Co-NOMA: AP Coordination Based NOMA Protocol for the Next-Generation WLANs

Zhenzhen Yan[1] · Mao Yang[1] · Xiaochang Zhang[1]

Abstract

In recent years, with the ever-increase connectivity, high-density deployment scenarios have become important scenarios for future wireless networks. Achieving extreme high throughput (EHT) in high-density deployment scenarios is the technical goal of IEEE 802.11be, the next generation wireless local area network (WLAN) standard. However, the severe interference and suppression relationship between basic service set (BSS) in the high-density deployment scenario causes the throughput of the WLAN to be very severely affected. Therefore, this paper proposes an access point (AP) coordination-based non-orthogonal multiple access (NOMA) protocol named Co-NOMA for the next generation WLANs standard. Its core idea is to transform the relationship between interference and suppression between neighboring BSS into a relationship of mutual coordination and assistance through AP coordination and NOMA methods. Specifically, this article first designed the media access control (MAC) protocol based on AP coordination technique and NOMA method. Moreover, the protocol and its frame structure have good backward compatibility. According to the theoretical analysis, the proposed AP coordination based NOMA scheme has significant performance gains which is proved in the simulation.

Keywords Wireless local area network · Non-orthogonal multiple access · AP coordination · IEEE 802.11be · Media access control

1 Introduction

The wireless local area network (WLAN) is one of the most important carriers for network services. And its latest generation standard: IEEE 802.11ax will be released in 2021. In recent years, with the ever-increase connectivity, high density deployment scenarios are important scenarios for future WLAN. According to the "2020 Global Networking Trends Report" report, the video business has become the main business in the communication network, and this trend continues to intensify. Its proportion will increase from 63% in 2019 to 76% in 2025 [1, 2]. At the same time, starting in 2019, industry and academia are working on the standardization and key technologies of the next generation WLAN: IEEE 802.11be.

The technical goal of IEEE 802.11be is to achieve extremely high throughput (EHT) in high-density deployment scenarios.

However, in a high-density deployment scenario, stations (STAs) are often located in the overlapped coverage areas of multiple basic service set (BSS) [3–16]. Therefore, the interference and collisions of STAs are more random and larger. And STAs in overlapped coverage areas of multiple BSS may be not necessarily at the edge of BSS with poor signal quality. However, due to inter BSS interference, their service qualities are seriously degraded. Thus, severe interference and suppression relationships between BSS will cause the throughput of the WLAN to be very severely affected, as shown in [17–19]. Therefore, achieving EHT in high-density deployment scenarios is very challenging [20–27].

Access points (APs) coordination is one of the key technologies of IEEE 802.11be. By mutual negotiation between APs, it enables access and transmission between multiple BSS more efficient, thus reducing mutual interference and conflict. AP coordination technologies include coordination beamforming (Co-BF), coordination joint transmission (Co-JF), coordination orthogonal frequency division multiple

✉ Mao Yang
  yangmao@nwpu.edu.cn

  Zhenzhen Yan
  yanzhenzhen@mail.nwpu.edu.cn

[1] School of Electronics and Information, Northwestern Polytechnical University, Xi'an 710072, People's Republic of China

access (Co-OFDMA), coordination spatial reuse (Co-SR), coordination time division multiple access (Co-TDMA), and other alternatives [28–35]. Among them, Co-BF method means that both the master AP and the slave APs use multiple input multiple output (MIMO) to send downlink data to their respective STAs. Co-JF method refers to the integration of multiple antenna resources with APs to jointly serve STAs from various BSS in the form of distributed MIMO. Co-OFDMA method means APs which successfully access the channel coordinate with each other add allocate frequency resources jointly. Meanwhile, each AP occupies a part of resource units (RUs) by sending downlink data or uplink data through orthogonal frequency division multiple access (OFDMA). Co-SR method performs downlink transmission or uplink transmission with respective STAs on the same channel by information exchange and negotiation between multiple APs. Co-TDMA method is that a master AP shares a transmission opportunity (TXOP) with other slave APs which all successfully access the channel. The existing AP coordination technology can alleviate the conflict and interference, but it is difficult to greatly increase the throughput.

In addition, non-orthogonal multiple access (NOMA) methods have been extensively studied in 5G, which can significantly improve throughput. The research in WLAN is relatively limited. Capture effect power control algorithms and NOMA technology are used to improve the system throughput of WLANs in a fair transmission environment [36]. An improved detection algorithm is proposed to apply the tentative decision-making of weak signals to the detection of strong signals [37]. After improving the detection of strong user signals, a more reliable decision is achieved for weak signals. Based on the joint optimization of the smart antenna-based NOMA scheme and the smart antenna-based beam distribution system, a heuristic scheduling and power distribution scheme is proposed [38]. A carrier sense multiple access (CSMA) media access control (MAC) protocol is proposed, which uses the opportunity provided by NOMA technology in the downlink access of WLANs to improve the downlink throughput [39]. A practical WLANs downlink NOMA scheme is proposed, and a prototype of the proposed NOMA scheme has been established on a wireless test bed [40]. The carrier sense multiple access/ collision avoidance (CSMA/CA) combined with NOMA client pairing (CP-NOMA) proposed which can provide more connectivity for the client in the downlink, alleviate the problem of low transmission efficiency caused by abnormal rate, and improve the efficiency of downlink transmission [41]. The first prototype of a WLAN device that supports NOMA is introduced and evaluated, which is implemented in a software-defined radio platform with backward compatibility [42]. However, the existing AP coordination, NOMA method, and other solutions do not solve the problem of difficulty in achieving EHT in high-density deployment scenarios.

On the one hand, AP coordination technology can alleviate interference and conflicts, but it is difficult to significantly increase the limit throughput. On the other hand, NOMA technology has little research on WLAN which can significantly improve network throughput, but is difficult to control interference and conflicts. Therefore, in view of the problem that the throughput of WLAN is seriously affected by the interference and suppression relationship between BSS in high-density deployment scenarios, it is difficult to achieve EHT. This paper proposes an AP coordination based NOMA protocol namely Co-NOMA for the next generation WLANs standard. By using the AP coordination technique and the NOMA method, the proposed Co-NOMA scheme transforms the relationship of interference and suppression between neighboring BSS into a relationship of mutual coordination and assistance.

The main contributions of this article are summarized as follows:

1) This paper proposes an AP coordination based NOMA method namely Co-NOMA for the next generation WLANs standard. Its core idea is to transform the relationship between interference and suppression between neighboring BSS into a relationship of mutual coordination and assistance.
2) The detailed MAC frame structures is designed. We highlight that they have good backward compatibility with IEEE 802.11be.
3) The simulation results are consistent with the theoretical analysis, and the proposed AP coordination based NONA scheme has a significant performance gain.

The composition of the rest of this article is as follows: in Section 2, we give an introduction to related work. The principle and process of the proposed Co-NOMA protocol are described in Section 3. And Section 4 shows the modeling and mathematical analysis. Then, the analysis results are verified through simulation in Section 5. Finally, we summarize the whole paper in Section 6.

2 Related Work

2.1 An Overview of IEEE 802.11be

With the promotion of the IEEE 802.11ax standard coming to an end and gradual commercialization, experts and scholars in the industry and academia have begun to study the next generation of WLAN standard: IEEE 802.11be and its key technologies.

Considering that video service is the main business in the communication network at present and even in the short term
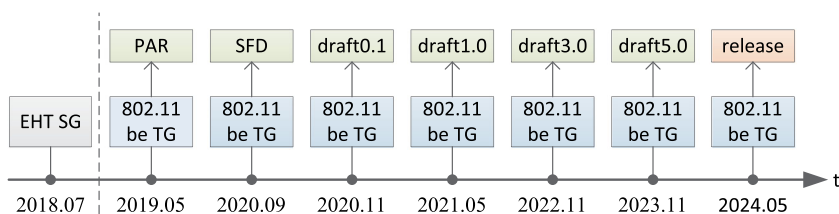
of future, the proportion of video service will increase from 63% in 2019 to 76%s in 2025 [1, 2]. Especially in recent years, the demand for 4K and other UHD video is increasingly strong, and it can be predicted that UHD video traffic will become the killer scene of the next generation of wireless networks. In addition, real-time applications have emerged in recent years and received more and more attention. For example, VR, AR, wireless video conferencing, online games, mobile cloud computing and so on are typical real-time application cases. In particular, some applications, such as VR and AR, require high speed and low latency. This puts forward the very strict request and the challenge to the wireless network. As a result, IEEE 802.11be aims to achieve EHT of 30Gbps and above in 4K streaming and online gaming scenarios, as well as improve worst-case latency and jitter.

In order to achieve these technical goals, IEEE 802.11be introduces a number of key technologies at the PHY and MAC layers, wich are PHY enhancements, multi-band operation, multi-AP coordination, enhanced link reliability, and latency and jitter guarantee. Here, the development of PHY technology is the most direct means to improve throughput. Extending the resource domain capability and improving the modulation mode are the main methods. For the frequency domain, IEEE 802.11be intends to extend the maximum transmission bandwidth from 160MHz to 320MHz. For spatial domains, IEEE 802.11be intends to increase the maximum number of spatial streams from 8 to 16. However, the adoption of multiple RUs per STA is an important improvement over IEEE 802.11be. In addition, the PHY protocol data unit (PPDU) format should be redesigned to support a range of new capabilities. Finally, multi-band operations, HARQ and other mac-layer protocols also require improved PHY technology. In addition, in terms of modulation mode, high-order modulation such as 4096 orthogonal amplitude modulation (4096-AQM) is also a possible can-

didate. Full-duplex communication can also help achieve the goal of extremely high throughput. IEEE 802.11be is planned to introduce multi-band operation on the basis of supporting three frequency bands of 2.4GHz, 5GHz and 6GHz. The core idea is that AP or STA can work in multiple bands at the same time, in order to achieve the purpose of improving throughput and ensuring latency. Among them, multi-link operation is the most important feature of multi-band operation. IEEE 802.11ax introduces spatial multiplexing technology. However, due to the lack of coordination between APs, the interference in multi-AP scenes is more serious and uncontrollable. Therefore, IEEE 802.11be plans to introduce multi-AP coordination technology, which enables multiple APs to exchange information with each other, serve STA coordinately, and optimize network performance from a more global perspective. In order to further consider transmission efficiency and link reliability, IEEE 802.11be plans to introduce HARQ technology. Although it has been used in cellular networks for many years, HARQ is the first time to be introduced into WLAN. The lack of support for delay and jitter in WLAN is also an important defect restricting the development of WLAN. Therefore, IEEE 802.11be focuses on support for latency and jitter, and plans to introduce at least one mode to improve performance in the worst-case latency and jitter.

The standardization process for IEEE 802.11be is shown in Fig. 1. The EHT SG was first established in 2018 by the IEEE 802.11 standards committee prior to the formal establishment of the working group. After in-depth research and discussion on the EHT SG, the IEEE 802.11be working group (TGBE) was established in May 2019. The specification framework document (SFD) began in 2020, and in early 2020, the TGBE agreed to divide the standardization process into two phases. IEEE 802.11be version 1.0 draft will be completed in 2021. After that, draft 3.0 and draft 5.0
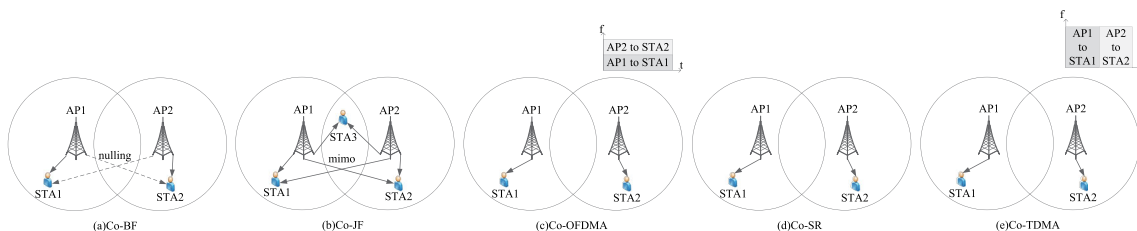
Fig. 2 Methods based on AP coordination

are expected to be completed in 2022 and 2023 respectively. IEEE 802.11be is scheduled to be officially released in May 2024. At present, IEEE 802.11be and its key technologies are in a critical period of research.

2.2 AP Coordination

In order to improve the system throughput and network resource utilization, and to avoid the mutual interference and suppression caused by lack of coordination among AP in multi-AP scenarios, IEEE 802.11be protocol introduces AP coordination technology. AP coordination technology [28–35] is designed to enable multiple APs to coordinate and assist each other to improve system network performance.

Currently, IEEE 802.11be mainly proposes five AP coordination methods, which are: coordination beamforming (Co-BF), coordination joint transmission (Co-JF), coordination OFDMA (Co-OFDMA), coordination spatial reuse (Co-SR), coordination TDMA (Co-TDMA), as shown in Fig. 2.

Co-BF refers to the fact that both a master AP and its slave APs use MIMO to send DL data to their respective STAs after a master AP has successfully connected to the channel with other slave APs. As shown in Fig. 2(a), AP1 and AP2 send data to STA1 and STA2 in MIMO mode, respectively. Because of the use of MIMO, the interference of AP1 to STA2 and AP2 to STA1 are theoretically eliminated.

Co-JT, also known as distributed MIMO (D-MIMO). In this method, a master AP and slave APs are successfully connected to the channel. By using all antennas of AP and all STAs from each BSS, the master AP and slave APs to send downlink data to multiple STAs in the manner of MIMO. Co-JT allows APs to serve STA of OBSS and allows multiple APs to serve the same STA. As shown in Fig. 2(b), the antenna resources of AP1 and AP2 are put together to serve all the STAs through MIMO, namely STA1, STA2 and STA3 from the two BSS.

Co-OFDMA refers to the mutual coordination and common allocation of frequency resources among the APs that have successfully accessed to the channel. By sending DL data or UL data simultaneously in the manner of OFDMA, each AP occupies a portion of RU, and there is no interference theoretically. As shown in Fig. 2(c), AP1 can send data from RU1 to STA1 through Co-OFDMA method. The same as AP2 which sends data from RU2 to STA2.

Co-SR is the information exchange and negotiation between multiple APs. By using this method, multiple APs use their STAs respectively in downlink or uplink transmission on the same channel. This is due to the fact that the Co-SR does not use federated MIMO and there is interference between the multiple links. In order to suppress interference, information exchange between APs is needed in order to

ensure that the interference between the two links is acceptable. As shown in Fig. 2(d), AP1 sends the downlink data to STA1 while AP2 sends the downlink data to STA2. Because there is little interference between the two links, data from both links can be received successfully.

Co-TDMA method provides a shared transmission opportunity (TXOP) between a master AP and another slave APs, all of which are successfully connected to the channel. In TXOP, different APs schedule their UL/DL transfers at different time periods. As shown in Fig. 2(e), AP1 performs the downlink transfer first, followed by AP2 performs the downlink transfer in the same TXOP.

The vast majority of existing AP coordination technologies adopt more effective method of resources allocation in order to improve throughput. For example, Co-BF divides beamforming, Co-JT divides antennas, Co-OFDMA divides frequency, Co-SR divides spatial and Co-TDMA divides time, etc. However, those orthogonal resource allocation methods are limited by the total amount of resources. If the total amount of resources is constant, the throughput improvement of the above methods is limited. On this basis, NOMA uses non-orthogonal methods to divide resources, which can significantly improve throughput.

2.3 Application of NOMA Protocol in WLAN

As a new manner of multiple access, NOMA protocol appears in wireless networks. Although there are many research achievements, most of them are confined to the theoretical exploration and performance analysis of cellular networks. So far, very limited progress has been made in the design of existing NOMA schemes applied to WLANs. And the relevant researches on the application of NOMA protocol to WLAN are as follows.

In order to improve the system throughput of WLANs in fair transmission environment, the power control algorithm of capture effect is utilized, adjusts the transmission probability of each STA adaptively in the competition window and adopts NOMA technology [36].

The continuous interference cancellation receiver is one of the important modules of NOMA protocol. An improved detection algorithm is proposed [37]. The algorithm allows the NOMA method to be used in the uplink so that the power difference between sharing resources of terminals is within a smaller range. The idea is to apply the tentative decision of weak signal to the detection of strong signal. After improving the detection of strong user signals, more reliable decisions can be made for weak signals.

In order to reduce the influence of user-to-user interference in single BSS network, two users can serve simultaneously in NOMA method based on smart antenna, and the non-overlapping beam mode can realize the reuse of spatial

resources. Due to the high computational complexity of the joint optimization of the NOMA scheme and the beam allocation system based on smart antenna in practical application, a heuristic scheduling and power allocation scheme is proposed [38]. The performance evaluation of the scheme shows that the scheme can achieve high average user throughput in high density network.

A CSMA MAC protocol and an algorithm are proposed to select an optimal user set with appropriate power allocation from a randomly selected user set, by taking advantage of the opportunity provided by NOMA technology in WLANs downlink access in order to improve downlink throughput [39]. It can be seen that the proposed NOMA protocol significantly improves the downlink throughput without significantly reducing the uplink throughput. And as the transmission power increase, the throughput gain increases. As the increase of data rate and path loss decrease, the throughput gain decreases.

A practical NOMA scheme for WLANs downlink is proposed [40]. It has three key components: preencoder design, user grouping and SIC. At the sending end, a lightweight user grouping algorithm is proposed in order to construct the downlink NOMA transmission preencoder. At the receiving end, a new SIC method without channel evaluation is proposed to decode the desired signal in the case of strong interference. The proposed NOMA scheme can significantly improve the weak user data rate and the WLAN weighted sum rate. A prototype of the proposed NOMA scheme has been established on a wireless test bed.

Compared with the traditional CSMA/CA, the proposed CSMA/CA combined with NOMA client pair. It can provide more connectivity for clients in the downlink, alleviate the problem of low transmission efficiency caused by abnormal rate, and improve the efficiency of downlink transmission [41]. The method is compatible with the traditional CSMA/CA system. In addition, enabling technologies that support more client connections are vary considerably in internet of things (IoT) applications.

The first prototype of WLAN devices is described and evaluated which supports NOMA method [42]. The device is implemented in a software-defined radio platform. The prototype is backward compatible with the traditional WLAN version, where one of the multiplexed streams may be received by legacy stations that do not support NOMA method. This feature benefits heterogeneous deployment of different generations of WLAN devices.

To sum up, the existing MAC protocols cannot take full advantage of the opportunities brought by NOMA technology in the power domain of WLANs. It is urgent to propose a new MAC protocol based on NOMA technology of WLANs.

3 Protocol Design

3.1 Basic Ideas

In the scenario of high-density deployment in WLANs, STAs are usually located in the overlapped coverage area of multiple BSS. As a result, STAs are subject to more randomness and greater interference. But at the same time, STAs have more opportunities to be accessed. Moreover, STAs in the overlapped coverage area of multiple BSS are not necessarily at the edge of BSS which have poor signal quality. So, the signal quality is basically good.

In the high-density deployment scenario, the throughput of WLAN will be seriously affected by the interference and suppression relationship between BSS. In the overlapped coverage area of multiple BSS, it is better that one STA is working while other STAs are not working. It is better for other STAs to help the STA transmit some data than not work. Therefore, this paper proposes an AP coordination based NOMA scheme which names Co-NOMA for the next generation WLANs standard. The core idea of this protocol is to transform the interference and inhibition relationship between neighboring BSS into a relationship of mutual coordination and help through AP coordination and NOMA protocol. That is to say, when a STA transmits data, other STAs can also transmit some data for the STA through power allocation, so as to improve the system throughput.

The proposed Co-NOMA protocol mainly includes the following three stages.

1) The first phase is the establishment of AP coordination. First, the master AP needs to send a beacon frame which contains the group information based on the AP coordination to STAs in the BSS. Then, STAs selects the appropriate slave AP from the coordination group and interacts with the slave AP to confirm that AP coordination can be carried out. After the mutual confirmation is completed, the STAs report to the master AP. Finally, the master AP confirms receipt of AP coordination information sent by STAs.

2) The second phase is the collection of the requirement information in AP coordination uplink transmission. The master AP asks STAs about the requirements of AP coordination uplink transmission. Then, STAs send the requirement information of AP coordination uplink transmission to the master AP.

3) The third phase is the uplink transmission of AP coordination. Based on the AP coordination established in the first phase and the requirement information of AP

coordination uplink transmission collected in the second phase, the AP coordination uplink transmission is performed. Moreover, the proposed Co-NOMA scheme can be selected whether to use according to the power that is allocated to both the master AP and the slave AP or only the master AP. That is, when all power is allocated to the master AP, the traditional uplink transmission is perform. When power is assigned to both the master AP and the slave AP, uplink transmission is carried out according to the proposed Co-NOMA protocol.

In addition, the proposed Co-NOMA protocol has good backward compatibility.

3.2 Details

The proposed Co-NOMA scheme mainly includes three stages, which are AP coordination setup stage, AP coordination information collection stage, and AP coordination transmission stage as shown in Alg. 1 and Fig. 3. In Alg. 1, master AP is represented by M-AP and slave AP is represented by Co-AP.

Algorithm 1 Steps of AP coordination based NOMA protocol

Input: transmit data
Output: receive data
1: beacon frames carry AP coordination group information
2: **while** a M-AP sends beacon frames to all STAs in its BSS **do**
3:   **if** a STA selects a Co-AP from AP coordination group **then**
4:     the STA sends a slave association request frame to the Co-AP
5:     the Co-AP sends a slave association response frame to the STA
6:     the STA sends a slave association report frame to the M-AP
7:     the M-AP responds a ACK frame to the STA
8:     **while** the M-AP sends enhanced TF-BSRP frames to all STAs **do**
9:       the M-AP collect uplink transmission requirement
10:      all STAs transmit BSR frames to the M-AP to report coordination information
11:      the M-AP sends eTF frames to all STAs with schedule information
12:      **if** RU assignment in NOMA form **then**
13:        perform uplink transmission based on AP coordination based NOMA scheme
14:        the M-AP and the Co-AP send MBA frames to the STA
15:      **else**
16:        perform uplink transmission using the original scheme
17:        the M-AP sends MBA frames to the STAs
18:      **end if**
19:    **end while**
20: **end if**
21: **end while**

3.2.1 AP Coordination Setup Stage

The establishment stage of AP coordination includes the following five steps, as shown in Fig. 3.

Firstly, the group message of AP coordination is notified. The master AP sends beacon frames to all STAs in the BSS to start the transmission of AP coordination. The beacon frame contains group information of AP coordination.

Secondary, the establishment of AP coordination is requested. The STA which get the transmission opportunity selects a slave AP from the AP coordination group and send a slave coordination request frame to a slave AP in order to request the establishment of AP coordination.

Next, it is a response to AP coordination. The slave AP sends slave coordination response frames to STAs in response to the request of AP coordination.

Then, the AP coordination information is reported. STAs send slave coordination report frames to the master AP. The slave coordination report frame contains the information of AP coordination and reports it to the master AP.

Last, the information of AP coordination is responded. The master AP sends ACK frames to STAs in order to confirm the information of AP coordination has been received.

The completion of the above steps marks the establishment of AP coordination. Then, the requirement information of uplink transmission based on AP coordination will be collected.

3.2.2 AP Coordination Information Collection Stage

In uplink transmission, the collection stage of demand information based on the AP coordination mainly includes the following two steps, as shown in Fig. 3.

First, the collection of requirements information based on the AP coordination is triggered. In uplink transmission, the master AP sends eBSRP frames to all STAs in the BSS to collect the requirement information of AP coordination. The eBSRP frame is modified on the basis of the BSRP frame in IEEE 802.11be protocol. As there are often multiple STAs in a BSS, the AP coordination uplink transmission is often concurrent.

And then, it is to report the requirement information for AP coordination uplink transfer. In the BSS, all STAs report the information of AP coordination to the master AP respectively via eBSR frames. The eBSR frame is modified on the basis of the BSR frame in IEEE 802.11be protocol.

Here, the requirement information of AP coordination uplink transmission is completed collection. On this basis, AP coordination uplink transmission can be carried out.
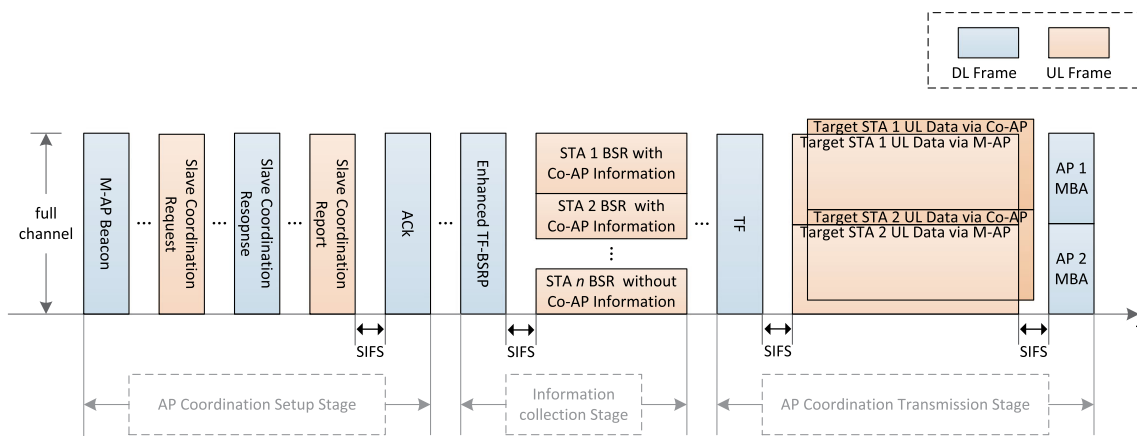
Fig. 3 The sequence diagram of the Co-NOMA protocol

3.2.3 AP Coordination Transmission Stage

The uplink transmission stage of AP coordination includes the following three parts, as shown in Fig. 3.

First of all, the uplink transfer of AP coordination is triggered. In order to initiate the uplink transfer of AP coordination, the master AP sends enhance-TF (eTF) frames to all STAs in the BSS which contain scheduling information and RU allocation information. The eTF frame is modified on the basis of TF in IEEE 802.11be protocol and has good compatibility. In the information carried by the eTF frame, if the STA assigned to RU is in the form of NOMA, the address of the slave AP needs to be indicated. Otherwise, there is no need to indicate the address of the slave AP.

Secondly, the coordination uplink transmission is performed. In the step, if all the power is allocated to the master AP, the legacy uplink transmission is performed. Otherwise, if the power master is allocated to the master AP and the slave AP proportionally, the uplink transmission based on

the proposed Co-NOMA protocol is performed. Here, STAs transmit two independent Trigger based protocol data units (TB PPDU). The PPDU which is sent to the master AP fills the information which relevant to master AP into TB preamble (such as BSS color) and A-MPDU. Meanwhile, the PPDU which is sent to the slave AP fills the information which relevant to the slave AP into TB preamble (such as BSS color) and A-MPDU. For example, in the PPDU transmitted to the master AP, the BSS color of HE SIG-A in IEEE 802.11ax format or that of U-SIG in IEEE 802.11be format will be filled with that of the master AP. In the same way, in the PPDU assigned to the slave AP, the BSS color will be filled with that of slave AP. The corresponding PPDU of the master AP and the slave AP can be analyzed respectively by using SIC in the manner of NOMA method. Therefore, the method proposed in this paper has good downward compatibility.

Last, a response of uplink transmission based on the AP coordination is performed. If the legacy uplink transmission is performed, the master AP sends MBA frames to STAs
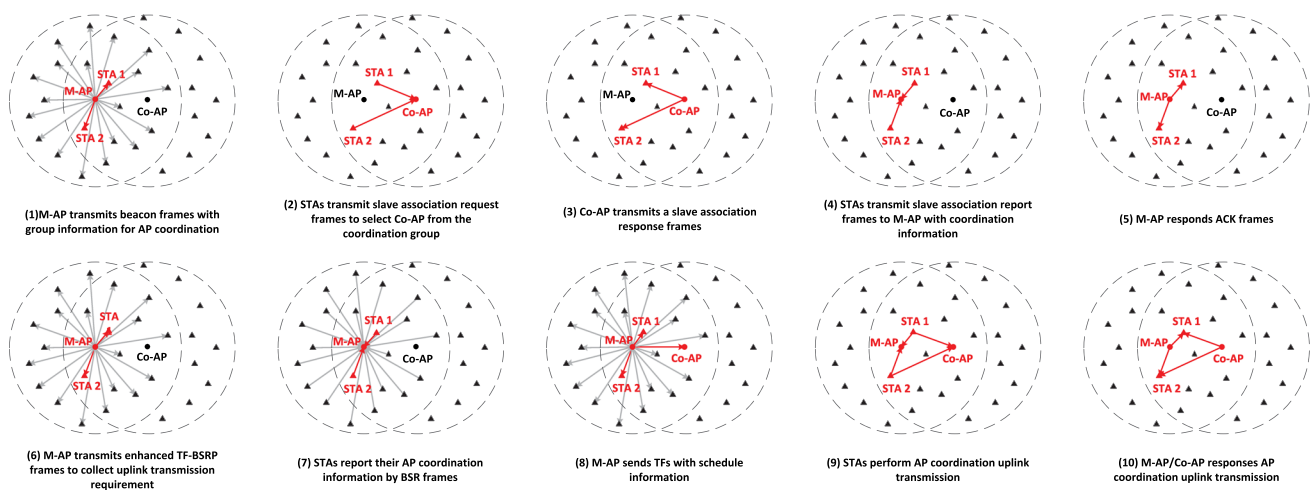

Fig. 4 The example diagram of the Co-NOMA protocol

based on the transmission result of the previous step. If the uplink transmission of Co-NOMA protocol is performed, the master AP and the slave AP send MBA frames of uplink transmission based on the AP coordination to STAs respectively.

So far, the uplink transmission of the proposed Co-NOMA protocol has been completed. Using the protocol, the interference and suppression relationship between BSS in the high-density deployment scenario can be transformed into the relationship of mutual coordination and assistance, so as to improve the throughput.

3.2.4 Example

In order to more clearly demonstrate the proposed Co-NOMA protocol, this paper presents a concrete example of this protocol as shown in Fig. 4.

Where, master AP is represented by M-AP, slave AP is represented by Co-AP. Two STAs are randomly selected from the BSS and called STA1 and STA2 respectively. Here is an example of STA1.

M-AP transmits beacon frames containing group information of AP coordination to all STAs in its BSS in order to trigger the AP coordination process, as shown in Fig. 4(1). The group information of AP coordination includes all the APs which APs can be used as slave APs.

When STA1 get the transmission opportunity, it selects a Co-AP from the group of AP coordination to transmit slave association request frames, as shown in Fig. 4(2).

The selected Co-AP transmits slave association response frame to STA1, indicating that AP coordination can be established, as shown in Fig. 4(3).

After STA1 gets the response that Co-AP can establish AP coordination, it transmits a slave coordination report frame containing AP coordination information to M-AP, which indicates the Co-AP participating in AP coordination as shown in Fig. 4(4).

M-AP sends an ACK reply frame to STA1, indicating receiving of the above AP coordination information, as shown in Fig. 4(5). Here, the establishment of AP coordination part is completed, and the operation of the next stage can be carried out.

After finishing the establishment of AP coordination, M-AP transmits enhanced TF-BSRP (eBSRP) frames to all STAs in its BSS to collect the uplink transmission requirements of AP coordination, as shown in Fig. 4(6). The eBSRP frame is modified on the basis of BSRP frame, a special TF frame in IEEE 802.11be protocol, and it has good compatibility.

All STAs within the BSS report their AP coordination information by sending the enhance BSR (eBSR) frame to M-AP respectively, as shown in Fig. 4(7). The eBSR frame

is the response frame of eBSRP frame which instructs uplink transmission request of the AP coordination. It is modified on the basis of BSR frame in IEEE 802.11be protocol and has good compatibility. The requirement information of AP coordination uplink transmission is uploaded to M-AP through eBSR frame. Then, the demand information of AP coordination uplink transmission has been collected and completed the interaction, and the operation of the next stage can be carried out.

M-AP sends an eTF frame with scheduling information to all STAs in the BSS and the selected Co-AP, as shown in Fig. 4(8). Here, the eTF frame is modified from the TF of IEEE 802.11be protocol and has good compatibility.

According to the result of power allocation, STA1 performs AP coordination uplink transmission through M-AP and Co-AP, as shown in Fig. 4(9). If both M-AP and Co-AP have been allocated power, the uplink transmission of the proposed Co-NOMA method will be performed. If only M-AP has been allocated power and Co-AP is not, the legacy uplink transfer will be performed.

M-AP and Co-AP send MBA frames of AP coordination uplink transmission to STA1 respectively, as shown in Fig. 4(10). When the uplink transmission of the proposed Co-NOMA method is completed, M-AP and Co-AP send MBA frames to STA1 respectively. After performing the legacy uplink transmission, M-AP sends a MBA frame to STA1. Then, the uplink transmission process of the proposed Co-NOMA protocol will been completed.

Through the above steps, the whole uplink transmission process of Co-NOMA protocol can be clearly seen.

3.3 MAC Frame Structure

3.3.1 eTF Frame

In order to maintain good compatibility, the eTF frame in this paper is modified based on the TF frame of IEEE 802.11be protocol. Besides MAC header field, the two most important parts of the TF frame of IEEE 802.11be protocol are common info field and user info list. Among them, common info field configures the key parameters required for this TF frame, such as TF frame type, uplink transmission duration, etc. User info list consists of a series of user info fields. In IEEE 802.11be protocol, each user info field allocates OFDMA RU to a specific user and controls some transmission parameters, such as power, MCS, etc.

On the basis of TF frame of IEEE 802.11be protocol, the eTF in this paper needs to be enhanced as follows:

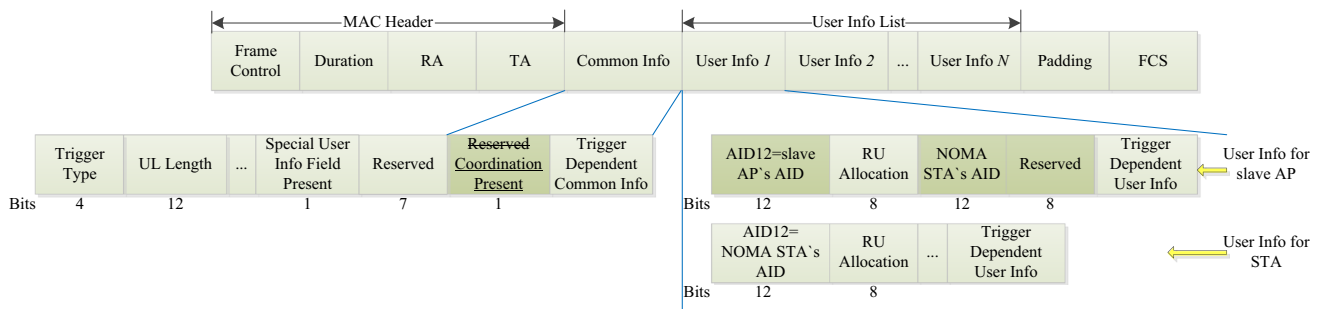1) It needs to indicate that this TF frame is eTF frame, so slave AP needs to parse this frame;

Fig. 5 The frame format of the eTF frame

2) It needs to instruct that slave AP is prepared to receive uplink data for STA on a specific RU;
3) A specific STA needs to be instructed to send uplink data to multiple APs in the manner of NOMA on multiple RU;
4) It needs to indicate for a particular STA which slave AP to send uplink data to.

As shown in Fig. 5, enhancement methods of frame structure are as follows:

First, the 63rd bit in the common info field of the IEEE 802.11be TF frame was previously reserved. In eTF frame, the bit becomes the coordination present field. The field setting 1 indicates that this frame is eTF frame. In the subsequent user info list, a specific STA will be scheduled to send uplink data to slave AP. Thus, slave AP needs to continue to parse the subsequent user info list of this eTF. The field set to 0 means that this frame is a traditional TF frame, so slave AP does not need to continue to parse the subsequent user info list.

Secondly, if the auxiliary ID (AID) 12 field in user info field is filled with the AID of slave AP, it means that this slave AP needs to receive the uplink data sent from STAs on the corresponding RU of the RU allocation field. The 12 bits after the RU allocation field are used to indicate the STA AID that needs to be sent to the slave AP. It is worth noting that AID of slave AP must not be repeated with AID of STA. In addition, the STA also needs to read this domain so as to know which RU it needs to send uplink data to which slave AP, and the BSSID of this slave AP needs to be taken as the destination address in the uplink MAC packet.

Thirdly, the format of the user info field corresponding to the STA does not need additional modification. However,

the difference with IEEE 802.11be is that if the STA finds that it is scheduled to transmit to the slave AP in the user info corresponding to the previous slave AP, it needs to send packets to the master AP and the corresponding slave AP simultaneously in the same way as NOMA.

The eTF frame has good compatibility. AP can schedule both STAs with the capabilities of the proposed Co-NOMA scheme in this paper and STAs with only the capabilities of IEEE 802.11be at the same time. For STAs with only the capabilities of IEEE 802.11be receive eTF frames, they will no longer parse if the AID fields of the user info field in TF frames do not match their AID fields. Thus, STAs of IEEE 802.11be does not lead to a misunderstanding in the interpretation of frame structure.

3.3.2 eBSRP and eBSR Frames

In IEEE 802.11be, BSRP frame is a special kind of TF frame. That is, BSRP frame and TF frame are generally the same format. As shown in Fig. 6, the common info field of a TF frame has a TF type field. When the value of TF type field is 4, it represents BSRP. Also, this paper changes the 39th bit of the user info field from reserved bit to NOMA required field. If the value of this field is 1, it indicates that the STA is required to feedback the BSR with NOMA requirements. If the value of this field is 0, it represents the traditional BSPR.

In IEEE 802.11be, BSR frame is one of the a-control frame types, and its control ID is 3. As shown in Fig. 7, the changes of eBSR frame are as follows. First, the highest bit in the queue size high field is set as the NOMA required field. If the value of this bit is 1, it indicates that the NOMA requirement is required, and if the value of this bit is 0, it means that the
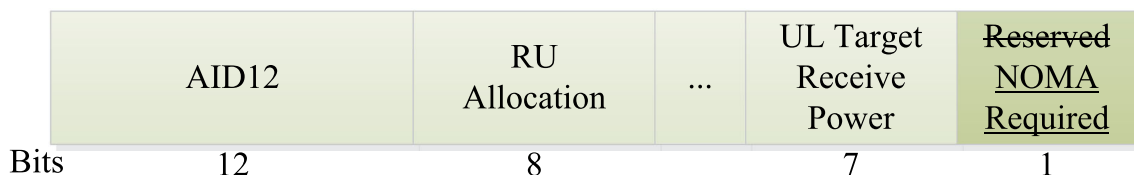

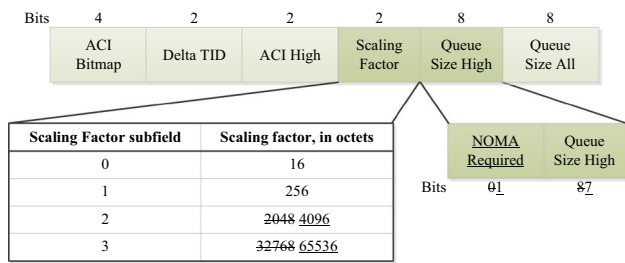**Fig. 6** The frame format of the eBSRP frame

Fig. 7 The frame format of the eBSR frame

Fig. 9 The frame format of the slave coordination report element

NOMA requirement is not required. Since the occupying of the highest bit in the original queue size high domain would lead to a narrowing of the size range of the represented buffer, the values of the two scaling factors in the scaling factor domain were doubled in this paper to ensure the consistency of the maximum indication length.

In IEEE 802.11be, STAs must be issued according to the traditional BSR format. And APs know the version of STAs which are STAs with the capabilities of the proposed Co-NOMA scheme in this paper or STAs with only the capabilities of IEEE 802.11be. When APs send BSRP frames to STAs with only the capabilities of IEEE 802.11be, STAs need to reply with BSR frames. When APs send BSRP frames to STAs with the capabilities of the proposed Co-NOMA scheme in this article, STAs needs to respond with eBSR frames. Therefore, neither AP nor STAs leads ambiguity and misunderstanding. And those frames have good compatibility.

3.3.3 Multiple Coordination Management Frames

A slave coordination element is added to the slave coordination request frame and slave coordination response frame, and its frame structure is shown in Fig. 8. Among them, master BSSID represents the BSSID of master AP associated with this STA, coordination reason represents the possible reasons for multiple coordinations, such as large traffic volume, poor channel quality, etc., and coordination duration control represents the time associated with slave AP. For the slave coordination request frame, the value of coordination duration control represents the time when the STA applies to the slave AP. For the slave coordination response frame, the value of coordination duration control means the slave AP finally determining the duration that STA can be associated with. A value of it is 0 meaning no coordination is allowed. Thus, STA must withdraw from the coordination relationship with this slave AP after this time.
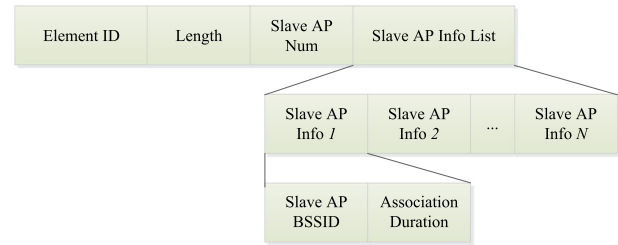
The slave coordination report frame is used by the STA to feedback the situation of its coordination with other slave APs to the master AP, and a slave coordination report element is required to be carried in this frame, as shown in Fig. 9. Where, slave AP num represents the number of slave AP associated by the STA, followed by a slave AP info list composed of one or more slave AP info fields, and the number of slave AP info fields is equal to the value of slave AP num plus 1. The slave AP info field consists of the slave AP BSSID field and the coordination duration field.

Because slave coordination element and slave coordination report element are new elements, STAs with only the capabilities of IEEE 802.11be do not parse them. Therefore, no ambiguity and misunderstanding will be caused.

4 Modeling and Mathematical Analysis

4.1 System Model

In uplink transmission of the AP coordination based NOMA protocol, the signal that the target STA sends to the M-AP is assumed to be x_1, and the signal sent to the Co-AP signal is assumed to be x_2, and $E[|x_i|^2] = 1, i = 1, 2$.

Therefore, the transmitting signal of the target STA is assumed to be x, which can be expressed as:

$$x = \sqrt{P_1} \cdot x_1 + \sqrt{P_2} \cdot x_2 \tag{1}$$

The receiving signals of the M-AP and the Co-AP are assumed to be y_1, y_2 respectively, and $y_i(i = 1, 2)$ can be expressed as:

$$y_i = h_i \cdot x + n_0, i = 1, 2 \tag{2}$$

Whereinto, $h_i(i = 1, 2)$ is the channel coefficient between the target STA and the M-AP or between the target STA and

Fig. 8 The frame format of the slave coordination element

the Co-AP. It is assumed that their corresponding additive white gaussian noise are the same and both of them are n_0.

Considering that the target STA sends signals to the M-AP and the Co-AP through the NOMA method, since the target STA is far closer to the M-AP than the Co-AP, most of the transmitting power is allocated to the Co-AP which is assumed to be P_2 while a small part of the transmitting power is allocated to the M-AP which is assumed to be P_1. Assuming that the maximum transmitting power is P_0, the relationship between P_1 and P_2 is as follows:

$$P_1 + P_2 = P_0 \tag{3}$$

When decoding at the receiver, the part of Co-AP is decoded at first. According to Shannon's formula, the receiving capacity of Co-AP can be obtained as follows:

$$C_2 = log_2(1 + \frac{P_2 \cdot |h_2|^2}{n_0}) \tag{4}$$

After that, the part of the M-AP is decoded according to the part of the Co-AP. Similarly, according to Shannon's formula, the receiving capacity of the M-AP can be obtained as shown below:

$$C_1 = log_2(1 + \frac{P_1 \cdot |h_1|^2}{P_2 \cdot |h_1|^2 + n_0}) \tag{5}$$

The total receiving capacity is shown as follows:

$$C_0 = C_1 + C_2 \tag{6}$$

As can be seen from Eqs. 4, 5 and 6, the power allocated to both the M-AP and the Co-AP can greatly affect the system performance.

Therefore, we use the modulation and coding scheme (MCS) for data transmission of the proposed protocol. The system performance is improved by adjusting the power allocated to both the M-AP and the Co-AP, that is, by adjusting the transmitting power distribution ratio $\frac{P_1}{P_2}$ to maximize the rate.

4.2 Theoretical Analysis

Because of its strong advantages in improving data transmission rate, link adaptive technology has become one of the research hotspots and key technologies of communication in current and the future. The link adaptive technology involved in the proposed scheme includes MCS and power control technology. MCS can adjust the transmission rate according to the change of channel. When the channel condition is good, this technique can improve the MCS grade and rate. When the channel condition is relatively poor, this technology can

reduce the MCS grade and rate. Power control technology can adjust the transmitting power according to the change of channel. When the channel condition is good, this technique can reduce the transmitting power. On the contrary, when the channel condition is relatively poor, the technology can also improve the transmitting power. Therefore, the proposed AP coordination based NOMA protocol not only needs to allocate power to the M-AP and the Co-AP, but also needs to appropriately reduce the MCS grade.

MCS is a collection of different modulation schemes, encoding schemes and data transmission rates determined by them. Any of these combinations is a MCS grade, which can also be called a modulation encoding strategy. Assuming that there are N_S MCS grades, denoted as $\{MCS_1, MCS_2, ..., MCS_{N_S}\}$, and the corresponding rate is denoted as $\{r_1, r_2, ..., r_{N_S}\}$, and the higher the level is, the higher the rate is. The corresponding threshold of signal to interference plus noise ratio (SINR) is denoted as $\{SR_1, SR_2, ..., SR_{N_S}\}$. Here, the SINR threshold of each MCS grade can be judged according to the packet loss rate of 0.05. The above detailed contents are shown in Table 1.

The received power of the M-AP is assumed to be P_M, and that of the Co-AP is assumed to be P_{Co}. According to the fading model of the channel based on the system, P_M and P_{Co} can be respectively expressed as follows:

$$P_M = P_1 \cdot d_1^{-\alpha} \tag{7}$$

$$P_{Co} = P_2 \cdot d_2^{-\alpha} \tag{8}$$

Where, d_1 is the distance between the target STA and the M-AP, and d_2 is the distance between the target STA and the Co-AP. α represents the path loss factor.

In order to improve the system performance, the total received power needs to be maximized. As a result,

Table 1 MCS index (20MHz)

MCS index	Data rate (Mbps)	SINR
0	8.6	
1	17.2	4.0
2	25.8	6.6
3	34.4	10
4	51.6	13
5	68.8	17.4
6	77.4	18.8
7	86.0	20
8	103.2	24.1
9	114.7	25.6
10	129.0	31.5
11	143.4	35.2

Objective function:

$$maximize \quad P = P_M + P_{Co} \quad (9)$$

Where P represents the total power of the receiver. By optimizing the allocation of P_M and P_{Co}, the objective function can be maximized. In other words, the transmitting rates of both M-AP and Co-AP need to be optimize. Therefore, the objective function can be transformed into:

$$maximize \quad r_i + r_j \quad (10)$$

At each MCS grade, the rate and the SINR threshold correspond one to one. In order to optimize Eq. 10, the optimal MCS grade needs to be found. However, it is also subject to:

Constraint functions:

$$SR_i \le \frac{P_M}{n_0} = \frac{P_1 \cdot d_1^{-\alpha}}{n_0} \quad (11)$$

$$SR_j \le \frac{P_{Co}}{n_0 + P_1 \cdot d_2^{-\alpha}} = \frac{P_2 \cdot d_2^{-\alpha}}{n_0 + P_1 \cdot d_2^{-\alpha}} \quad (12)$$

$$0 \le P_1 \le P_0 \quad (13)$$

$$0 \le P_2 \le P_0 \quad (14)$$

$$i = 1, 2, ..., N_S \quad (15)$$

$$j = 1, 2, ..., N_S \quad (16)$$

Among them, Eqs. 11 and 12 are the ranges of the M-AP and the Co-AP respectively. Similarly, Eqs. 13 and 14 represent the ranges of P_1 and P_2 respectively. The value range of i and j is shown as Eqs. 15 and 16 respectively.

To solve the above problems, Shannon's formula can be used to find the optimal P_1 and P_2. And according to Eqs. 4 and 5, the actual receiving capacity of Co-AP and that of the M-AP can be obtained as follows:

$$C_{Co} = log_2(1 + \frac{P_{Co}}{n_0}) \quad (17)$$

$$C_M = log_2(1 + \frac{P_M}{P_2 \cdot d_2^{-\alpha} + n_0}) \quad (18)$$

The actual total receiving capacity is shown as follows:

$$C = C_M + C_{Co} \quad (19)$$

Substituting Eqs. 3, 7 and 8 into Eq. 19, the following Eq. 20 can be obtained:

$$C = log_2(1 + \frac{P_2 \cdot d_2^{-\alpha}}{n_0}) + log_2(1 + \frac{(P_0 - P_2) \cdot d_1^{-\alpha}}{P_2 \cdot d_1^{-\alpha} + n_0}) \quad (20)$$

By taking the derivative of Eq. 20, the optimal P_1 and P_2 can be obtained. Then, combining with Eqs. 11, 12, 15 and 1 and Table 1, the enumeration method can be used to find the optimal solution through simulation.

5 Performance Evaluation

5.1 Simulation Settings

The simulation platform is built based on the proposed Co-NOMA protocol. Simulation considers to establish a network with some adjacent BSS. Each BSS is a square area with sides of 20 meters. Its AP is located in the center of each BSS while STAs are stochastically distributed. Simulation parameters are set according to the relevant standards and the typical configurations of IEEE 802.11ax. Specific simulation parameters are summarized in Table 2.

In simulation scenarios, the influences of three factors on throughput of both the proposed Co-NOMA scheme and two comparison schemes under two deployment scenarios are studied respectively. Two comparison schemes are the IEEE 802.11ax OFDMA scheme without AP coordination and NOMA method and the AP coordination based OMA method. Three factors are the number of STAs per BSS, the number of RUs per BSS namely the maximum number of accessible STAs per BSS and the uplink length. One of these two scenarios is the STAs super-dense deployment scenario, which is defined in this paper as that the communication range of APs can cover almost all STAs in the neighboring BSS, and the other is the STAs general intensive deployment scenario, which is similarly defined in this paper as that the communication range of APs can cover part of STAs in the neighboring BSS. For example, in this simulation, the

Table 2 Simulation parameters

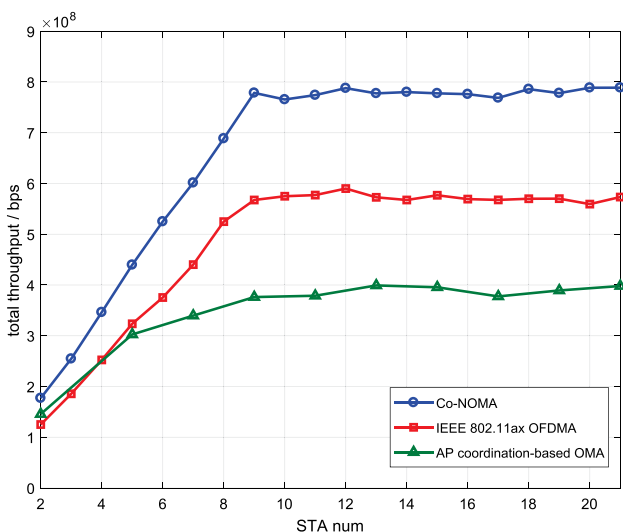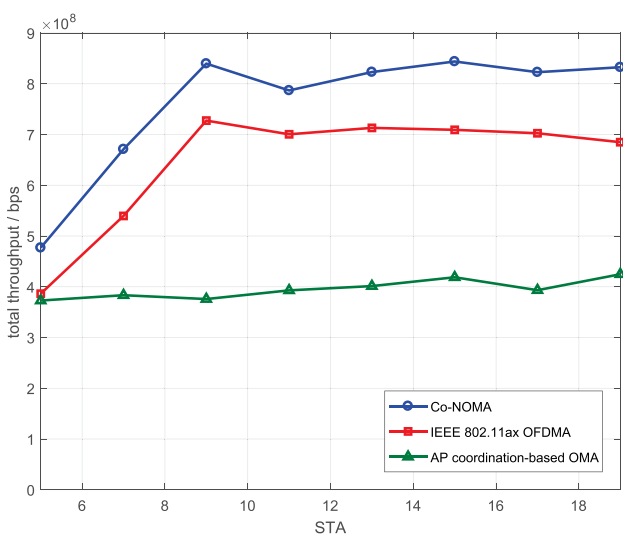| Parameters	Value
Total simulation time	2500 ms
Bit sequences length	1000 bits
Available bandwidth	320 MHz
Bandwidth per RU	20 MHz
Channel coding	LDPC, $\frac{1}{2}$ coding rate
The rate of STAs to their M-AP	68.8 Mbps
The rate of STAs to their Co-AP	25.8 Mbps

Fig. 10 Total throughput of two BSS under STAs super-dense deployment scenario versus the number of STAs per BSS

In the STAs super-dense deployment scenario, the total throughput curves of two BSS in each of the three schemes are shown in Fig. 10. Obviously, the total throughput performance of the proposed Co-NOMA scheme performs optimally than that of the other two methods. As the number of STAs in the BSS increases, the total throughput of two BSS using three schemes all continues to grow until nearly all the RUs in the BSS has been allocated. Then the total throughput of each scheme remains roughly the same. However, as the AP coordination based OMA solution does not use the NOMA method resulting in more interference and inhibition, the proposed scheme is significantly superior to the other two approaches.

Figure 11 shows total throughput curves of four BSS in the STAs super-dense deployment scenario. It is obvious that the total throughput performance of the proposed Co-NOMA scheme is superior to that of the other two schemes. The throughput curve of four BSS shows the same trend as that of two BSS above. As the number of STAs in the BSS increases, the total throughput of four BSS using three schemes all continues to increase until almost all the RUs in the BSS is basically allocated. After that, the total throughput of the three schemes all remains basically the same.

communication range of APs can cover $\frac{1}{3}$ of STAs in the neighboring BSS.

5.2 Simulation Performance Analysis of STAs Super-Dense Deployment Scenario

5.2.1 The impact of the number of STAs per BSS on performance

Let's assume that the number of RUs per BSS is 9 and the uplink length is 128 slots. This paper changes the number of STAs per BSS and records the total throughput of the three schemes respectively.

5.2.2 The Impact of the Number of RUs per BSS on Performance

Let's assume that the number of STAs per BSS is 9 and the uplink length is 128 slots. Then this paper changes the number of RUs per BSS and records the total throughput of the three schemes respectively.

Figure 12 shows total throughput curves of two BSS based on the three schemes in the STAs super-dense deploy-

Fig. 11 Total throughput of four BSS under STAs super-dense deployment scenario versus the number of STAs per BSS
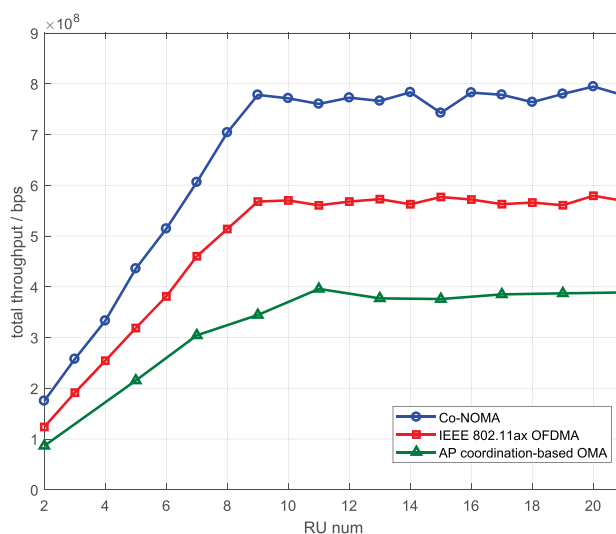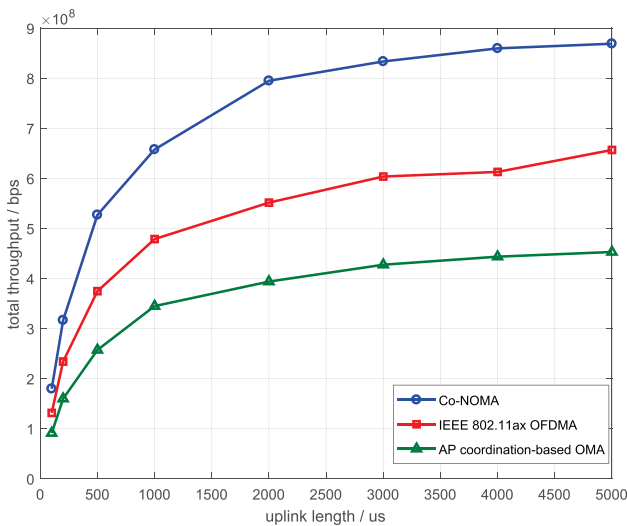

Fig. 12 Total throughput of two BSS under STAs super-dense deployment scenario versus the number of RUs per BSS

Fig. 13 Total throughput of two BSS under STAs super-dense deployment scenario versus uplink length

ment scenario. The proposed Co-NOMA scheme performs optimally than the other two methods clearly in the total throughput performance. As the number of RUs in the BSS increases, the total throughput of two BSS based on the three schemes increases continuously until all STAs in the BSS are basically allocated. After that, the total throughput using the three schemes all remains basically the same.

5.2.3 The Impact of Uplink Length on Performance

Let's assume that the number of STAs per BSS is 9 and the number of RUs per BSS is 9. After that, this paper changes uplink length and records the total throughput of the three schemes respectively.

The total throughput curves of two BSS based on the three schemes in the STAs super-dense deployment scenario are shown in Fig. 13. The total throughput performance of the proposed Co-NOMA scheme is obviously better than that of the other two methods. With the increase of uplink length, the service is gradually saturated, and the total throughput growth trend of two BSS in the three schemes is gradually slowing down.

### 5.3 Simulation Performance Analysis of STAs General Intensive Deployment Scenario

5.3.1 The Impact of the Number of STAs per BSS on Performance

Let's assume that the number of RUs per BSS is 9 and the uplink length is 128 slots. This paper changes the number of STAs per BSS and records the total throughput of the three schemes respectively.
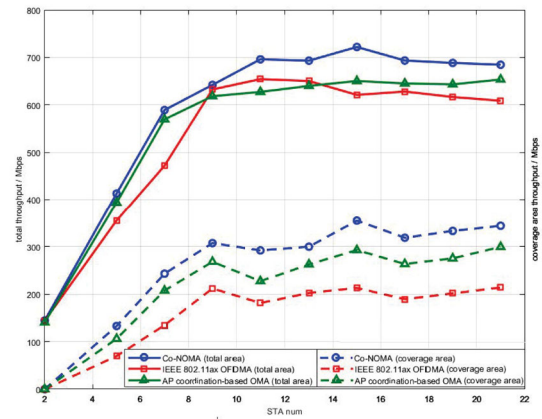
Fig. 14 Total throughput of two BSS under STAs general intensive deployment scenario versus the number of STAs per BSS

The total throughput curves of two BSS based on the three schemes in the STAs general intensive deployment scenario are shown in Fig. 14. Where, solid lines represent the total throughput of two BSS, while dashed lines represent the throughput of the area covered by APs communication range. Simulation results show that the proposed Co-NOMA scheme has the highest throughput, followed by AP coordination based OMA method, and finally IEEE 802.11ax OFDMA method. Because only coverage areas adopt the proposed Co-NOMA scheme or the AP coordination based OMA method, the throughput of this area is significantly improved. However, the total throughput of two BSS based on the three schemes has been improved, but the effect is not significant. When the number of STAs is less than 9, all curves increase linearly. When the number of STAs is greater than or equal to 9, all curves are basically stable.
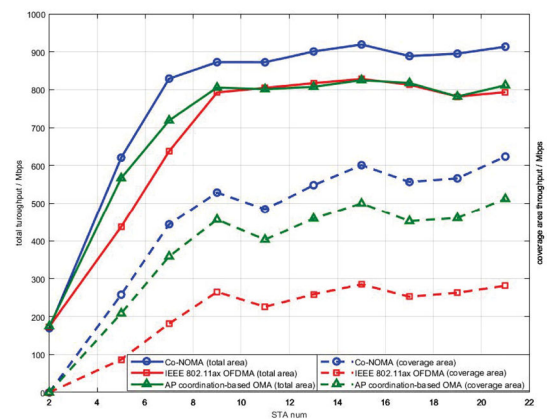
Fig. 15 Total throughput of four BSS under STAs general intensive deployment scenario versus the number of STAs per BSS

The total throughput curves of four BSS using the three schemes in the STAs general intensive deployment scenario are shown in Fig. 15. Among them, solid lines represent the total throughput, while dashed lines represent the throughput of the area covered by APs communication range. The throughput performance of the proposed Co-NOMA scheme is obviously better than that of the other two schemes. Similar to the above two BSS, the throughput of coverage areas is significantly improved, while their total throughput is improved slightly. All curves increase linearly when the number of STAs is less than 9, and are basically stable when the number of STAs is greater than or equal to 9. The total throughput using the AP coordination based OMA approach is similar to that using the IEEE 802.11ax OFDMA method. This is because there are only 9 RUs per BSS. When all RUs are fully utilized, throughput performances between the AP coordination based OMA method and IEEE 802.11ax OFDMA method is close.

5.3.2 The impact of the Number of RUs per BSS on Performance

Let's assume that the number of STAs per BSS is 9 and the uplink length is 128 slots. Then this paper changes the number of RUs per BSS and records the total throughput of the three schemes respectively.

Figure 16 shows total throughput curves of two BSS using the three schemes in the STAs general intensive deployment scenario. Where, solid lines represent the total throughput, while dashed lines represent the throughput of the area covered by APs communication range. The throughput performance of the proposed Co-NOMA scheme is obviously better that that of the other two schemes. Because APs of the proposed Co-NOMA scheme and the AP coordination
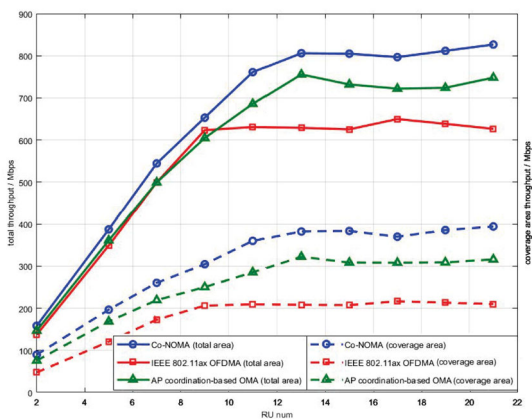
based OMA method can schedule STAs in coverage areas, their throughput in coverage areas improves significantly, while the total throughput only improves slightly. In the IEEE 802.11ax OFDMA method, its throughput curves increase linearly when the number of STAs is less than 9, and remain basically stable when the number of STAs is greater than or equal to 9. In both the proposed Co-NOMA scheme and AP coordination based OMA method, their throughput curves increase linearly when the number of STAs is less than 12. When the number of STAs is greater than or equal to 12, their throughput curves are basically stable. This is because APs of these two schemes can schedule STAs in coverage areas. When the number of RUs is sufficient, APs can schedule up to 12 STAs each time.

5.3.3 The Impact of Uplink Length on Performance

Let's assume that the number of STAs per BSS is 9 and the number of RUs per BSS is 9. After that, this paper changes uplink length and recorded the total throughput of the three schemes respectively.

Figure 17 shows total throughput curves of two BSS based on the three schemes in the STAs general intensive deployment scenario. Where, solid lines represent the total throughput, while dashed lines represent the throughput of the area covered by APs communication range. The proposed Co-NOMA scheme has the highest throughput, followed by the AP coordination based OMA method and the IEEE 802.11ax OFDMA method. The throughput of both the proposed Co-NOMA scheme and the AP coordination based OMA method in coverage areas improves significantly, while the total throughput just improves a little as their APs can schedule STAs in coverage areas. As uplink length increases, the proportion of data transmission time in each
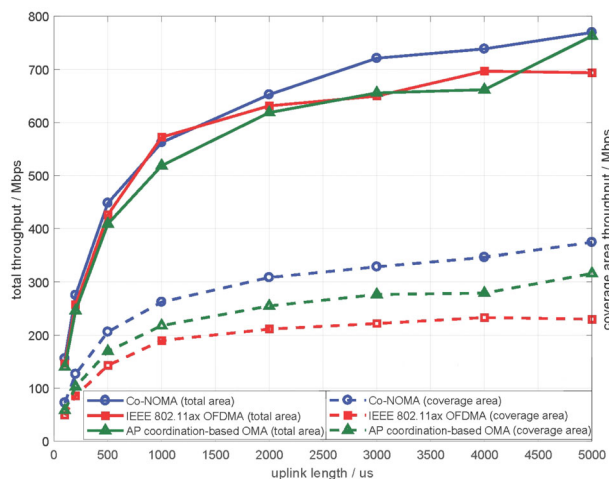

Fig. 16 Total throughput of two BSS under STAs general intensive deployment scenario versus the number of RUs per BSS

Fig. 17 Total throughput of two BSS under STAs general intensive deployment scenario versus uplink length

cycle increases. Therefore, the throughput increases rapidly at the beginning, and then it improvement slows down or even becomes stable.

6 Conclusions

In order to solve the problem that the throughput is seriously affected by the serious interference and suppression relationship between BSS in the high-density deployment scenario of WLAN, this paper proposes an AP coordination based NOMA protocol named Co-NOMA for the next generation WLANs standard. This method can effectively transform the relationship of serious interference and suppression between neighboring BSS into the relationship of mutual coordination and help. Compared with the traditional IEEE 802.11ax OFDMA method and the AP coordination based OMA method, it can be proved that total throughput performances of the proposed Co-NOMA method are improved dramatically, and the simulation results are consistent with the theoretical analysis. In the future research, the proposed Co-NOMA protocol can be considered to be applied to more scenarios, such as millimeter wave (MMW) scene [43, 44], device to device (D2D) scene [45, 46] and so on.

References

1. Ericsson Mobility Report (2019) Experiences from Smart Fixed Wireless Access Deployment Technical report
2. Cisco Visual Networking Index (2019) Global Mobile Data Traffic Forecast Update, 2017–2022 Technical report
3. IEEE 802.11ax (D3.0) 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 (2018)
4. IEEE 802.11ax proposed draft specification. http://www.tp-ontrol.hu/index.php/TP Toolbox (2016)
5. Liu Y, Qin Z, Elkashlan M et al (2017) Non-orthogonal Multiple Access for 5G and Beyond. Proc IEEE 105(12)
6. Ding Z, Peng M, Vincent H (2015) Cooperative Non-Orthogonal Multiple Access in 5G Systems. IEEE Commun Lett 19(8)
7. Li X, Ma W, Luo L et al (2018) Power allocation for NOMA system in downlink, Xi Tong Gong Cheng Yu Dian Zi Ji Shu. Syst Eng Electron 40(7):1595–1599
8. Cao Y, Yang Z, Feng Y (2017) New NOMA power allocation strategy, Tongxin Xuebao. Journal on. Communications 38(10):157–165
9. Islam S, Avazov N, Dober O (2016) Power-domain non-orthogonal multiple access (NOMA) in 5G systems: potentials and challenges. IEEE Communications Surveys and Tutorials

10. WangL C, Chen J, Chen Y (2016) Power Allocation for a Downlink Non-Orthogonal Multiple Access System. IEEE Wireless Communications Letters
11. Alabbsai Z, Daniel K (2015) Power allocation for sum rate maximization in non-orthogonal multiple access system. 2015 IEEE 26th International Symposium on Personal Indoor and Mobile Radio Communications-(PIMRC): Mobile and Wireless Networks
12. Oviedo J, Sadjadpour H (2016) A new NOMA approach for fair power allocation. 2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)
13. Datta S, Kalyanasundaram S (2016) Optimal power allocation and user selection in non-orthogonal multiple access systems. IEEE Wireless Communications and Networking Conference (WCNC 2016)-Track 2-MAC and Cross Layer Design
14. Evangelista J, Sattar Z, Kaddoum G et al (2018) Fairness and Sum-Rate Maximization via Joint Channel and Power Allocation in Uplink SCMA Networks
15. Han S, Huang Y, Meng W et al (2019) Optimal Power Allocation for SCMA Downlink Systems Based on Maximum Capacity. IEEE Trans Commun 67(2):1480–1489
16. Chen J, Wang Z, Xiang W et al (2018) Outage Probability Region and Optimal Power Allocation for Uplink SCMA Systems. IEEE Trans Commun 66(10):4965–4980
17. Bo Y, Shotaro K, Koji Y et al (2017) Starvation Mitigation for Dense WLANs through Distributed Channel Selection: Potential Game Approach. 2017 14th IEEE Annual Consumer Communications and Networking Conference (CCNC), 548–553
18. Qu Q, Li B, Yang M et al (2019) Survey and Performance Evaluation of the Upcoming Next Generation WLANs Standard - IEEE 802.11ax. Mobile Networks and Applications 24(5):1461–1474
19. Yang M, Li B, Yan Z (2020) MAC Technology of IEEE 802.11ax: Progress and Tutorial. Mobile Networks and Applications
20. Bellalta B, Kosekszott K (2018) AP-initiated Multi-User Transmissions in IEEE 802.11ax WLANs. Ad Hoc Netw
21. Kyuhaeng L (2019) Performance Analysis of the IEEE 802.11ax MAC Protocol for Heterogeneous Wi-Fi Networks in Non-Saturated Conditions. Journal of Sensors 19(7)
22. Kiryanov A, Krotov A, Lyakhov A et al (2019) Algorithm for Dynamic Power Control and Scheduling in IEEE 802.11ax Infrastructure NetworksSpringer. J Commun Technol Electron 64(8):900–909
23. Ericsson: The power of 5g is here and will continue to spread across the globe in the coming years. Ericsson Mobility Report
24. Qiao J, He Y, Shen X (2018) Improving video streaming quality in 5g enabled vehicular networks. IEEE Wirel Commun 25(2):133–139
25. Fan Q, Yin H, Min G et al (2018) Video delivery networks: Challenges, solutions and future directions. Comput Electr Eng 66:332–341
26. Zhao G, Imran M, Pang Z et al (2019) Toward real-time control in future wireless networks: Communication-control co-design. IEEE Commun Mag 57(2):138–144
27. Cariou L, Stacey R, Cordeiro C et al (2019) 802.11be timeline proposal. doc.: Ieee 802.11-19/0787r2. IEEE TGbe Proposal, 1–16
28. Yang M, Li B, Yan Z et al (2019) AP coordination and full-duplex enabled multi-band operation for the next generation wlan: Ieee 802.11be (eht). In The 11th International Conference on Wireless Communications and Signal Processing, 1–7
29. Guo Y, Huang G, Yu J et al (2019) AP coordination in eht.doc.:Ieee 802.11-19/0801r0. IEEE TGbe Proposal, 1–12
30. Nan L, Bo S, Chen J et al (2019) Consideration on multi-ap coordination. doc.: Ieee 802.11-19/1219r0. IEEE TGbe Proposal, 1–8
31. Guo Y, Huang G, Yang B (2019) A unified transmission procedure for multi-AP coordination, doc.: Ieee 802.11-19/1102r0. IEEE TGbe Proposal, 1–8

32. Doostnejad R, Cariou L, Chen X et al (2019) Multi-ap collaborative bf in ieee 802.11, doc.: Ieee 802.11-19/0772r0. IEEE TGbe Proposal, 1–18

33. Yang B, Lv Y, Chen P (2019) Consideration on joint transmission, doc.: Ieee 802.11-19/1595r0. IEEE TGbe Proposal, 1–12

34. Verma L, Cherian G, Wentink M (2019) Coordinated ap time/frequency sharing in a transmit opportunity in 11be, doc.: Ieee 802.11-19/1582r0. IEEE TGbe Proposal, 1–12

35. Li B, Qu Q, Yan Z et al (2015) Survey on ofdma based mac protocols for the next generation wlan. In 2015 IEEE Wireless Communications and Networking Conference Workshops (WC-NCW), 131–135

36. Su S, Chih T, Wang Y (2019) Application of Power Control to Improve System Throughput in IEEE 802.11 WLAN. 2019 11th International Conference on Computational Intelligence and Communication Networks, 46–52

37. Ghazi H, Wesolowski K (2019) Improved Detection in Successive Interference Cancellation NOMA OFDM Receiver. IEEE Access 7:103325–103335

38. Kyungseop S, Ohyun J (2017) Joint Scheduling and Power Allocation Using Non-Orthogonal Multiple Access in Directional Beam-Based WLAN Systems. IEEE Wireless Communications Letters 6(4):482–485

39. Uddin M (2019) Throughput performance of NOMA in WLANs with a CSMA MAC protocol. Wirel Netw 25(6):3365–3384

40. Kheirkhah S, Pedram P, Hossein Y et al (2020) A Practical Downlink NOMA Scheme for Wireless LANs. IEEE transactions on communications 68(4):2236–2250

41. Tian Z, Wang J, Wang J (2017) More clients connected by NOMA in the downlink transmission of WLANs. 2017 13th International Wireless Communications and Mobile Computing Conference, 1968–1973

42. Evgeny K, Aleksey K, Ilya L (2020) Prototyping and Experimental Study of Non-Orthogonal Multiple Access in Wi-Fi Networks. IEEE Netw 34(4):210–217

43. Liu Y, Chen X, Niu Y et al (2018) Mobility-aware transmission scheduling scheme for millimeter-wave cells. IEEE Trans Wirel Commun 17(9):5991–6004

44. Niu Y, Ding W, Wu H, et al (2019) Relay-assisted and QoS aware scheduling to overcome blockage in mmWave backhaul networks. IEEE Trans Veh Technol 68(2):1733–1744

45. Chen X, Zhao Y, Li Y et al (2018) Social trust aided D2D communications: Performance bound and implementation mechanism. IEEE Journal on Selected Areas in Communications 36(7):1593–1608

46. Ahmed M, Shi H, Chen X0, et al (2018) Socially aware secrecy-ensured resource allocation in D2D underlay communication: An overlapping coalitional game scheme. IEEE Trans Wirel Commun 17(6):4118–4133