



# A Channel Reservation Mechanism in IEEE 802.11be for Multi-cell Scenarios

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**Abstract.** With the surge in demand for latency-sensitive traffic, the next-generation Wireless Local Area Network (WLAN) standard IEEE 802.11be has recognized the improvement of worst-case latency and jitter as one of its core objectives. Reservation-based contention-free channel access scheme achieves lower latency. Nevertheless, the channel reservation still has some limitations. In a multi-cell scenario, the Access Point (AP) is not capable of managing external cell users, which will cause interference to the reserved users during the reservation period, resulting in deteriorating channel conditions and increasing latency. Hence, in this paper, we propose a channel reservation mechanism with multi-cell coordination capability, enabling the sharing of channel reservation information among different cell APs and restricting the corresponding users to remain in silence during the reservation period, to avoid interference from internal and external cell users on the reserved users. Moreover, we propose a management frame protection scheme based on channel reservation mechanism that reduces the probability of management frame loss by offering channel reservation to the management frames. The effectiveness of the channel reservation mechanism and the management frame protection scheme is verified by simulations. It is demonstrated that the latency of latency-sensitive traffic in a multi-cell scenario using the proposed mechanism is significantly improved over the existing works.

**Keywords:** Wireless local area network (WLAN) · IEEE 802.11be · Channel Reservation · Multi-Cell Coordination · Low Latency

## 1 Introduction

Recently, latency-sensitive traffic has emerged for various sectors, such as cloud gaming and remote medical monitoring. This traffic usually requires low latency and high reliability to meet the demands of their application scenarios, whereas the widely used Wireless Local Area Network (WLAN) standard IEEE 802.11ax [1] has efficient network performance, but it cannot guarantee timely data delivery due to the uncertainty of the CSMA/CA channel access mechanism, and thus cannot meet the requirements of latency-sensitive traffic.

As a result, the next-generation WLAN standard IEEE 802.11be [2] has listed the worst-case latency and jitter improvement as one of the core objectives, and new technologies and features will be introduced in the Physical layer (PHY) and Medium Access Control layer (MAC) to improve the latency.

The traditional IEEE 802.11 standard defines the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF). DCF uses contention-based CSMA/CA mechanism to access the channel and simultaneously uses binary exponential backoff algorithm to defer channel access time to reduce the probability of collision. The standard also proposes Enhanced Distributed Channel Access (EDCA) mechanism based on DCF to meet QoS requirements. EDCA classifies traffic into four categories, each with different priorities and backoff parameters. High-priority traffic has more optimal backoff parameters, like smaller maximum contention window size. PCF uses contention-free point coordinators to manage channel access and schedules node transmissions by polling. This method introduces significantly more cost and complexity, plus the loss of scheduling information due to uncertainty in unlicensed bands. In contrast, DCF has higher reliability, lower cost, and simpler implementation. Therefore, DCF has been more widely used. But DCF still has a higher probability of collision when the number of users is large, and channel access becomes more difficult, resulting in increased latency. Accordingly, the contention-based channel access mechanism may not meet the low latency and high-reliability requirements of latency-sensitive traffic.

The IEEE 802.11ax standard introduces Orthogonal Frequency Division Multiple Access (OFDMA) technology and Multi-User Multi-Input Multi-Output (MU-MIMO) technology to strengthen the concurrency capability. Based on these two technologies, the multi-user uplink transmission scheduling scheme allows users to access the channel free of competition for latency reduction. The IEEE 802.11ax standard enhances the Target Wake Time (TWT) technique introduced by the IEEE 802.11ah standard [3] as well as introduces broadcast TWT, which utilizes reservation-based channel access to enable users to transmit data during the reserved period with less contention, thereby reducing latency. The next generation WLAN standard, IEEE 802.11be, introduces Restricted TWT (R-TWT) technology derived from broadcast TWT technology, a mechanism that reduces latency by providing additional channel protection to channel reservation period to further reduce contention. These scheduling or reservation-based channel access methods are more appropriate for transmitting latency-sensitive traffic than competition-based access methods.

A few limitations exist, however, in the use of the above techniques. One of the very critical limitations is the interference from OBSSs. In multi-cell scenarios, whether using scheduling-based or reservation-based channel access, the Access Point (AP) cannot effectively coordinate external cell users. While the channel is idle, the external cell users may transmit data at any time and even transmit without contention when they have TXOP. Channel conditions deteriorate due to the uncertainty of the access channel for external cell users, and users with low latency demand who are scheduled or have reservation periods

may not be able to access the channel rapidly, and thus latency-sensitive traffic cannot be transmitted in time. Therefore, in multi-cell scenarios, APs need to coordinate with external cell users in an effective way to reduce the competition from external cell users. Besides, in the multi-cell high-density scenario, when the AP performs channel reservation or schedule, the relevant management frames could be lost due to collision, and since the retransmission mechanism does not apply to such management frames, the users cannot establish communication with the AP in the period following and thus cannot provide rapid channel access to the latency-sensitive traffic, which results in increased latency. Therefore, in multi-cell high-density scenarios, APs need to minimize management frame transmission loss effectively.

In light of this, this paper investigates the solution to the problem of interference from OBSSs for channel reservation and management frame loss in a multi-cell scenario. The contributions of this paper are mainly as follows:

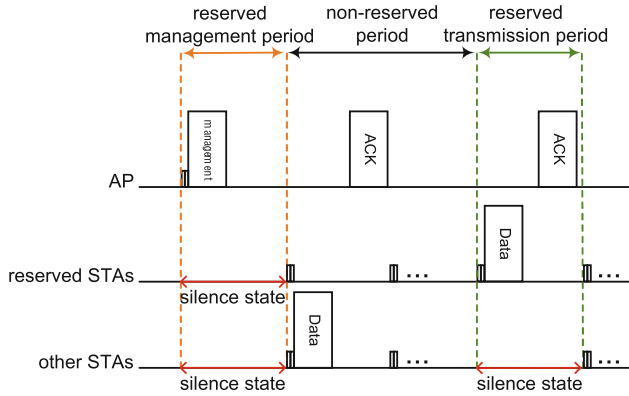
- 1) A channel reservation mechanism in a multi-cell scenario is proposed. It reduces the competition by coordinating the channel access of different BSS users through APs and Wireless Access Point Controller (AC). In the multi-cell scenario, before the AP allocates reservation periods to users, the channel reservation information is first forwarded to the external cell AP through the AC so that it can coordinate the external cell users. With multi-cell coordination, APs can eliminate interference from external cell users, and users with low latency demand can rapidly access the channel for data transmission during the reservation period, consequently reducing latency.
- 2) In addition, this paper proposes a scheme to transmit management frames using channel reservation, where the AP can transmit management frames during a regular channel reservation period, while the user remains in silence during that period, which reduces the probability of management frame loss and allows the user to receive the channel reservation information correctly, thereby preventing the latency increase due to channel reservation information loss.

The remainder of this paper is organized as follows: In Sect. 2, the related work is introduced. Section 3 presents the channel reservation mechanism in the multi-cell scenario and the scheme of utilizing channel reservation to protect the management frame transmission in the multi-cell high-density scenario. The performance is simulated and analyzed in Sect. 4. Section 5 concludes the whole paper.

## 2 Related Work

Many researchers have investigated in recent years for MAC protocol performance enhancement. Paper [4] proposed a distributed reservation MAC protocol called EBA. The node sends information about future backoff values to other nodes through data frames, and other nodes select backoff values avoiding the already selected values. A centralized channel reservation MAC mechanism is proposed in the paper [5]. Nodes transmit data during reserved periods and compete to obtain channel reservations during unreserved periods. The

paper [6] proposes a competition-based distributed channel reservation MAC protocol. Nodes compete during the competitive periods and the nodes that succeed in the competition broadcast their reservation information of the channel using RTS/CTS like mechanism before transmitting the data. Nodes reserving channels send data during the reservation period. A multi-hop distributed channel reservation mechanism has been proposed in the papers [7,8]. The node sends multiple future channel reservation information to other nodes through data frames, so that the reservation information can be sent multiple times. A collision-free backoff mechanism is proposed in the paper [9]. Nodes can reserve or release the backoff value by managing frames. In paper [10], a distributed channel reservation mechanism is proposed. When a node sends data, the channel is reserved in the form of NAV and the node can send data again after successful data delivery. Extensive research on TWT has been carried out in academia in recent years. The paper [11] investigated the effect of clock drift on TWT and compared two channel access modes under TWT uplink transmission: random contention access and AP scheduling access, and found that the former provides lower transmission time, while the latter provides lower power consumption. The paper [12] investigates the performance gain of TWT and finds that it brings significant throughput gains when combined with the uplink multi-user feature of IEEE 802.11ax, despite the additional management overhead required, along with almost constant average latency when the traffic load varies. The paper [13] combines the MU-based orthogonal frequency division multiple access (OFDMA) function of IEEE 802.11ax with TWT scheduling to improve throughput by negotiating the appropriate target beacon transmission time and staggering the wake time of nodes to reduce competition. In the paper [14], the MU function of IEEE 802.11ax is combined with broadcast TWT to improve throughput by scheduling the suitable number of nodes through AP to maximize their parallel transmission without collision using the channel resources. The paper [15] proposes a machine learning-based traffic category detection model and an adaptive TWT wake interval configuration scheme so that the TWT parameters can be adjusted according to the traffic category of real-time data to reduce competition and power consumption. A time-aware scheduling scheme based on TWT is proposed in the paper [16]. The paper [17] treats as a graph coloring problem by grouping nodes to find the minimum chromatic number enabling as many nodes as possible to transmit in parallel at the same time, thus improving throughput and energy efficiency. Although the above research has improved the MAC protocol performance, it has not paid much attention to the OBSSs interference. Hence, this paper proposes a channel reservation mechanism in a multi-cell scenario to solve the OBSSs interference by multi-cell coordination, as well as to solve the management frame loss problem by using channel reservation to transmit management frames.



**Fig. 1.** Period classification of channel reservation mechanism and operation of various types STAs during different period.

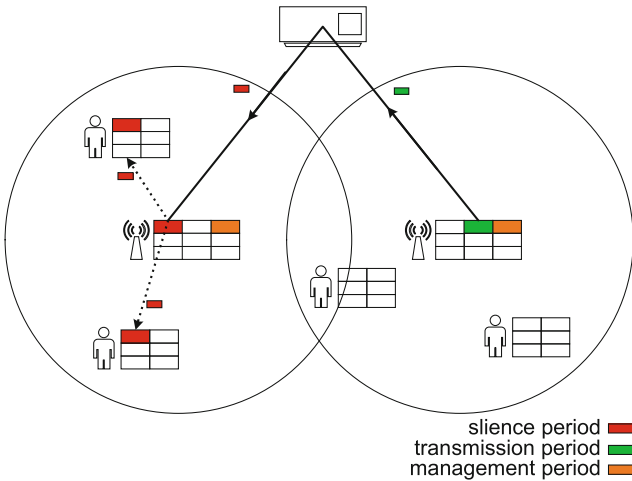
### 3 A Channel Reservation Mechanism in a Multi-cell Scenario

#### 3.1 Basic Idea

In the channel reservation mechanism, the period is classified into reserved period and non-reserved period, as shown in Fig. 1. Among them, the reserved period is further classified into reserved management period and reserved transmission period, which will be referred to as management period and transmission period respectively. During the transmission period, the reserved Station (STA) transmits latency-sensitive traffic through randomly contention access channels, while other STAs enter silence state. During the management period, APs transmit reservation information over randomly contention access channels, and other STAs enter silence state. During non-reserved period, all STAs transmit data over random contention access channels. Benefits from the above classification, AP can exclude contention of STAs during the management period, thus reducing the probability of losing management frames and their reservation information due to collision. The reserved STAs can rapidly access the channel without contention during the transmission period, thus eliminating the contention and conflicts caused by other STAs and thereby reducing latency.

To implement period classification, all nodes will maintain two period lists, reservation list and silence list. For STAs, the reservation list records the transmission period information allocated to itself, and the silence list records the reserved period (including transmission period and management period) information allocated to other nodes. For APs, the reservation list records the transmission periods allocated to internal cell STAs, and the silence list records the transmission periods allocated to external cell STAs. Besides, AP maintains an additional management list to record management period information. STAs enter the silence state when the Time Synchronization Function (TSF) matches

any of the silence list recording periods, and the silence state will last for a fixed duration. Nodes start to randomly compete for access channels when the TSF matches any of the reservation list or management list recording periods. For ensuring that the channel remains idle at the beginning of the reserved period so that the reserved node can access the channel quickly, the node must determine before each transmission whether the frame exchange sequence can end before the nearest reserved period, otherwise, this transmission is not performed.



**Fig. 2.** Multi-cell coordination operation of channel reservation mechanism.

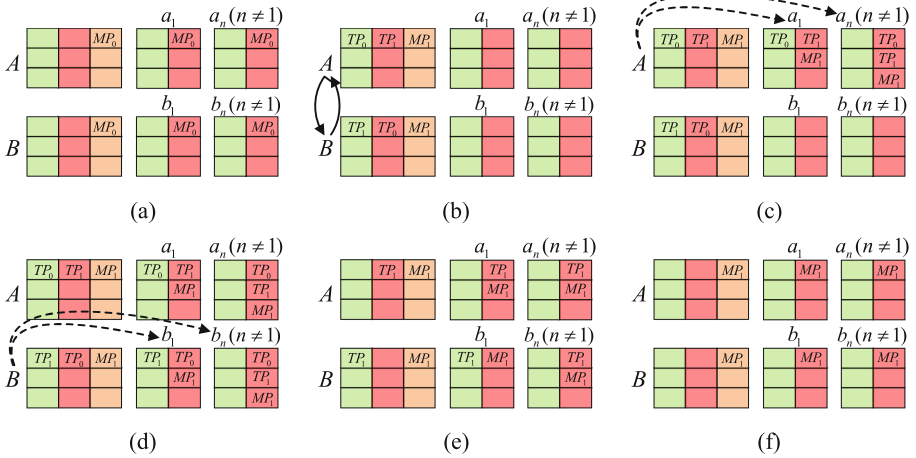
To eliminate the interference of OBSSs, AP needs to notify the reservation list to the adjacent external cell nodes for multi-cell coordination, as shown in Fig. 2. AP forwards its reservation list to the adjacent AP through AC, and the adjacent AP adds the list to its silence list and then broadcasts the silence list to all STAs in the belonging BSS through management frames, and STAs add the list to their silence list. As a result of the above operation, the transmission period information can be shared among the cell nodes, thus excluding the interference of OBSSs. In addition, the management period should occur cyclically and each reserved period included in the management frame shouldn't exceed the next management period.

### 3.2 Channel Reservation Mechanism Algorithm

We use the following notation to describe the channel reservation algorithm:

- 1) Node:  $A$  denotes AP1,  $a_n (n \geq 1)$  denotes the  $n$ -th STA associated with  $A$ ;  $B$  denotes AP2,  $b_n (n \geq 1)$  denotes the  $n$ -th STA associated with  $B$ . etc.

- 2) Period:  $T$  denotes the current time,  $TP$  denotes the transmission period, and  $MP$  denotes the management period.  $TP_i$  denotes the  $i$ -th transmission period and the same as the management period.
- 3) List:  $RL$  denotes the reservation list,  $SL$  denotes the silence list, and  $ML$  denotes the management list.  $RL_i (i \geq 0)$  denotes the  $i$ -th period in the reservation list and the same for the other lists. We assume that the list is always in ascending order and there is no invalid period (an invalid period is a period whose beginning time is less than the current time), so  $RL_0$  denotes the nearest valid reservation period to the current time and the same for other periods.



**Fig. 3.** Illustration of node operation and list status at different periods of channel reservation mechanism in two cell network topologies. (a) Node operation and list status before management period  $MP_0$ . (b) Node operation and list status after AP allocation and exchange transmission period in management period  $MP_0$ . (c) Node operation and list status after  $A$  sends a management frame in management period  $MP_0$ . (d) Node operation and list status after  $B$  sends a management frame in management period  $MP_0$ . (e) Node operation and list status in the first transmission period  $TP_0$ . (f) Node operation and list status in the second transmission period  $TP_1$ .

The channel reservation algorithm is described in Fig. 3. The green list represents the reservation list, the red list represents the silence list, the orange list represents the management list, and the periods in the list are sorted in ascending order from top to bottom:

- (a) Before the management period  $MP_0$  is about to arrive, there are no other periods recorded in the node list except  $MP_0$ . In the STAs silence list,  $SL_0 = MP_0$ ; in the APs management list,  $ML_0 = MP_0$ .
- (b) On the arrival of management period  $MP_0$ , the node refreshes the list to delete  $MP_0$ . APs update the management period, and in the management

list,  $ML_0 = MP_1$ .  $A$  allocates transmission period  $TP_0$ , and in the reservation list,  $RL_0 = TP_0$ ;  $B$  allocates transmission period  $TP_1$ , and in the reservation list,  $RL_0 = TP_1$ ; After the allocation,  $A$  and  $B$  exchange  $RL$  information and add each other  $RL$  to their own  $SL$ , and in the  $A$  silence list,  $SL_0 = TP_1$ ; In the  $B$  silence list,  $SL_0 = TP_0$ .

- (c) After the above operation, APs start to contend for channels, and  $A$  successfully contends and sends management frames to STAs, where  $a_1$  is an STA with low latency demand.  $a_1$  receives management frames and adds  $RL$  to its own reservation list,  $RL_0 = TP_0$ , and adds  $SL$  and  $ML$  to its own silence list,  $SL_0 = TP_1$ ,  $SL_1 = MP_1$ ;  $a_n (n \geq 2)$  receives management frames and adds  $RL, SL$  and  $ML$  to its own silence list,  $SL_0 = TP_0$ ,  $SL_1 = TP_1$ ,  $SL_2 = MP_1$ .
- (d)  $B$  After successful contention sends management frames to STAs, where  $b_1$  is an STA with low latency demand.  $b_1$  receives management frames and adds  $RL$  to its own reservation list,  $RL_0 = TP_1$ , and adds  $SL$  and  $ML$  to its own silence list,  $SL_0 = TP_0$ ,  $SL_1 = MP_1$ ;  $b_n (n \geq 2)$  receives management frames and adds  $RL, SL$  and  $ML$  to its own silence list,  $SL_0 = TP_0$ ,  $SL_1 = TP_1$ ,  $SL_2 = MP_1$ .
- (e) On the arrival of transmission period  $TP_0$ , the node refreshes the list to delete  $TP_0$ .  $a_1$  starts contending for the channel and the other STAs enter the silence state.
- (f) On the arrival of transmission period  $TP_1$ , the node refreshes the list to delete  $TP_1$ .  $b_1$  starts contending for the channel and the other STAs enter the silence state. At this time, the node state is similar to the state in (a), and the process will be repeated for each node in the next management period  $MP_1$ .

## 4 Performance Evaluation

### 4.1 Simulation Environment and Parameter Settings

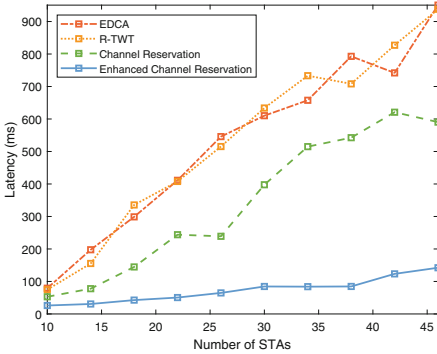
In this paper, we use the NS-3-based IEEE 802.11be network simulation platform for simulation. We validate the performance of the scheme by comparing the latency and throughput of users with low latency demand and other users respectively in four scenarios: EDCA scenario, R-TWT scenario, channel reservation scenario, and channel reservation scenario combined with management frame protection scheme (hereafter referred to as enhanced channel reservation scenario). The simulation parameters are shown in Table 1.

### 4.2 Simulation Results and Analysis

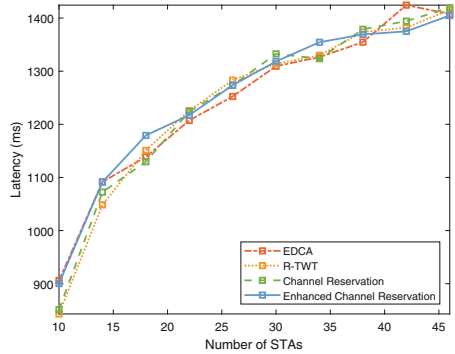
Figure 4 and Fig. 5 show the trend of the average latency of users with low latency demand and the average latency of users without low latency demand in different scenarios when the number of STAs increases in the  $2 \times 2$  multi-cell network topology, respectively. From Fig. 4 and Fig. 5 we can observe that:

**Table 1.** Simulation parameter value table.

Parameter	Value
Management period cycle	100 ms
Reserved period duration	1 ms
Number of transmission periods in the management period cycle	5
Traffic rate	1e8bps
BSS size	15×15 m
network topology	2×2
Number of AP in BSS	1
Number of user with low latency demand in BSS	1
Latency sensitive traffic access category	VI
other traffic access category	BE
VI min/max contention window	15/31
BE min/max contention window	15/1023

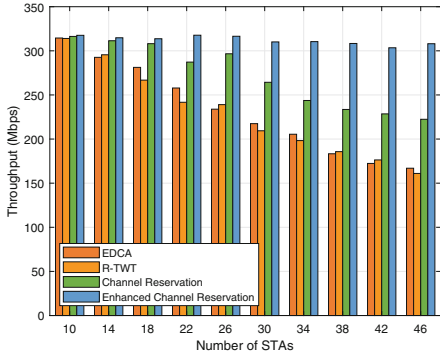


**Fig. 4.** Average latency of users with low latency demand in four scenarios of 2 × 2 network topology

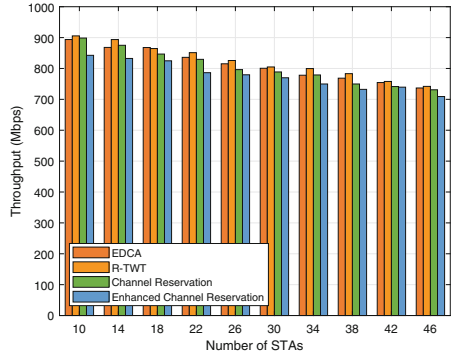


**Fig. 5.** Average latency of users without low latency demand in four scenarios of 2 × 2 network topology

- 1) For users with low latency demand. Enhanced channel reservation scenario latency is the lowest and increases slowly with a larger number of STAs. Channel reservation scenario latency is only higher than enhanced channel reservation scenario and increases faster with a larger number of STAs. EDCA scenario latency and R-TWT scenario latency are the highest, and there is no significant difference between them, both of which increase rapidly with a larger number of STAs. Therefore, when the number of STAs becomes larger, the difference between the latency of the enhanced channel reservation scenario and the other three scenarios gradually expands.
- 2) For users without low latency demand. There is no significant difference between the latency of the four scenarios. The latency increases with a larger



**Fig. 6.** Average throughput of users with low latency demand in four scenarios of  $2 \times 2$  network topology



**Fig. 7.** Average throughput of users without low latency demand in four scenarios of  $2 \times 2$  network topology

number of STAs for all four scenarios. When the number of STAs is less, the latency increases faster, and when the number of STAs is more, the latency increases slower.

Figure 6 and Fig. 7 show the trend of the average throughput of users with low latency demand and the average throughput of users without low latency demand in different scenarios when the number of STAs increases in the  $2 \times 2$  multi-cell network topology, respectively. From Fig. 6 and Fig. 7 we can observe that:

- 1) For users with low latency demand. Enhanced channel reservation scenario throughput is the highest and remains stable with a larger number of STAs. Channel reservation scenario throughput is only lower than enhanced channel reservation scenario and decreases with a larger number of STAs. EDCA scenario throughput and R-TWT scenario throughput are the lowest and there is no significant difference between them, both decrease with a larger number of STAs. Therefore, when the number of STAs becomes larger, the difference between the throughput of the enhanced channel reservation scenario and the other three scenarios gradually expands.
- 2) For users without low latency demand. The enhanced channel reservation scenario has the lowest throughput, and the channel reservation scenario throughput is only higher than the enhanced channel reservation scenario. The R-TWT scenario has the highest throughput, followed by the EDCA scenario. However, there is no significant difference between them. The throughput of all four scenarios decreases slowly as the number of STAs becomes larger.

The main reasons for the trends in Fig. 4, 5, 6 and Fig. 7 are:

- 1) For users with low latency demand, when the number of STAs becomes larger, the network environment deteriorates, leading to an increase in latency as well as a decrease in throughput. In the EDCA scenario, although users with

low latency demand enjoy the backoff parameter for easier access to the channel, they still have difficulty accessing the channel when the number of STAs is larger and are prone to conflicts, resulting in higher latency and lower throughput; in the R-TWT scenario, although it is possible to keep other users in the cell in silence during the reservation period to provide channel protection for users with low latency demand, it is incapable of managing users from external cells. Therefore, when the number of external cell users is large, channel protection is ineffective, resulting in high latency and low throughput; the channel reservation mechanism, with multi-cell coordination capability, can silence other users including external cell users during the reservation period, providing channel protection for users with low latency demand. However, when the number of STAs is large, the management frames carrying reservation information are easily lost, resulting in better delay and throughput than the above two mechanisms, but the improvement is not significant; the enhanced channel reservation mechanism, with multi-cell collaboration and management frame protection capability, can effectively avoid the loss of management frames and make users with low delay demand free from interference by other users including external cell users during the reservation period. Therefore, the latency is minimized and the throughput is maximized.

- 2) For users without low latency demand, when the number of STAs becomes larger, the network environment deteriorates, leading to an increase in latency as well as a decrease in throughput. When the number of STAs is less, the network environment is better, and the increment in the number of STAs leads to a sudden deterioration of the network environment and an intensified trend of latency increase, but the throughput decreases slowly due to the high number of STAs. When the number of STAs is more, the network environment is poor, the increment in the number of STAs only leads to a gradual deterioration of the network environment, the trend of increasing delay slows down, and the throughput still keeps decreasing slowly. In the EDCA scenario, users without low delay demand are not restricted, the throughput is higher, but the impact on delay is smaller. The R-TWT scenario silences other users in this cell during the reservation period, and the overall network conflict is reduced. For users without low latency demand, throughput is improved, but the impact on latency is smaller. In the channel reservation scenario and the enhanced channel reservation scenario, users without low latency demand cannot transmit during the reservation period, resulting in a decrease in throughput, but with a small impact on latency.

We can see from the above analysis that the proposed channel reservation mechanism combining the management frame protection scheme as compared to the EDCA mechanism, and R-TWT mechanism, can significantly improve the latency and throughput of users with low latency demand without sacrificing too much the latency and throughput of users without low latency demand.

## 5 Conclusion

To solve the interference problem of OBSSs to channel reservation in multi-cell scenarios, this paper proposes a novel channel reservation mechanism, and a management frame protection scheme to solve the management frame loss problem in multi-cell high-density scenarios. It is demonstrated through simulation that the proposed channel reservation mechanism and management frame protection scheme can effectively solve the interference problem of OBSSs and management frame loss, thus improving the latency and throughput of users with low latency demand.

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## References

1. IEEE. IEEE 802.11ax Draft Standard for Information technology Telecommunications and information exchange between systems Local and metropolitan area networks Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (2021)
2. IEEE. IEEE 802.11be (D2.0) Draft Standard for Information technology Telecommunications and information exchange between systems Local and metropolitan area networks Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (2022)
3. IEEE. IEEE 802.11ah Draft Standard for Information technology Telecommunications and information exchange between systems Local and metropolitan area networks Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (2016)
4. Choi, J., Yoo, J., Choi, S., Kim, C.: EBA: an enhancement of the IEEE 802.11 DCF via distributed reservation. *IEEE Trans. Mob. Comput.* **4**(4), 378–390 (2005). <https://doi.org/10.1109/TMC.2005.57>
5. Chao, I., Lai, C., Chung, Y.: A reservation-based distributed MAC scheme for infrastructure wireless networks. In: 2018 3rd International Conference on Intelligent Green Building and Smart Grid (IGBSG), pp. 1–4 (2018). <https://doi.org/10.1109/IGBSG.2018.8393531>
6. Ma, M., Yang, Y.: A novel contention-based MAC protocol with channel reservation for wireless LANs. *IEEE Trans. Wirel. Commun.* **7**(10), 3748 (2008). <https://doi.org/10.1109/T-WC.2008.08885>
7. Bo, L., Wenzhao, T., Hu, Z., Hui, Z.: m-DIBCR: MAC protocol with multiple-step distributed in-band channel reservation. *IEEE Commun. Lett.* **12**(1), 23–25 (2008). <https://doi.org/10.1109/LCOMM.2008.071561>
8. Li, B., Li, W., Valois, F., Ubeda, S., Zhou, H., Chen, Y.: Performance analysis of an efficient MAC protocol with multiple-step distributed in-band channel reservation. *IEEE Trans. Veh. Technol.* **59**(1), 368–382 (2010). <https://doi.org/10.1109/TVT.2009.2028029>

9. Lei, X., Rhee, S.H.: Design of a collision-free backoff method to improve the IEEE 802.11 DCF. In: 2016 Eighth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 395–397 (2016). <https://doi.org/10.1109/ICUFN.2016.7537057>
10. Lei, X.Y., Rhee, S.H.: Sender-initiated reservations for reducing collisions in 802.11 MAC. In: 2013 Fifth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 288–291 (2013). <https://doi.org/10.1109/ICUFN.2013.6614827>
11. Bankov, D., Khorov, E., Lyakhov, A., Stepanova, E.: Clock drift impact on target wake time in IEEE 802.11ax/ah networks. In: 2018 Engineering and Telecommunication (EnT-MIPT), pp. 30–34 (2018). <https://doi.org/10.1109/EnT-MIPT.2018.00014>
12. Nurchis, M., Bellalta, B.: Target wake time: scheduled access in IEEE 802.11ax WLANs. *IEEE Wirel. Commun.* **26**(2), 142–150 (2019). <https://doi.org/10.1109/MWC.2019.1800163>
13. Chen, Q., Liang, G., Weng, Z.: A target wake time based power conservation scheme for maximizing throughput in IEEE 802.11ax WLANs. In: 2019 IEEE 25th International Conference on Parallel and Distributed Systems (ICPADS), pp. 217–224 (2019). <https://doi.org/10.1109/ICPADS47876.2019.00040>
14. Chen, Q., Zhu, Y.-H.: Scheduling channel access based on target wake time mechanism in 802.11ax WLANs. *IEEE Trans. Wirel. Commun.* **20**(3), 1529–1543 (2021). <https://doi.org/10.1109/TWC.2020.3034173>
15. Qiu, W., Chen, G., Nguyen, K.N., Sehgal, A., Nayak, P., Choi, J.: Category-based 802.11ax target wake time solution. *IEEE Access* **9**, 100154–100172 (2021). <https://doi.org/10.1109/ACCESS.2021.3096940>
16. Schneider, B., Sofia, R.C., Kovatsch, M.: A proposal for time-aware scheduling in wireless industrial IoT environments. In: 2022 IEEE/IFIP Network Operations and Management Symposium, NOMS 2022, pp. 1–6 (2022). <https://doi.org/10.1109/NOMS54207.2022.9789864>
17. Chen, Q.: An energy efficient channel access with target wake time scheduling for overlapping 802.11ax basic service sets. *IEEE Internet Things J.* <https://doi.org/10.1109/JIOT.2022.316333>