW. We designed a method for selecting a simple CW size using the variation of this collision probability. For example, similar throughput with an optimized CW was achieved when the collision probability was between 0.05 and 0.1, as shown in Fig. 6. When the collision probability dropped below 0.5, the binary CW size is set to a smaller value, and if it exceeds 0.1, the binary CW size will set to a larger value.

The binary CW size is very simple, because there are only seven possible sizes (i.e., 15, 31, 63, 127, 255, 511, 1023). Therefore, this method is not complex.



(a) Conventional scheme



(b) Proposed scheme

Fig. 8 Throughput characterizations vs. offered traffic.

4.3 Throughput Performance in an Unsaturated Environment

We evaluated the performance in an unsaturated environment. Figures 8(a) and 8(b) show the relationship between the throughput and the offered traffic. The offered traffic is defined as the ratio of the total traffic volume generated from the STAs to the transmission rate. The throughput performance in saturated environments (assumed in Sects. 4.1 and 4.2) corresponds to offered load of about 0.7 to 1 in the proposed scheme (i.e., throughput is saturated). CSMA/CA could not achieve higher throughput, especially with a large number of STAs. The proposed scheme, however, achieved a higher throughput performance in the unsaturated environment.

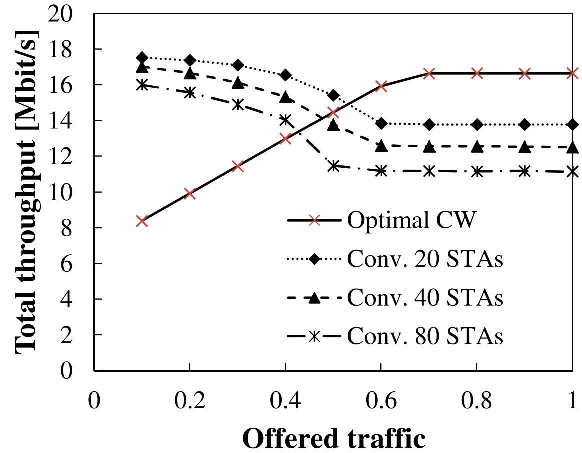


Fig. 9 Evaluation of bias traffic environment.

Thus, with the proposed scheme, throughput comparable to that of the conventional scheme could be obtained when the offered traffic was under 0.5. Moreover, the proposed scheme provided high throughput, even when the throughput of the conventional scheme was saturated, namely, when the offered traffic was between 0.5 and 0.7. Finally, the proposed scheme obtained the highest throughput overall, regardless of the number of contending STAs, when the offered traffic was above 0.7. From these results, the proposed scheme always achieved high transmission efficiency in all ranges of traffic.

4.4 Throughput Performance in Nearly Realistic Environments

Finally, we evaluated throughput performance with bias traffic and an environment resembling a real environment with estimation errors. Figure 9 shows the evaluation of the biased traffic environment. The results show that 10% of the connected STAs are heavy traffic users. The remaining STAs changed the amount of traffic from 10% to 100% against the transmission rate. The horizontal axis shows normalized traffic without heavy traffic users. The vertical axis shows the total throughput. These results were the same when we used the optimum CW size for the number of connected STAs. The conventional CSMA/CA scheme decreased throughput when increasing the number of STAs and traffic. Thus, the proposed scheme obtained higher throughput when increasing traffic and the number of contending STAs. The proposed scheme, however, obtained low throughput when decreasing the number of contending STAs, along with bias in the traffic of each STAs using the number of connected STAs. Thus, the proposed scheme is able to use offered traffic over approximately 0.5, whereas the conventional CSMA/CA scheme is able to use offered traffic under approximately 0.5. In addition, we evaluated the estimated number of contending STAs in an erroroneous environment (see Fig. 10). These results pertain to an evaluation of the throughput when the collected CW size is not

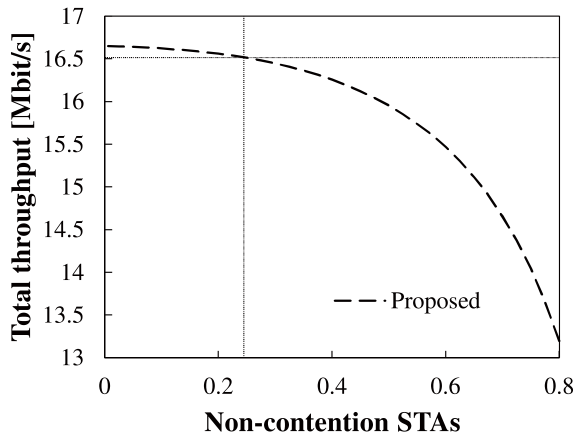


Fig. 10 Evaluation of estimation error environment.

based on the actual number of contending STAs. The horizontal axis shows number of non–contending STAs. The vertical axis shows the total throughput. For example, when the number of non–contending STAs is 0.1 with 80 STAs, 8 STAs do not offer traffic. Thus, the AP estimated that the number of contending STAs was 80, and thereby derived the optimum CW size. Yet, the actual number of contending STAs was 72. As a result, we confirmed the decreased throughput under approximately 1.0% when the error margin of the number of contending STAs is 0.25. Therefore, this scheme is effective for estimated error margins in real environments.

4.5 Issue and Future Works

In this paper, we evaluated the basic performance of the proposed scheme. Thus, we used fixed evaluation parameters. Nevertheless, we do not believe this evaluation is sufficient. Rather, an evaluation is needed in a real environment. For example, the bias transmission rate and the packet size in real environments entail more detailed traffic and other IEEE 802.11 standardizations. In addition, the overlapping cell has a hidden terminal problem and accidental interference signals. Thus, in future research, we shall address the impact of overlaps in the same channel in WLAN cells.

5. Conclusion

In this paper, we proposed a novel CW control scheme for the IEEE 802.11 standard for WLAN environments. The proposed scheme estimates the number of STAs based on a calculation of the collision probability, and it calculates the optimum CW size based on the estimated number of STAs. Simulation experiments and results from a theoretical analysis demonstrated that the proposed scheme significantly improves the throughput performance in saturated environments.

Acknowledgments

This research was supported in part by KAKEN C, a Grant-in-Aid for Scientific Research (C) (25330111 and No. 25330102), by Telecommunications Advancement Foundation 2016, and by the Hoso Bunka Foundation 2015.

References

[1] IEEE802.11 Standard for Local and Metropolitan Area Networks Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, March 2012.
[2] B. Bellalta, "IEEE 802.11ax: High Efficiency WLANs," arXiv: 1501.01496, July 2015, available: http://arxiv.org/abs/1501.01496
[3] Y. Morino, T. Hiraguri, H. Yoshino, K. Nishimori, A. Tachibana, and T. Matsuda, "A novel contention window control scheme based on a Markov chain model in dense WLAN environment," Proc. Third International Conference on Artificial Intelligence, Modelling and Simulation (AIMS2015), pp.417–421, Dec. 2015.
[4] G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," IEEE J. Sel. Areas. Commun., vol.18, no.3, pp.535–547, March 2000.
[5] G. Bianchi and I. Tinnirello, "Remarks on IEEE 802.11 DCF performance analysis," IEEE Commun. Lett., vol.9, no.8, pp.765–767, Aug. 2005.
[6] M.N. Krishnan, S. Yang, and A. Zakhor, "Contention window adaptation using the busy-idle signal in 802.11 WLANs," 2014 IEEE Global Communications Conference (GLOBECOM), pp.4794–4800, 2014.
[7] S. Chun, D. Xianhua, L. Pingyuan, and Z. Han, "Adaptive access mechanism with optimal contention window based on node number estimation using multiple thresholds," IEEE Trans. Wireless Commun., vol.11, no.6, pp.2046–2055, June 2012.
[8] P. Patel and D.K. Lobiyal, "A simple but effective contention aware and adaptive back-off mechanism for improving the performance of IEEE 802.11 DCF," Wireless. Pers. Commun., vol.83, no.3, pp.1801–1841, Aug. 2015.
[9] H. Cheng, X. Yan, H. Lian, L. Weng, Q. Zhang, and Z. Feng, "A novel collision avoidance algorithm for IEEE 802.11 wireless LANs," 2014 IEEE Military Communications Conference (MILCOM), pp.879–884, 2014.
[10] D.-J. Deng, R.-S. Cheng, H.-J. Chang, H.-T. Lin, and R.-S. Chang, "A cross-layer congestion and contention window control scheme for TCP performance improvement in wireless LANs," Telecommun. Syst., vol.42, no.1-2, pp.17–27, Oct. 2009.
[11] X. Tian, X. Chen, T. Ideguchi, and Y. Fang, "Improving throughput and fairness in WLANs through dynamically optimizing backoff," IEICE Trans. Commun., vol.E88-B, no.11, pp.4328–4338, Nov. 2005.
[12] Q. Yu, Y. Zhuang, and L. Ma, "Dynamic contention window adjustment scheme for improving throughput and fairness in IEEE 802.11 wireless LANs," 2012 IEEE Global Communications Conference (GLOBECOM), pp.5074–5080, 2012.
[13] H. Ma, X. Li, H. Li, P. Zhang, S. Luo, and C. Yuan, "Dynamic optimization of IEEE 802.11 CSMA/CA based on the number of competing stations," Proc. 2004 IEEE International Conference on Communications, pp.191–195, 2004.
[14] A. Kishida, M. Iwabuchi, T. Shintaku, T. Onizawa, and T. Sakata, "Frame collision reduction method employing adaptive transmission control for IEEE802.11 wireless LAN system," IEICE Trans. Commun., vol.E97-B, no.9, pp.1790–1799, Sept. 2014.
[15] Y. Xiao, "Performance analysis of IEEE 802.11e EDCF under saturation condition," Proc. 2004 IEEE International Conference on Communications, Vol.1, pp.170–174, 2004.
[16] Z. Kong, D.H.K. Tsang, B. Bensaou, and D. Gao, "Performance

analysis of IEEE 802.11e contention-based channel access," IEEE J. Sel. Areas. Commun., vol.22, no.10, pp.2095–2106, Dec. 2004.
[17] H. Wu, X. Wang, Q. Zhang, and X. Shen, "IEEE 802.11e enhanced distributed channel access (EDCA) throughput analysis," Proc. 2006 IEEE International Conference on Communications, pp.223–228, 2006.
[18] Riverbed Modeler ver. 17.5, http://www.riverbed.com

Yoshiaki Morino received the B.E. and M.E. degrees from faculty of engineering in Nippon Institute of Technology in 2014 and 2016 respectively. He is currently studying D.S. degree at graduate school of electronics, information and media engineering in Nippon Institute of Technology. His research interest is access control scheme on wireless LAN.

Takefumi Hiraguri received the M.E. and Ph.D. degree from the University of Tsukuba, Ibaraki, Japan, in 1999 and 2008, respectively. In 1999, he joined the NTT Access Network Service Systems Laboratories, Nippon Telegraph and Telephone Corporation in Japan. He has been engaged in research and development of MAC protocol for the high speed and the high communication quality in wireless systems. He is now associate professor in Nippon Institute of Technology. He is a member of IEEE.

Hideaki Yoshino received the B.Sc., M.Sc. and D.Sc. degrees in information science from the Tokyo Institute of Technology, Tokyo, Japan, in 1983, 1985 and 2010, respectively. He joined NTT Laboratories in 1985 and has been engaged in communication traffic and service quality research for 27 years. As a visiting scholar, he stayed at the University of Stuttgart, Germany, during 1990–1991. He is currently a professor at the Department of Electrical and Electronics Engineering at Nippon Institute of Technology. He served as Chair of the Technical Committee on Communication Quality, IEICE, from 2009 to 2011, and Chair of the Technical Committee on Communications Quality and Reliability, IEEE ComSoc, from 2014 to 2015. Prof. Yoshino was involved in many international conferences related to communication network and quality, such as CQRM symposium co-chair of IEEE ICC and GLOBECOM. He is a member of IEEE, IEICE (Fellow), and the Operations Research Society of Japan.

Kentaro Nishimori received the B.E., M.E. and Ph.D. degrees in electrical and computer engineering form Nagoya Institute of Technology, Nagoya, Japan in 1994, 1996 and 2003, respectively. In 1996, he joined the NTT Wireless Systems Laboratories, Nippon Telegraph and Telephone Corporation (NTT), in Japan. He was senior research engineer on NTT Network Innovation Laboratories. He is now associate professor in Niigata University. He was a visiting researcher at the Center for Teleinfrastructure (CTIF), Aalborg University, Aalborg, Denmark from Feb. 2006 to Jan. 2007. He was an Associate Editor for the Transactions on Communications for the IEICE Communications Society from May 2007 to May 2010 and Assistant Secretary of Technical Committee on Antennas and Propagation of IEICE from June 2008 to May 2010. He received the Young Engineers Award from the IEICE of Japan in 2001, Young Engineer Award from IEEE AP-S Japan Chapter in 2001, Best Paper Award of Software Radio Society in 2007 and Distinguished Service Award from the IEICE Communications Society in 2005, 2008, 2010, and 2015. His main interests are spatial signal processing including MIMO systems and interference management techniques in heterogeneous networks. He is a member of IEEE and IEICE. He received IEICE Best Paper Award in 2010.

Takahiro Matsuda received his B.E. with honors, M.E., and Ph.D. in communications engineering from Osaka University in 1996, 1997, 1999, respectively. He joined the Department of Communications Engineering, at the Graduate School of Engineering, Osaka University in 1999. He is currently an Associate Professor in the Department of Information and Communications Technology, Graduate School of Engineering, Osaka University. His research interests include performance analysis and design of communication networks and wireless communications. He received Best Tutorial Paper Award and Best Magazine Paper Award from IEICE ComSoc in 2012, and Best Paper Award from IEICE in 2014. He is a member of IPSJ and IEEE.