# Coordinated TDMA MAC Scheme Design and Performance Evaluation for the Next Generation WLAN: IEEE 802.11be

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**Abstract.** The next generation Wireless Local Area Network (WLAN) standard: IEEE 802.11be focuses on achieving extremely high throughput (EHT). High-dense deployment network is still one challenging and important scenario for IEEE 802.11be. In order to improve quality of experience (QoE) of users in high-dense scenario, access point (AP) coordination is considered as a promising technology for IEEE 802.11be. Many researchers and engineers have proposed different specific AP coordination solutions, but the work on the performance verification of the proposed protocol is not yet fully validated. This article focuses on the detailed protocol design and performance of the Coordinated time division multiple access (co-TDMA), one type of AP coordination technologies. We design a specific simulation protocol implementation scheme, perform simulations based on the system-level and link-level integrated simulation platform, evaluate the performance of co-TDMA. Simulation results show that the co-TDMA protocol can improve the throughput and packet loss rate performance under certain network scenarios.

**Keywords:** WLAN · TDMA · AP coordination · MAC protocol

## 1 Introduction

Wireless communication technology plays an increasingly important role in our lives. Whether it is communication, entertainment or online office, wireless communication technology can bring us flexibility and convenience. With the increase of end users, the business volume of wireless communication has also increased dramatically. The ever-increasing demand for data services has also brought challenges to Wireless Local Area Network (WLAN) research. In order to bring users a better user experience, countless researchers are devoted to the research of wireless technology. The study of WLAN has always been the focus of academic and industrial attention. From the first WLAN standard released by IEEE in 1997, it has experienced more than twenty years of development [1]. IEEE 802.11ax, which is considered as the standard as WiFi 6 and will be probably


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released in 2020, introduces a number of new technologies such as uplink and downlink Orthogonal Frequency Division Multiple Access (OFDMA) technology, uplink and downlink Multi-User Multiple-Input Multiple-Output (MU-MIMO) technology, spatial reuse (SR), and etc. [2–4]. It can be seen that WLAN has made great progress [5]. In order to make a better breakthrough in WLAN technology, the researchers are still persevering and are exploring and researching on the next-generation WLAN standard: IEEE 802.11be.

IEEE 802.11be aims to extremely high throughput (EHT). It is worth noting that high-dense deployment network is still one challenging and important scenario for IEEE 802.11be [6]. It means there are many cells and the cross-cell interferences is deteriorated. It will seriously affect the performance of the entire network and the quality of experience (QoE) of users without efficient solutions [7]. In this case, the objective of extremely high throughput can hardly be achieved.

Access point (AP) coordination is considered as a promising technology for IEEE 802.11be. This technology reduces link conflicts and improves network performance. In previous studies, there were similar related technologies. Some of the related AP coordination protocols are described below. Literature [8] proposes a trigger-based Distribute Multiple-Input Multiple-Output (D-MIMO) Media Access Control (MAC) protocol. This protocol is triggered by STAs. Multiple AP performs joint transmission in D-MIMO mode, combining the advantages of D-MIMO and joint transmission to achieve reliable concurrent transmission. The protocol can meet the needs of high-speed users. Literature [9] proposes a joint reservation and coordinative MAC protocol based on ALOHA, which combines channel reservation technology and joint transmission technology, and makes full use of the advantages of channel reservation technology under reliable joint transmission. This protocol realizes the improvement of network throughput in dense network scenarios. Literature [10–13] also introduced some different protocols for coordinative transmission between AP. Coordinated time division multiple access (co-TDMA) is that multiple APs share time resources during a Transmission Opportunity (TXOP) period, that is, multiple APs are scheduled by one AP called the master AP to perform data transmission in different time periods during this TXOP period. That is to say, in a coordinative transmission, only the master AP needs to compete for the channel, and the slave AP does not need to compete for the channel again, so it gets an opportunity for data transmission and can directly perform data transmission. The most important advantage of co-TDMA is easy to implement. But, there are few studies focusing on the performance evaluation of co-TDMA. In this paper, we design a detailed MAC protocol. After that, we fully evaluate the performance of co-TDMA by our designed simulation platform. Simulation results show that the protocol designed in this article can improve network performance in certain network scenarios.

The chapter structure of this article is as follows: Section 2 discusses the motivation of this article. Section 3 introduces the design details of the protocol. Section 4 designs protocol simulation scenarios and performs protocol simulation and performance evaluation. Section 5 summarizes the work done and prospects of this article.

# 2 Motivation

## 2.1 Principle of Coordinated AP

AP coordination, as the name implies, is that multiple APs coordinated with each other to jointly perform data transmission. AP coordination technology enables more than one AP to perform data transmission in a period of time. This technology requires master AP scheduling and each slave AP to obey the master AP's scheduling instructions. Generally, the master AP notifies the slave AP after competing for the channel, and can perform data transmission together with the master AP at the opportunity of the master AP competing for the channel to complete a coordinative transmission. The transmission scenario is shown in Fig. 1.

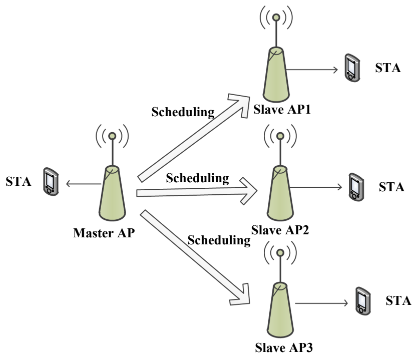


**Fig. 1.** AP coordination transmission scenario diagram

The link transmitted by the master AP is called the master link, and the link transmitted by the slave AP is called the slave link. The master link and slave link have equal opportunities for data transmission, and the two coordination with each other to jointly improve network performance. The basic transmission process is that at the beginning of transmission, each AP competes for the channel fairly through Carrier Sense Multiple Access with Collision Avoid(CSMA/CA). Once an AP competes for the channel, this AP is determined to be the master AP for this coordinative transmission. The master AP undertakes this scheduling leader role of coordinative transmission. Only if the master AP correctly implements the scheduling process, can the entire coordination process be carried out intact. Then the master AP according to network conditions, selects the slave APs for this coordinative transmission through a selection algorithm, and then the master AP sends a Trigger Frame (TF) to each slave AP to notify these slave APs and the master AP to transmit data together within a certain period of time. After receiving the TF from the master AP, it knows that it has been selected as the slave AP for this coordination transmission and starts to prepare for data transmission with the master AP. After a period of time, the master AP and the slave AP start data transmission simultaneously. Some of the proposed AP coordination protocols are described below.

Coordinated Beamforming/Null Steering (co-BF) Protocol, which proposes a beamforming/zero-direction control cooperation method. The main idea of this protocol is to use beamforming technology to coordinate the use of space resources by APs and make full use of the available array. The degree of freedom in space allows data to be transmitted between the coordinating APs simultaneously with little interference between links.

Coordinated OFDMA (co-OFDMA) protocol, the main idea of this protocol is that in a transmission, multiple APs are scheduled to each other in a downlink/uplink Multi-User, and cooperate to transmit in OFDMA mode. Different APs coordinate and use different frequency resources to achieve sharing of frequency resources.

Co-TDMA is studied in some in the proposals. The main idea of this protocol is that multiple APs share the time resources in one transmission. The master AP can jointly schedule the slave AP during the data transmission time of the master AP. During this time, The master AP and the slave AP transmit data in different time periods during this period of time. The master and slave APs share all frequency resources.

### 2.2 Motivation

The co-TDMA protocol introduces the mechanism of AP coordination, which enables multiple APs to cooperate in the same time period. The co-TDMA protocol studies how multiple APs share time resources. Because the co-TDMA protocol is easy to implement, it has received the attention of many researchers. But there are few studies on the performance verification of co-TDMA protocol. This article conducts research on this protocol flow, focusing on the specific implementation of this protocol, that is, how to implement the co-TDMA protocol flow and co-TDMA protocol performance evaluation. This article designs a specific MAC implementation scheme, and emulates this protocol flow according to the designed scheme. According to the simulation results, the performance of this protocol is discussed and evaluated.

## 3 Detailed Protocol Design for co-TDMA

This protocol is mainly for the specific protocol design of how the master AP and the slave AP share time resources during AP coordination. Set some APs as a group, each AP in the group can be the master AP when competing for the channel. Each AP can compete for the channel regardless of whether there is a service to be transmitted or not. After the competition reaches the channel as the master AP, if the master AP has a service to transmit, the master AP service will be transmitted first, and the other slave AP services will be transmitted. If the master AP has no business to transmit, it will directly transmit other slave AP services. During the transmission time of a master AP, divide this time into different time periods. The master and slave APs occupy different time periods for data transmission. In this way, the master and slave APs share this transmission opportunity of the master AP. These slave AP does not need to compete for channels, and can directly send data when the allocated time period arrives. This protocol is compared with the scenario where AP does not perform joint transmission. Protocol process is:

(1) Each AP competes for the channel fairly. The AP competing for the channel sets itself as the master AP.
(2) The main AP sends a detection frame to obtain whether other APs have services to transmit.
(3) The other APs that have uplink or downlink data to send an ACK to the master AP, indicating that it has business to transmit.
(4) The master AP sends a co-TDMA TF to each slave AP. The co-TDMA TF carries the slave AP information and the time segment information transmitted from the slave AP.
(4) If the master AP has services to transmit, the master AP starts to transmit data within the time period allocated by itself. If not, go to step 4.
(5) After receiving the TF from the master AP, the slave APs obtain the time segment information of the transmission assigned by the master AP to itself. When the time segment arrives, the corresponding slave AP becomes the TXOP holder and starts uplink and/or downlink data transmission. The slave AP have to guarantee that the transmission should finished before the next time segment start time. The process is shown in Fig. 2. After the AP contends for the channel, set the master AP, obtain the slave APs, and share the time with the slave AP in the time period of the master AP's current transmission. Data transmission takes place in different time periods within a certain period of time.

In the process of implementing this protocol, the setting of NAV is extremely important, There are two ways to solve the NAV setting problem.

(1) Newly introduce a Group NAV and a one bit indication filed named IsGroup. After the master AP competes for the channel, The slave APs receives the TF of the master AP and sets its IsGroup to TRUE, if IsGroup of the filed is TRUE, the Group NAV is allowed to be ignored for slave AP. IsGroup is FALSE at this time, the Group NAV is not allowed to be ignored, and data transmission is not possible.
(2) Newly introduce a Group NAV and modify the TF frame, that is, add a 1bit co-TDMA Indication field to the TF frame. Since the information between the master AP and the slave APs is interoperable, it is mainly necessary to solve the NAV problem of the STA. First, if the STAs associated with

the slave AP receive other frames in a Group, they need to update the Group NAV. Then, if the STA receives the TF frame sent by the slave AP it is associated with and schedules it to send uplink data, if the co-TDMA Indication field in the TF frame is set to 1, the Group NAV can be ignored, and if it is set to 0, it is not allowed to be ignored. And Group NAV should not be ignored in other situations where the TF frame is not received.

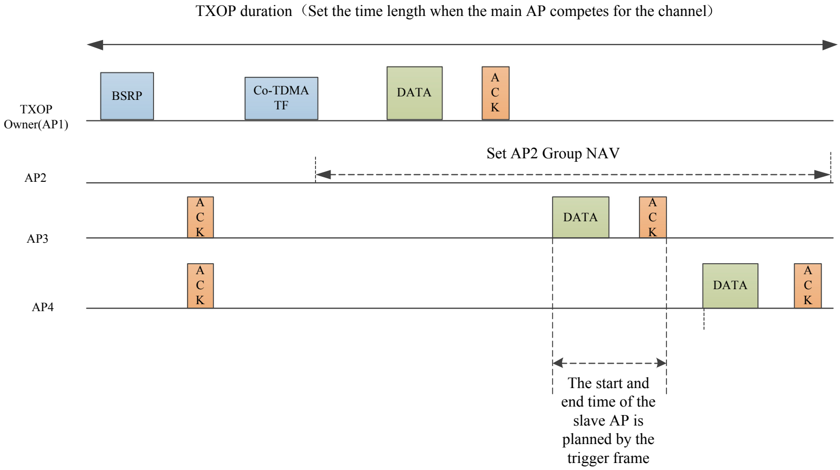


**Fig. 2.** Protocol process

# 4 Performance Evaluation

## 4.1 Simulation Scenario Configuration

Simulation on the system-level and link-level integrated simulation platform verifies the protocol proposed in this paper. By writing the MAC layer code, the MAC flow of the designed protocol is realized, the simulated network scenario is designed, and compared with the Enhanced Distributed Channel Access (EDCA) mechanism, the following simulation results are obtained, and the obtained simulation results are analyzed and evaluated. The set simulation scene configuration and parameter configuration is shown in Table 1.

## 4.2 Performance Analysis

Taking the EDCA mechanism as a comparison, under the same scenario configuration, using different simulation rates to obtain the average simulation throughput results of each cell of the two are shown in the figure. The result is shown in Fig. 3, Fig. 5, Fig. 7 and the average packet loss rate of the two is shown in Fig. 4, Fig. 6, Fig. 8.

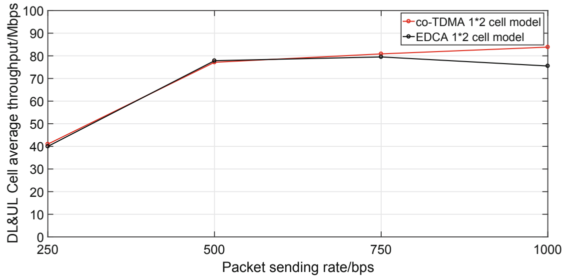


**Fig. 3.** Scene one throughput comparison.

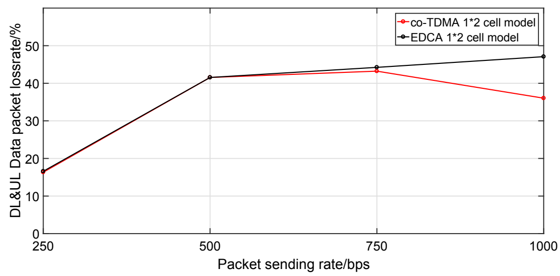


**Fig. 4.** Scene one comparison of packet loss rate.

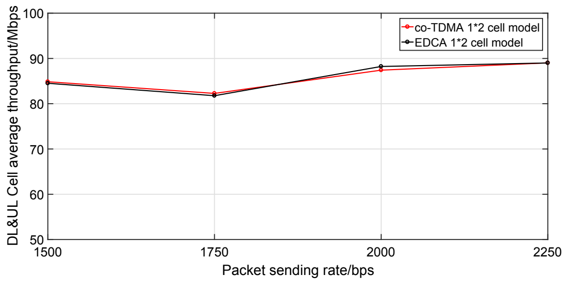


**Fig. 5.** Scene two throughput comparison.

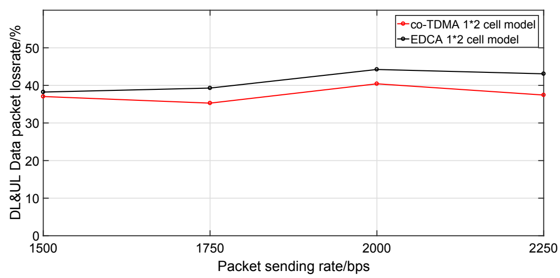


**Fig. 6.** Scene two comparison of packet loss rate.

**Table 1.** Simulation scene configuration and parameter configuration

| Simulation parameters | Parameter value |
|---|---|
| Number of cells | 2 |
| Number of APs in each cell | 1 |
| Number of STAs in each cell | 5 |
| Cell size | 15 m |
| Packet size | 1500 Byte |
| Bandwidth | 20 MHz |
| Protocol | Co-TDMA/EDCA |
| Simulation duration | 5 s |

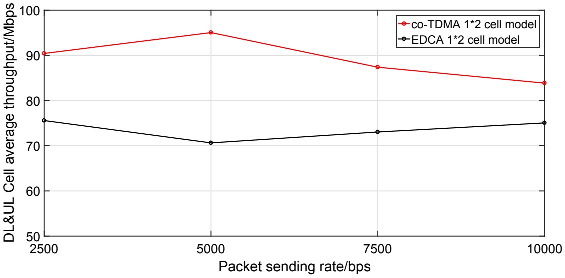


**Fig. 7.** Scene three throughput comparison.

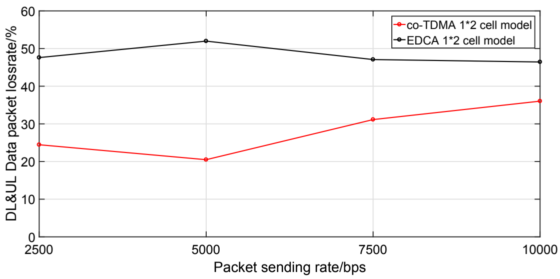


**Fig. 8.** Scene three comparison of packet loss rate.

It can be seen from the simulation results that under different simulation rates, the co-TDMA mechanism has different performance compared to the EDCA mechanism. When the simulation rate is between two hundred and fifty bps to one thousand bps, the result showns its cell network throughput and packet loss rate is basically consistent with the EDCA mechanism.

As the data packet sending rate increases, the simulation rate is between fifteen hundred bps to two thousand two hundred and fifty bps, Although the throughput of the network has increased, its network performance is still basically the same as the EDCA mechanism.

The rate of sending packets continues to increase, the simulation rate is between two thousand five hundred to ten thousand bps, the co-TDMA mechanism has a more obvious gain than the EDCA mechanism, indicating that the co-TDMA mechanism is more suitable for a network environment with relatively large competition.

## 5 Conclusion and Future Works

Based on the idea of co-TDMA protocol design, this paper designs a specific co-TDMA protocol implementation scheme, implements the co-TDMA protocol process, and evaluates the performance of this protocol. It can be seen from the simulation results that in scenarios where network traffic is relatively intensive, using the co-TDMA mechanism, compared with the EDCA mechanism, can alleviate link conflicts and improve network throughput. In scenarios where network traffic is relatively small, the co-TDMA protocol does not show any advantages. So this protocol is suitable for scenarios with dense networks. In future research, different simulation implementation schemes can be designed, and the performance of this protocol can be evaluated in multiple aspects.

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