Latency Oriented OFDMA Random Access Scheme for the Next Generation WLAN: IEEE 802.11be

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Abstract. Real-time applications (RTA) develop rapidly these days. Latency sensitive traffic guarantee becomes increasingly important and challenging in wireless local area network (WLAN). In order to tackle the problem, this paper proposes a latency oriented random access scheme, which is compatible with IEEE 802.11 standards, based on orthogonal frequency division multiple access (OFDMA) in the next generation WLAN: IEEE 802.11be. AP utilizes trigger frame (TF) based OFDMA random access and reserves several resource units (RUs) for latency sensitive traffic only. According to the collision status in the past TF as well as the traffic arrival features, we theoretically analyze the estimated number of STAs who will have latency sensitive data to send during the next TF interaction. Thus, AP can allocate appropriate RUs for latency sensitive STAs dynamically. The simulation results show that the proposed dynamic RU adjusting algorithm outperforms the other schemes in both throughput and delay. The throughput utility of the proposed algorithm is 19.69% higher than that of IEEE 802.11ax. And the delay utility is 21.39% lower than that of IEEE 802.11ax, which validates the effectiveness of the proposed algorithm.

Keywords: Latency guarantee · Delay sensitive · Real-time application · WLAN · OFDMA

1 Introduction

In the past decades, with the rapid development of communication technology, wireless local area network (WLAN) has already penetrated into people's lives [1]. The number of terminals increases rapidly [2]. Meanwhile, live video streaming and online meeting have become more and more popular among people [3,4].

In recent years, lots of real-time applications (RTA) such as online game, virtual reality (VR) are becoming increasingly sensitive to delay [5,6]. Large delay will seriously influence the quality of experience (QoE) [7]. In order to improve quality of service (QoS) of RTA, schemes for latency guarantee need to

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be well designed. Therefore, delay guarantee is considered to be a key issue of the next generation WLAN standard: IEEE 802.11be [8].

There are some existing latency guarantee algorithms for WLAN. Higuchi et al. [9] improved latency-rate (LR) scheduling method to guarantee a bounded delay for hybrid coordination function (HCF) controlled channel access (HCCA). His new scheduling algorithm can optimize the number of stations according to the token bucket and service interval (SI). Kuo et al. [10] put forward a contention-based scheme to guarantee Qos of both the upstream and downstream. A fixed contention window backoff scheme and the parameters optimization procedure help to mitigate the downlink bottleneck at the access point (AP). Through the analysis of the relationship between the optimal size of initial backoff competition window and the maximum aggregate throughput, an admission control algorithm is proposed by Gao et al. [11] for the purpose of maximizing the number of real-time nodes. Gao et al. [12] presented an accurate theoretical model which can predict the queueing delay of RTA in WLAN. According to the model, a decentralized scheme is put forward to minimize the traffic delay. Hurtig et al. [13] proposed the block estimation (BLEST) scheduler and the shortest transmission time first (STTF) scheduler for multi-path protocols. And multi-path protocols can optimize performance through load-balancing and link failures. However, few of the existing studies are well compatible with IEEE 802.11ax [14] or fully use the new features such as orthogonal frequency division multiple access (OFDMA).

In order to reduce the latency of RTA while maintain the compatibility of IEEE 802.11 standards [15], this paper proposes an OFDMA based random access latency guarantee scheme. AP can reserve appropriate resource units (RUs) for latency sensitive traffic dynamically through trigger frame (TF). It can be found that the proposed algorithm outperforms the other schemes on both throughput and delay.

The contributions of this article are summarized as follows:

- This article proposes an OFDMA based random access latency guarantee algorithm in the next generation WLAN: IEEE 802.11be, which is compatible with the framework of IEEE 802.11 standards.
- Meanwhile, the proposed algorithm has the highest throughput and the lowest delay compared with IEEE 802.11ax and the other methods. It has the best comprehensive performance.

The rest of this article is arranged as follows. Section 2 briefly describes the problem and puts up the key idea of the solution. In Sect. 3, we detailedly introduce and infer the proposed algorithm. Then, simulation results and analysis will show in Sect. 4. And the final section will summarize this article in the end.

2 Motivation

2.1 Problem Formulation

IEEE 802.11ax first introduced OFDMA in WLAN. Available channels are divided into multiple RUs. Users can select different RUs for information transmission [16].

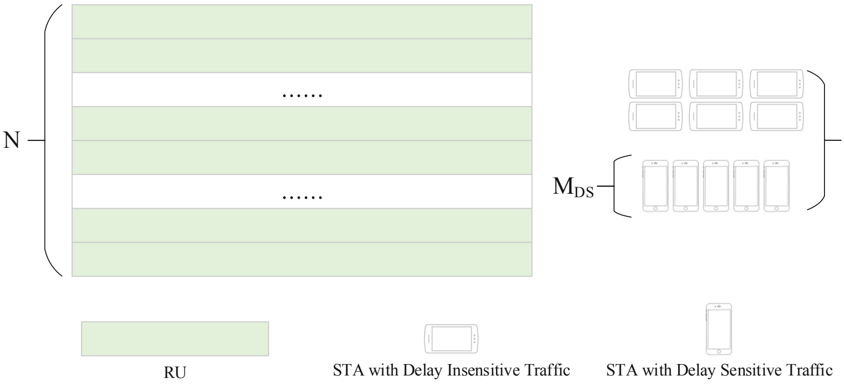

Fig. 1. Communication scenario.

As Fig. 1 shows, there are N resource units for M stations (STAs) to compete. And there are M_{DS} stations with delay sensitive traffic within the M stations. Due to random access, the successful possibility of stations with delay insensitive traffic is the same as that of stations with delay sensitive traffic. Therefore, latency sensitive service cannot be well guaranteed.

2.2 Key Idea of Proposed Algorithm

For the sake of improving the comprehensive performance of latency sensitive service, a dynamic RU random access scheme is proposed. In the proposed algorithm, some RUs are reserved and allocated to STAs which have delay sensitive traffic. Then, STAs with delay sensitive traffic will have higher successful transmission possibility than that of STAs with delay insensitive traffic. Therefore, the QoS of RTA can be well protected (Fig. 2).

Every time before AP sends TF, AP will estimate volume of latency sensitive traffic [17]. And the queue information of STAs can be deduced according to the proposed algorithm. Then, AP can reserve appropriate RUs and put the RU configuration information into the TF, which means that proposed algorithm can adapt to the variable traffic rate.

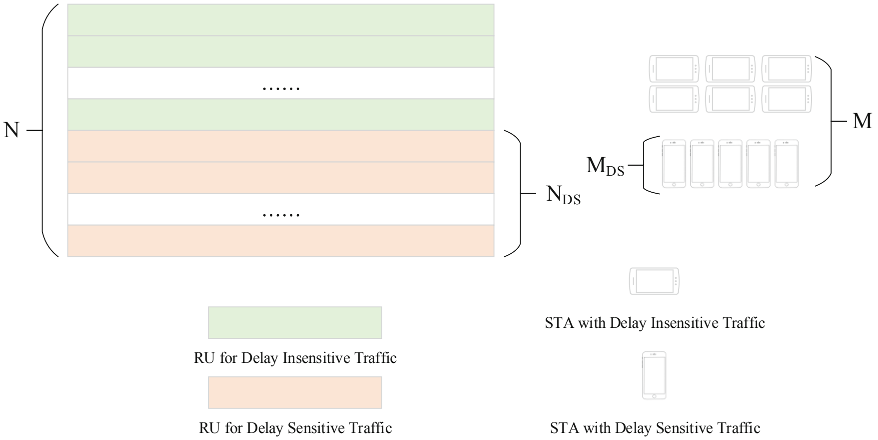

Fig. 2. Model of proposed algorithm.

3 Proposed Algorithm for Latency Guarantee

3.1 Procedures of Proposed Algorithm

Figure 3 shows procedures of the proposed algorithm. After a successful backoff, according to the collision status of RUs in the last TF interaction as well as the traffic arrival features, AP will estimate M_E, which is the number of STAs which will have latency sensitive data to send. Then, AP will configure appropriate N_{DS}, which is the RU number for latency sensitive STAs. And AP will send TF to STAs. A short interframe space (SIFS) after receiving TF, the STAs will send uplink (UL) data. A SIFS later, AP can respond block acknowledgment (BACK) frame to STAs. Table 1 shows the notations that will be involved in this paper.

3.2 Proposed Algorithm

A. Estimation

Because it is random for STAs to choose RU, there will be three states for a single RU. They are successful, idle and collided. A successful RU means that only one STA choose this RU. And an idle RU indicates that no STAs choose this RU. The situations of RUs can be utilized to estimate M_E.

When a collided RU occurs, it is obvious that there are at least two STAs choosing this RU. Cha et al. [18] pointed out that the estimated STA number is 2.39 times the number of collided RUs, which means that a collided RU is caused by 2.39 STAs on average. These STAs will retransmit data after receiving the next TF. In other words, STAs which chose collided RUs must send data at next transmission opportunity. However, it is not clear that whether the STAs which didn't choose collided RUs will send data at the next opportunity or not. In order to estimate M_E more accurately, we need to solve the above problem.

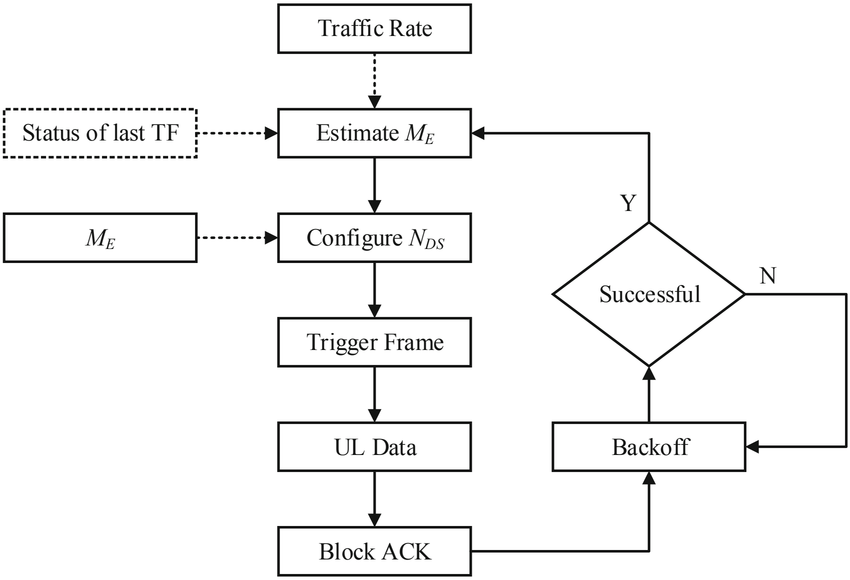

Fig. 3. Procedures of proposed algorithm.

Table 1. Notations.

Notations	Description
M	Number of all stations
M_{DS}	Number of stations with delay sensitive traffic
M_E	Estimated number of stations with delay sensitive traffic
N	Number of all resource units
N_{DS}	Number of resource units for delay sensitive traffic
N_S	Number of successful resource units within N_{DS} RU
N_I	Number of idle resource units within N_{DS} RU
N_C	Number of collided resource units within N_{DS} RU
T	Current time

Assume that the application traffic of STA i subject to Poisson distribution $P(\lambda_i)$ [19]. And the average traffic rate λ_i can be variable. AP is capable of recording the number of received packets $R(i)$ of station i. And AP also can extrapolate traffic rate of each STA. The detailed method is out of the scope of this paper. At the next transmission time T, an average of $\lambda_i T$ packets have been produced by STA i. If the number of received packets $R(i)$ is not larger than $\lambda_i T - 1$, STA i must send data at the next transmission. And if $R(i) > \lambda_i T - 1$, we infer that this STA will not send data at the next opportunity definitely. In order to present more intuitively, we define two indicative functions.

$$\chi_C(i) = \begin{cases} 1, & \text{STA } i \text{ didn't choose collided RU.} \\ 0, & \text{STA } i \text{ chose collided RU.} \end{cases} \tag{1}$$

$$\chi_T(i) = \begin{cases} 1, & R(i) \leq \lambda_i T - 1. \\ 0, & R(i) > \lambda_i T - 1. \end{cases} \tag{2}$$

Finally, we can derive that

$$M_E = round(2.39 N_C) + \sum_{i=1}^{M_{DS}} \chi_C(i)\chi_T(i) \tag{3}$$

B. Configuration

After estimate M_E, the number of STAs which will have latency sensitive data to send, we need to allocate appropriate N_{DS} RUs for these STAs to maximize access efficiency. For a single RU, because the total RU number for latency sensitive STAs is N_{DS}, the probability that each latency sensitive STA chooses this RU is $1/N_{DS}$. Then, the probability of selecting the other RUs is $1-1/N_{DS}$. So, the probability that a latency sensitive STA can transmit successfully on this RU is given by:

$$P_S = \frac{1}{N_{DS}} \left(1 - \frac{1}{N_{DS}}\right)^{M_E - 1} \tag{4}$$

And there are N_{DS} resource units for latency sensitive traffic. The probability that a latency sensitive STA transmits data successfully is:

$$N_{DS} P_S = \left(1 - \frac{1}{N_{DS}}\right)^{M_E - 1} \tag{5}$$

Since there are total M_E STAs which will have latency sensitive traffic to transmit, the expected successful STA number M_S will be:

$$M_S = M_E \left(1 - \frac{1}{N_{DS}}\right)^{M_E - 1} \tag{6}$$

Therefore, the expected successful ratio η can be calculated as:

$$\eta = \frac{M_E}{N_{DS}} \left(1 - \frac{1}{N_{DS}}\right)^{M_E - 1} \tag{7}$$

In order to maximize η, calculate derivative of function η with respect to N_{DS}. And solve the equation that derivative value is equal to 0. Then, we can get that the optimal N_{DS} is equal to M_E. Therefore, after get M_E, AP will allocate M_E resource units for latency sensitive traffic.

3.3 Compatibility Analysis

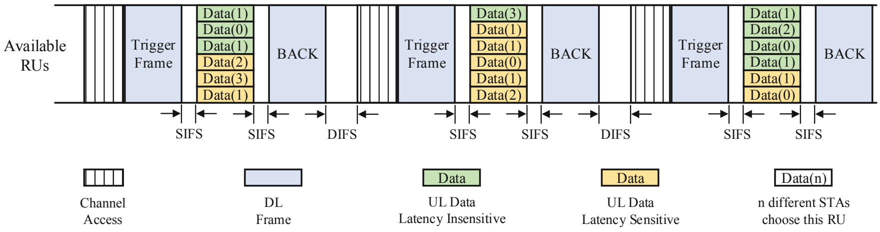

Fig. 4. Example of proposed algortithm.

Figure 4 presents an example of the proposed algortithm. There will be three types of frames in this system. They are trigger frame, data frame and block ACK frame, which are all included in IEEE 802.11ax standard. Data frame is used to transmit data. And block ACK frame is a kind of control frame, which indicates whether the data has been received correctly or not. Besides, we can put the configuration information of RUs into the TF, which is consistent with IEEE 802.11ax.

For latency sensitive traffic, we can set the user priority (UP) as 7. And put the packets into queue AC_VO, which has the highest transmission priority. As for latency insensitive traffic, the UP can be configured as 0. Packets will go into queue AC_BE, which has a lower priority.

4 Results and Analysis

NS3 [20] is used for our simulations. Suppose a STA only has one type of traffic. The traffic rate λ of all the STAs is the same and it can be time variant. The detailed configuration information is shown in Table 2.

In order to describe comprehensive performance of algorithms, weight coefficient α for delay sensitive STAs and β for delay insensitive STAs are defined to calculate utility. There are only two types of traffic. Thus, α and β need to meet the equation $\alpha + \beta = 1$. And for the reason that delay sensitive traffic has a higher priority, α will be larger than β.

Figure 5 shows the throughput of all delay sensitive STAs. IEEE 802.11ax performs uplink OFDMA (UORA) with total 72 RUs. The transmission opportunity for each STA is the same. And the throughput of each STA is equal. Therefore, the throughput has a linear relationship with the number of delay sensitive STAs. In the cases of fixed RU number mode, when the number of delay sensitive STAs is small, throughput will be higher as the delay sensitive STA number grows. And if the number of delay sensitive STAs is larger, the collision among delay sensitive STAs will be very serious. It also can be found that the maximum throughput achieves when the RU number is equal to the

Table 2. Simulation configuration.

Parameter name	Parameter value
M	100
M_{DS}	10–100
N	72
Initial N_{DS}	10
Interval of traffic rate changing	0.1 s
λ	100–1000
Simulation time	1s
Distributed interframe spacing (DIFS)	34 µs
Contention window (CW)	15
Slot time	9 µs
Physical layer preamble	40 µs
Trigger frame	108.8 µs
SIFS	16 µs
Packet size	1500 Bytes
Data Rate	11.8 Mbps
Block ACK	13.6 µs

number of delay sensitive STAs. The proposed dynamic RU algorithm can allocate appropriate RUs according to the current situation, so the throughput can be well guaranteed whatever the number of delay sensitive STAs is.

$\alpha = 0.8$ and $\beta = 0.2$ are chosen to calculate utility of throughput U_T, which is calculated by $\alpha T_{DS} + \beta T_{DI}$. T_{DS} is the throughput of delay sensitive STAs and T_{DI} is the throughput of delay insensitive STAs. From Fig. 6, we can find that the dynamic RU adjusting algorithm has the highest utility. The proposed algorithm's U_T can reach 123.99. It is 19.69% higher than that of IEEE 802.11ax. And it is 86.14% higher than that of fixed 30 RUs mode.

As Fig. 7 shows, the delay of IEEE 802.11ax is also a constant value because of its competition fairness for each STA. For fixed 30 RUs mode, as the number of delay sensitive STAs grows, the delay will be larger and larger due to the limited resource units. However, when the number of delay sensitive STAs is small, the delay of the proposed dynamic RU algorithm is nearly a constant due to the enough resource units. And the system will be saturated when the number of delay sensitive STAs is larger than 50. Therefore, the delay will increase if delay sensitive STAs is more than 50.

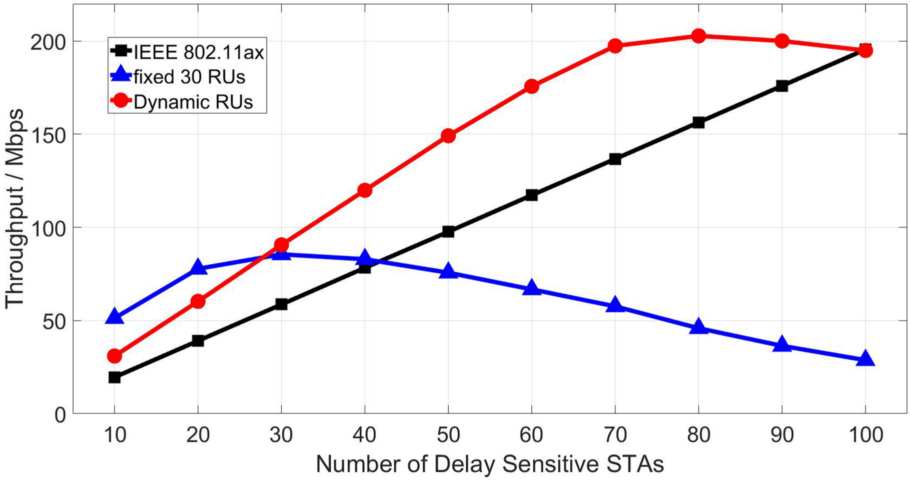

Fig. 5. Throughput of delay sensitive STAs.

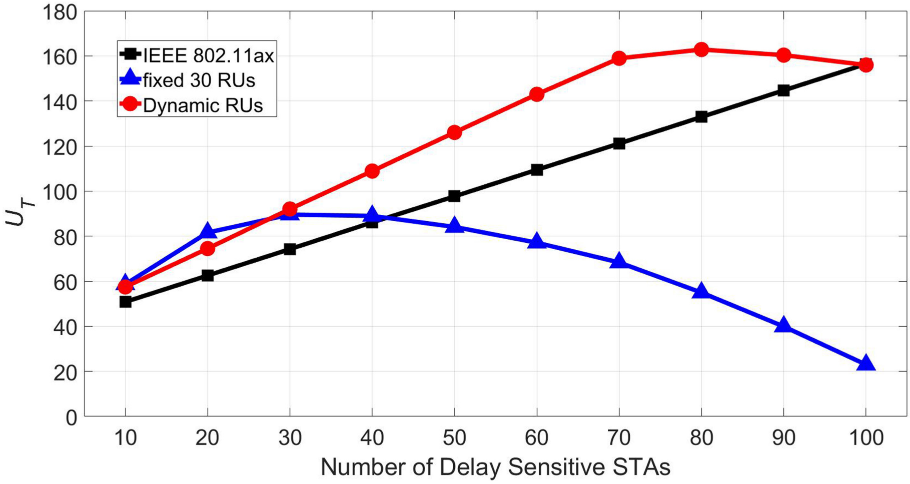

Fig. 6. Utility of throughput.

To calculate utility of delay U_D, we also choose $\alpha = 0.8$ and $\beta = 0.2$. Then, U_D can be calculated by $\alpha D_{DS} + \beta D_{DI}$. D_{DS} is the delay of delay sensitive STAs and D_{DI} is the delay of delay insensitive STAs. Figure 8 show the U_D of different algorithms. We can find that the proposed dynamic RU algorithm's U_D is 0.2227, which is the lowest among these algorithms. It is 21.39% lower than that of IEEE 802.11ax. And it is 15.93% lower than fixed 30 RUs mode.

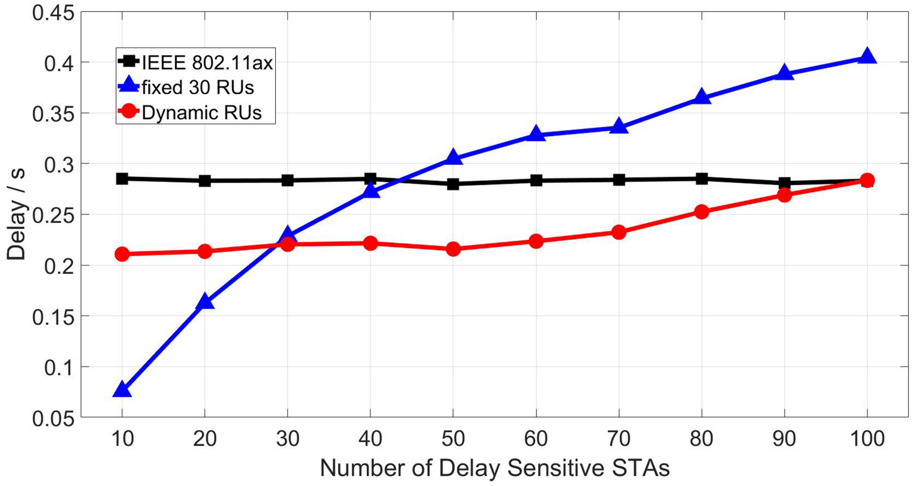

Fig. 7. Delay of delay sensitive STAs.

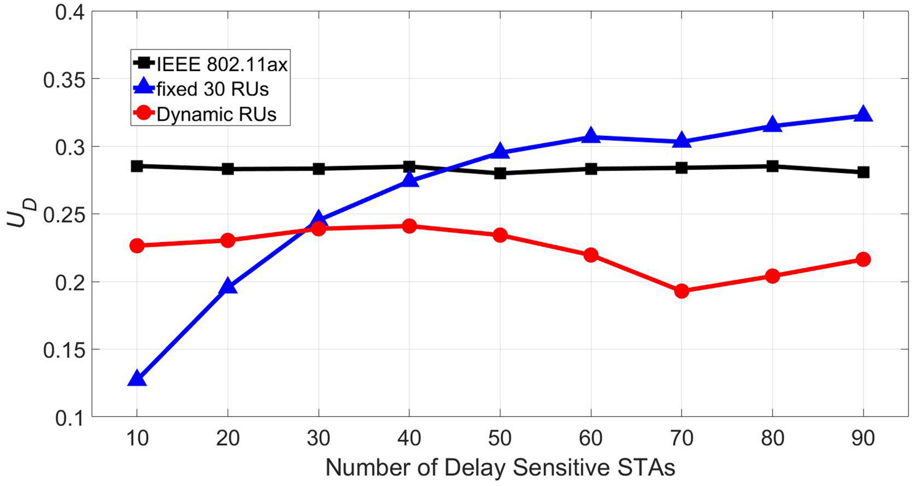

Fig. 8. Utility of delay.

5 Conclusion

For the purpose that guarantee the latency sensitive traffic better, this article proposes an OFDMA random access scheme for the next generation WLAN: IEEE 802.11be. According to the traffic rate and situations of last transmission, AP is capable of estimating the number of STAs which will have latency sensitive data to send. Then, AP can reserve appropriate RUs for latency sensitive traffic dynamically. Through our simulations, it can be found that the proposed dynamic RU adjusting scheme outperforms the other methods. U_T of proposed algorithm is 19.69% higher than that of IEEE 802.11ax. And it is also 86.14% higher than that of fixed 30 RUs mode. Besides, the proposed algorithm's U_D is 21.39% lower than that of IEEE 802.11ax. And it is also 15.93% lower than fixed 30 RUs mode. The proposed algorithm doesn't interrupt the transmission of delay insensitive traffic while latency sensitive traffic is guaranteed. Therefore, the proposed dynamic RU adjusting algorithm has the best comprehensive performance.

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