

A Study on Update Frequency of Q-Learning-based Transmission Datarate Adaptation using Redundant Check Information for IEEE 802.11ax Wireless LAN

Kazuto Yano[†] Kenta Suzuki[†] Babatunde Segun Ojetunde[†] Koji Yamamoto[‡]
[†]Wave Engineering Laboratories, Advanced Telecommunications Research Institute International
2-2-2 Hikaridai, Seika, Souraku, Kyoto 619-0288, Japan
[‡]Graduate School of Informatics, Kyoto University
Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan
{kzyano, kenta-suzuki, ojetunde}@atr.jp, kyamamot@i.kyoto-u.ac.jp

Abstract—The authors have proposed a practical transmission datarate adaptation (TDA) scheme using Q-learning applicable to IEEE 802.11ax wireless local area networks (WLANs). In the proposed scheme, each basic service set (BSS) selects an appropriate transmission datarate according to the buffer statuses of adjacent BSSs which are periodically collected and the transmission results of DATA frames in the BSS. Then, the BSS conducts underlay transmissions based on the framework of spatial reuse defined in IEEE 802.11ax. This paper compares two methods of Q-value update. One method is the frame-by-frame update taking account for the payload length and the transmission datarate of each DATA frame. The other method is the periodic update based on the total throughput in a BSS. The performance of the proposed scheme is evaluated through system-level computer simulation based on IEEE 802.11ax WLAN assuming downlink and uplink full-buffer traffic. It is confirmed that the proposed scheme can achieve better average area throughput than conventional Robust Rate Adaptation Algorithm (RRAA) and adaptive modulation and coding (AMC) in most of cases. It is also confirmed that the frame-by-frame Q-value update can achieve better area throughput than the periodic update based on the total throughput.

Index Terms—Wireless LAN, IEEE 802.11ax, Q-learning, transmission datarate adaptation, underlay transmission

I. INTRODUCTION

IEEE 802.11 wireless local area networks (WLANs) [1] have been widely and densely deployed, and their demand is still growing. The current WLAN generally employs a distributed and autonomous channel access mechanism based on carrier sense multiple access with collision avoidance (CSMA/CA). Therefore, increase of traffic demand in the WLAN brings severe contention among multiple basic service sets (BSSs) sharing the same radio channel. It causes frequent collision and resultant failure of frame transmission.

Since IEEE 802.11 WLANs support multiple transmission datarates, each transmitter needs to adjust its transmission datarate to a suitable one. When the signal-to-noise ratio (SNR) of a transmitted frame is insufficient, its transmitter should lower the transmission datarate. On the other hand, when transmission failure is caused by collision, the transmis-

sion datarate should be raised so as to shorten the length of the transmitted frame and to reduce the probability of collision consequently.

Therefore, in general, the transmission datarate is adjusted according to one or more metrics calculated from the results of frame transmission [2]. For example, Automatic Rate Fallback (ARF) [3] raises/decreases the transmission datarate if the number of successful/failed frame transmissions reaches predetermined a threshold. Robust Rate Adaptation Algorithm (RRAA) [4] raises/decreases the transmission datarate if a frame error rate (FER) becomes larger/less than a given FER threshold. SampleRate [5] measures the average transmission time on an other WLAN channel other than the current operating channel, and selects the WLAN channel on which the average transmission time becomes minimum.

However, IEEE 802.11 WLANs have no way to know directly whether a failure of frame transmission is caused by collision or by other reasons such as insufficient SNR because the transmitter recognizes its transmission failure by occurring timeout of ACK frame reception. Several studies were recently conducted to estimate the factor of transmission failure using one or more frame sniffers to utilize the estimated cause to adjust the transmission datarate [6], [7]. In these studies, frame sniffers are employed to collect information of frame transmissions and judge whether multiple transmitters transmit their frames simultaneously and cause a collision. The aim of these studies is to use the estimation result (i.e. the cause of transmission failure) to determine the proper transmission datarate on the operating channel.

Furthermore, a transmission datarate adaptation (TDA) scheme was studied to select an appropriate transmission datarate using Q-learning with the aid of side information called “redundant check information” about the frame transmission in adjacent basic service sets (BSSs) [8], [9]. This scheme collects, as the redundant check information, the information whether or not adjacent BSSs will transmit their frames in near future, and then learns and selects the best action

(i.e., selects the best transmission datarate or defers its frame transmission). If the best transmission datarate is selected, each BSS makes underlay transmission against its adjacent BSSs, and thus this scheme can improve the throughput.

However, the performance evaluation conducted in [8], [9] assumes slotted channel access. On the other hand, IEEE 802.11 WLANs employ random backoff based on CSMA/CA [1], and thus it is difficult to precisely know when each node will transmit its frame. Hence, the authors have proposed a practical scheme to apply the concept of transmission datarate adaptation (TDA) in [8], [9] to IEEE 802.11ax WLAN [10] which defines a mechanism of spatial reuse for underlay transmissions [11], [12]. The proposed scheme adjusts the transmission datarate of each BSS based on Q-learning at an adaptation interval. The buffer status of each BSS is collected as the redundant check information, and it is obtained using buffer status report (BSR) defined in the IEEE 802.11ax standard.

For further study of the proposed TDA scheme, this paper introduces and compares two methods of Q-value update in the Q-learning. One method is frame-by-frame update taking account for the payload length and the transmission datarate of each DATA frame. The other method is the update based on the total throughput in a BSS. The performance of the proposed scheme is evaluated through system-level computer simulation based on IEEE 802.11ax WLAN assuming downlink and uplink full-buffer traffic with different payload length.

The remainder of this paper is as follows. Section II explains our proposed TDA scheme. Section III introduces the two methods of Q-value update. Section IV explains the configuration of the system-level computer simulation and its results. Finally, conclusion is given in Sect. V.

II. TDA SCHEME USING REDUNDANT CHECK INFORMATION

A. Basic Concept of TDA using Redundant Check Information and Q-Learning

Figure 1 shows the concept of the TDA presented in [8], [9] applicable to slotted channel access. We focus on BSS 0 as the target BSS of TDA, and other BSSs are adjacent BSSs. BSS 0 collects the information whether adjacent BSSs will transmit their frames or not in the next slot. As shown in Fig. 1, this information is encoded as “state.” BSS 0 selects a transmission datarate randomly with a certain probability P_{rand} (hereafter, this probability is called as “random selection probability”) for searching the appropriate action. Otherwise, the transmission datarate with the maximum Q-value on the state using the knowledge obtained through learning. BSS 0 makes its DATA frame transmission at the selected transmission datarate, and then updates the Q-value according to the result of frame transmission.

The above process is conducted slot-by-slot (in other words, frame-by-frame). This scheme can improve throughput comparing with the conventional slotted ALOHA because it can select an appropriate transmission datarate even when collision is expected.

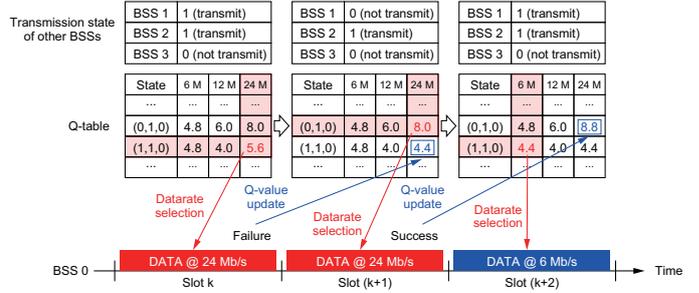


Fig. 1. Basic concept of TDA using redundant check information and Q-learning in [8], [9].

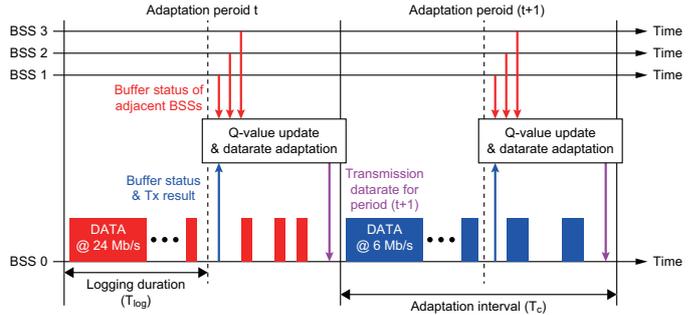


Fig. 2. Concept of our proposed TDA for IEEE 802.11ax WLAN [11], [12].

B. Proposed TDA for IEEE 802.11ax WLAN

Figure 2 shows the concept of our proposed TDA scheme [11], [12]. In the proposed scheme, the transmission datarate is adjusted at an interval (T_c). Since BSS 0 cannot know when adjacent BSSs will transmit their frames exactly due to the random backoff, it collects the buffer statuses of adjacent BSSs, and selects the transmission datarate that will be used in the next adaptation period. Here, an access point (AP) in each BSS obtains the buffer status of its associating stations (STAs) by BSR. Each node checks whether the received frame comes from the BSS that is expected to transmit frame(s) in the current adaptation period by using BSS Color [10] defined in the IEEE 802.11ax standard. (The state of such BSS is denoted by “1” in Fig. 2.) If the node detects a frame from such BSS, the CCA level at the node is raised so that the frame from the BSS is not detected using the framework of spatial reuse, which is also defined in the IEEE 802.11ax standard, in order to enable underlay transmissions.

The Q-value is updated using the transmission results of DATA frames in a logging duration (T_{log} from the beginning of the adaptation period). The detail of Q-value update is explained in the next section.

III. Q-VALUE UPDATE METHODS

Since our proposed TDA scheme uses the transmission results of DATA frames in the logging duration, we can take two ways of Q-value update. One is updating the Q-value

frame-by-frame using the transmission result of each DATA frames in the logging duration as follows [11], [12]:

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \{r_{t+1} - Q(s_t, a_t)\}, \quad (1)$$

where α is the learning rate, s_t is the state of buffers in adjacent BSSs, and a_t is the selected action of the target BSS (i.e., BSS 0 in Fig. 2). The reward r_{t+1} of each DATA frame is calculated by

$$r_{t+1} = \begin{cases} (\delta_{X,1}W_{\text{suc}} - \delta_{X,0}W_{\text{fail}})RD & \text{if } R \geq 0 \\ r_{\text{notx}} & \text{if } R = -1, \end{cases} \quad (2)$$

where $\delta_{a,b}$ denotes Kronecker delta, X is the transmission result (“1” means SUCCESS, and “0” means FAILURE) of the DATA frame, D [kbyte] is the payload length of the DATA frame, W_{suc} and W_{fail} are the weights of reward for successful and failed frame transmissions, respectively. R is the used transmission datarate [Mb/s]. Here, $R = -1$ denotes that frame transmission is pended in the corresponding adaptation period, and the reward is set to r_{notx} in this case.

Since the reward (and the Q-value) highly depends on the payload length in the above method, it may not work well if multiple traffic flows with different payload sizes coexist in a BSS. Hence, we also introduce another method to update the Q-value by aggregating the transmission results of DATA frames in an adaptation period (i.e., period-by-period update) as follows:

$$r_{t+1} = \begin{cases} \sum_i (\delta_{X_i,1}W_{\text{suc}} - \delta_{X_i,0}W_{\text{fail}}) D_i & \text{if } R \geq 0 \\ r_{\text{notx}} & \text{if } R = -1, \end{cases} \quad (3)$$

where X_i is the transmission result of the i th DATA frame in the logging duration, D_i [kbyte] is the payload length of the i th DATA frame. In this method, the transmission datarate R is not accounted for in the reward calculation because the rewards corresponding to the throughput of the BSS in the adaptation period by taking summation of the payload length of every DATA frame.

IV. COMPUTER SIMULATION

A. Simulation Configurations

The performance of the proposed TDA scheme is evaluated through system-level computer simulation based on IEEE 802.11ax WLAN. We compare four schemes: the proposed scheme with two different methods of the Q-value update, RRAA, and adaptive modulation and coding (AMC) based on the received power.

Table I shows the simulation parameters. The area size is assumed to be $80\text{ m} \times 80\text{ m}$, and it is segmented into 4×4 (thus, the segment size is $20 \times 20\text{ m}$). Each BSS is located in different segment as shown in Fig. 3. In the proposed scheme, each BSS collects the buffer statuses of the BSSs whose frame is received with the received power equal to or greater than -88 dBm which is same as the frame detection limit in this simulation. The random selection probability of action P_{rand} at the t th adaptation period is set by

$$P_{\text{rand}} = 1/(1 + t/133), \quad (4)$$

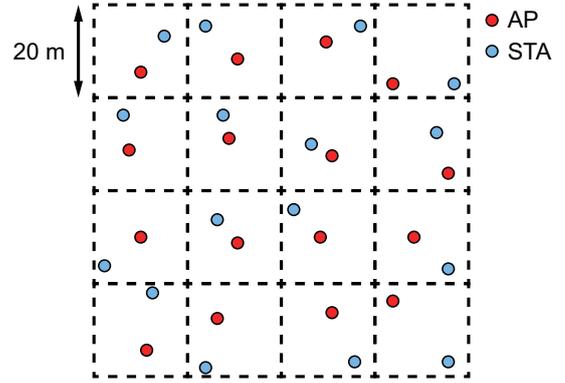


Fig. 3. Simulation area.

which gives $P_{\text{rand}} = 0.1$ at 2 minutes, because it gives high performance in the preliminary simulation.

In RRAA, the transmission datarate is adjusted every T_c if the number of transmitted DATA frames after the previous datarate adjustment is equal to or greater than 50. If frame error rate (FER) is greater than 0.1, the modulation and coding scheme (MCS) index is decremented by one, and it is incremented by one if the FER is less than 0.05. Otherwise, the current MCS index is retained. In AMC, the maximum MCS index at which the received power satisfies the minimum input sensitivity defined in the IEEE 802.11ax standard [10].

In this evaluation, downlink and uplink full-buffer traffic is assumed. Four configurations of the payload length of the DATA frames are assumed as follows.

- 3 kbytes (downlink), 1 kbyte (uplink)
- 3 kbytes (downlink), 3 kbytes (uplink)
- 15 kbytes (downlink), 5 kbytes (uplink)
- 15 kbytes (downlink), 15 kbytes (uplink)

It should be noted that the MAC efficiency improves, and the number of DATA frames used for updating the Q-value reduces as the payload becomes longer.

B. Simulation Results

Figures 4 and 5 show the average area throughput and the frame delivery rate of the proposed scheme, AMC, and RRAA, respectively when the number of BSSs is 4. In addition, the average number of DATA frames transmitted at each MCS index when the payload lengths for the downlink and uplink are 3 kbytes and 1 kbyte is shown in Fig. 6. The average number of DATA transmitted frames when the payload length is 15 kbytes for both the downlink and uplink is shown in Fig. 7.

The average area throughput of RRAA is quite low because it selects low transmission datarates (mainly, MCS indexes 0 and 1), and resultantly the number of DATA frame transmissions is smaller than other schemes. The average area throughput of AMC is lower than the proposed scheme even though it selects higher transmission datarates (mainly, MCS index 7). This is because it does not care frame collision, and resultantly the frame delivery rate is lower than other

TABLE I
SIMULATION SETTINGS

Evaluation duration	20 minutes
Area size	80 m × 80 m (20 × 20 m segment, 4 × 4 segments)
Number of BSSs	4, 16
Number of STAs per BSS	1
Supported MCS index	0–9 for IEEE 802.11ax [10]
Transmission power	20 dBm
Signal bandwidth	20 MHz
Noise level	−94 dBm (including 7 dB noise figure)
Minimum signal detection level	−88 dBm
Propagation model	IEEE 802.11 TGax Residential scenario [13]
Frequency channel	Ch 1 in the 2.4 GHz band
Retransmission limit	7 times
RTS/CTS exchange	Not in use
Interval of datarate adaptation (T_c)	100 ms
Logging duration (T_{\log})	80 ms
Learning rate (α)	0.1
Weights of reward	$(W_{\text{suc}}, W_{\text{fail}}) = (1, 0.1)$
Reward for pending transmission (r_{notx})	−2

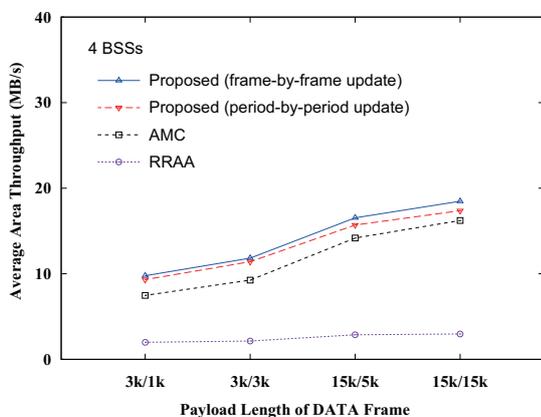


Fig. 4. Average area throughput performance (4 BSSs).

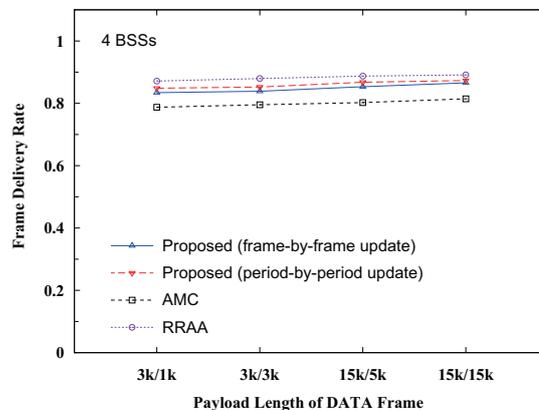


Fig. 5. Frame delivery rate performance (4 BSSs).

schemes. The proposed scheme achieves better average area throughput than the conventional two schemes because it selects higher transmission datarates and can keep the frame delivery rate relatively high even though underlay transmission is introduced. In the proposed scheme, the frame-by-frame Q-value update tends to select higher transmission datarates than the period-by-period Q-value update does. It implies that it is better to explicitly take the transmission datarate account for the reward calculation.

Figures 8 and 9 show the average area throughput and the frame delivery rate of the proposed scheme, AMC, and RRAA, respectively when the number of BSSs is 16. In addition, the average number of DATA frames transmitted at each MCS index when the payload lengths for the downlink and uplink are 3 kbytes and 1 kbyte is shown in Fig. 10. The average number of DATA transmitted frames when the payload length is 15 kbytes for both the downlink and uplink is shown in Fig. 11.

The proposed scheme with the period-by-period Q-value update likely selects middle transmission datarates (around MCS index 4), and the throughput degradation from the frame-by-frame Q-value update becomes larger than the 4-BSS case. The proposed scheme with the frame-by-frame Q-value update also less selects higher transmission datarates than the 4-BSS case, and the average area throughput is worse than AMC when the payload length is 15 kbytes. It is because transmission failure occurs more frequently as the payload becomes longer, especially when there are many interfering nodes. Therefore, further tuning of operation parameters will be necessary for heavily-congested situations. For example, the frame delivery rate will be affected by the magnitude of the weight for transmission failure W_{fail} . If we can set appropriate W_{fail} , the proposed scheme can further improve the average area throughput.

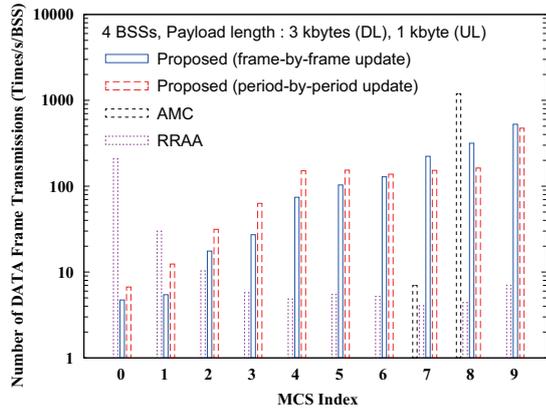


Fig. 6. Average number of transmit DATA frames per BSS (4 BSSs, 3 kbytes/1 kbyte payload).

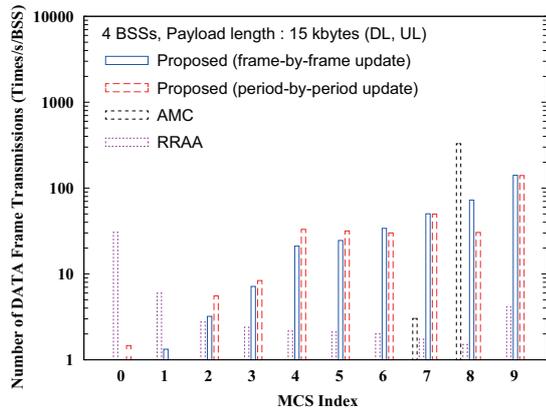


Fig. 7. Average number of transmit DATA frames per BSS (4 BSSs, 15 kbytes payload).

V. CONCLUSION

This paper introduced two methods of Q-value update for our proposed TDA scheme using Q-learning applicable to IEEE 802.11ax WLAN. One method updates the Q-value frame-by-frame with taking account for the payload length and the transmission datarate of each DATA frame. The other method updates the Q-value period-by-period based on the total throughput in a BSS. The performance of the proposed scheme with two different Q-value updating methods was evaluated through system-level computer simulation based on IEEE 802.11ax WLAN assuming four configurations of down-link and uplink full-buffer traffic. It was confirmed that the proposed scheme can achieve better average area throughput than conventional RRAA and AMC schemes except when there are many interfering nodes and the payload of the DATA frames is long. It was also confirmed that the frame-by-frame Q-value update can achieve better area throughput than the period-by-period update. It implies that it is better to explicitly take the transmission datarate account for the reward calculation.

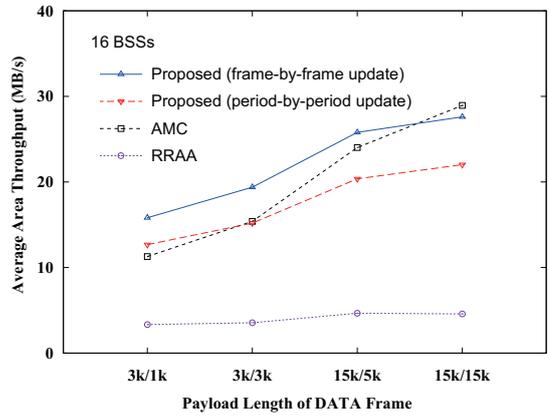


Fig. 8. Average area throughput performance (16 BSSs).

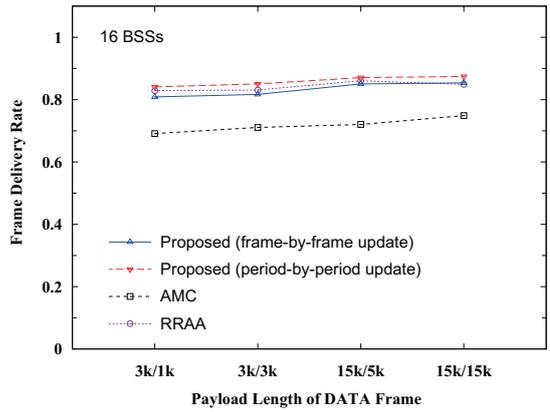


Fig. 9. Frame delivery rate performance (16 BSSs).

ACKNOWLEDGMENT

This research and development work was supported by the MIC/SCOPE #JP196000002.

REFERENCES

- [1] IEEE Std 802.11-2020, Feb. 2021.
- [2] W. Yin, P. Hu, J. Indulska, M. Portmann, and Y. Mao, "MAC-layer rate control for 802.11 networks: Lesson learned and looking forward," arXiv:1807.02827v1, July 2018.
- [3] A. Karmerman and L. Monteban, "WaveLAN-II: A high-performance wireless LAN for the unlicensed band," Bell Labs Technical Journal, vol. 2, no. 3, pp. 118–133, 1997. DOI:10.1002/bltj.2069
- [4] S. H. Y. Wong, H. Yang, S. Lu, and V. Bharghavan, "Robust rate adaptation for 802.11 wireless networks," Proc. ACM MOBICOM'06, pp. 146–157, Sept. 2006. DOI:10.1145/1161089.1161107
- [5] J. C. Bicket, "Bit-rate selection in wireless networks," Ph.D. thesis, MIT Master's Thesis, Feb. 2005.
- [6] H. Senda, O. Takyu, A. Kamio, M. Ohta, and T. Fujii, "Discrimination of communication quality deterioration utilizing retransmission flag and modulation and coding scheme(MCS) in wireless LAN," IEICE Technical Report, SR2020-7, pp. 45–49, June 2020.
- [7] K. Yamamoto, M. Mieda, S. Kondo, T. Nishio, A. Taya, and K. Yano, "Interference source determination based on history of transmissions in WLANs," IEICE Tech. Rep., RCS2021-141, pp. 122–125, Oct. 2021.
- [8] K. Yamamoto, Y. Kihira, Y. Koda, T. Nishio, and M. Morikura, "Factor analysis of communication quality using redundancy-check information in wireless LANs," Proc. IEICE Gen. Conf 2020, B-5-147, March 2020.

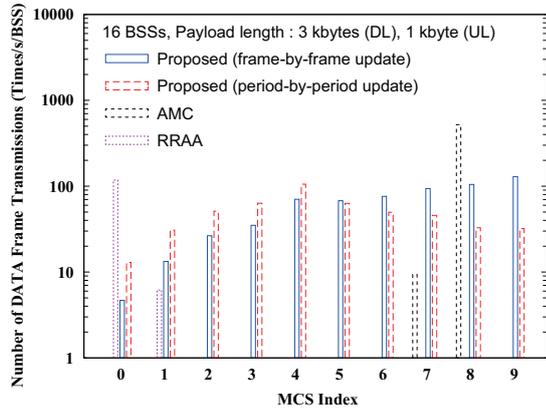


Fig. 10. Average number of transmit DATA frames per BSS (16 BSSs, 3 kbytes/1 kbyte payload).

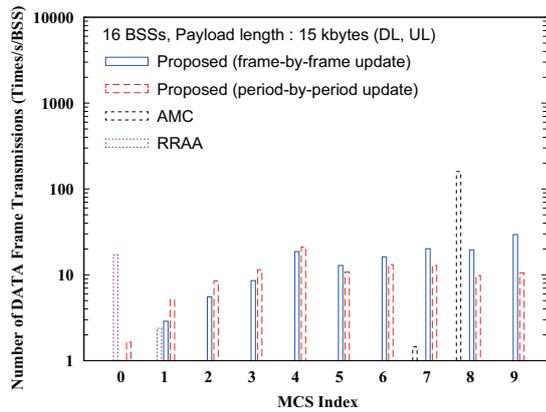


Fig. 11. Average number of transmit DATA frames per BSS (16 BSSs, 15 kbytes payload).

- [9] Y. Kihira, Y. Koda, K. Yamamoto, T. Nishio, and M. Morikura, "Adversarial reinforcement learning-based robust access point coordination against uncoordinated interference," Proc. the 92nd IEEE Vehicular Technology Conference (VTC2020-Fall), Online, Nov. 2020. DOI: 10.1109/VTC2020-Fall49728.2020.9348462
- [10] IEEE Std 802.11ax-2021, May 2021.
- [11] K. Yano, K. Suzuki, B. Ojetunde, and K. Yamamoto, "Transmission datarate adaptation using redundant check information for IEEE 802.11ax wireless LAN," submitted to IEICE ComEX.
- [12] K. Yano, K. Suzuki, B. Ojetunde, and K. Yamamoto, "Performance evaluation of access control and transmission datarate adaptation using redundant check information for IEEE 802.11ax wireless LAN," IEICE Tech. Rep., SR2021-81, pp. 103–110, Jan. 2022.
- [13] R. Porat, *et al*, "11ax Evaluation Methodology," doc. IEEE 802.11-14/0571r12, Jan. 2016.