Research and Performance Evaluation of Spatial Reuse Technology for Next Generation WLAN

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Abstract. In order to improve the network performance in the high dense multi-BSSs, the next generation WLAN: IEEE 802.11ax introduces spatial reuse (SR) technology to improve the spectrum utilization, manage the multi-BSSs interferences and increase the possibility of simultaneous transmissions. This paper firstly introduces the SR technologies of IEEE 802.11ax in detail. After that, to fully verify the performance, we build a system & link level integrated simulation platform for IEEE 802.11ax and achieve the SR. Finally, we evaluate the performance of the SR through the built simulation platform, the simulation results clearly indicate that the network throughput is improved by 34.3% in uplink scenarios. To the best of our knowledge, this is the first work to introduce and evaluate the SR technologies for IEEE 802.11ax.

Keywords: WLAN · IEEE 802.11ax · Spatial reuse

1 Introduction

With wireless network and wireless services quickly developing, the demands for the quality of wireless services are also increasing [1]. According to CISCO's statistics and forecast, from 2016 to 2021, the total traffic of global wireless services has increased sharply by 47% annually. The traffics carried by wireless local area network (WLAN) will account for nearly 50% of the total traffic in 2021 [2]. WLAN becomes one important wireless network because of its advantages of high throughput, low cost and flexible deployment. However, the existing WLAN technologies are difficult to meet the growing user needs, so the next generation WLAN standard, IEEE 802.11ax, is currently being developed.

The high dense scenarios such as enterprises, shopping malls, gymnasiums and hospitals will become an important feature of future wireless network [3]. To satisfy the needs of the users in the future, a large number of access points (APs)

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are required in a limited area to ensure the access of a large number of users, on the other hand, future wireless networks also need to support a lot of stations (STAs) in a basic service set (BSS), such as a large number of mobile phones in a gymnasium holding large football match and internet of things (IoT) terminals in families or enterprises. In view of the high dense scenarios and the technology requirement for IEEE 802.11ax in project authorization request (PAR) [4], IEEE 802.11ax has put forward a series of key technologies: multiple access technology based on orthogonal frequency division multiple access (OFDMA), enhanced physical layer (PHY) technologies, SR technology and uplink multi-user multiple-input multiple-output (UL MU-MIMO). Among them, SR technology provides the solutions to the high dense multi-BSSs scenarios.

At present, many studies focus on the key technologies and discuss about standard setting of IEEE 802.11ax from some different aspects, besides, some papers also introduce and evaluate SR technology. Among them, the [5,11] mainly discussed the standard setting of IEEE 802.11ax and predicted the possible key technologies. [5,7] summarized the current development of IEEE 802.11ax, pointed out the shortcomings of the traditional IEEE 802.11 in the high dense scenarios and discussed the possible technologies and challenges of medium access control (MAC) and PHY protocol for IEEE 802.11ax. In view of multi-user (MU) access in IEEE 802.11ax, [6] has analyzed and investigated the MU MAC protocol based on OFDMA and proposed a MU MAC protocol framework based on OFDMA. [10] introduced the MAC technologies of IEEE 802.11ax to well ensure QoS and user experience. [12,14] mainly introduced the key technologies of next generation WLAN - SR technology. [12] introduced key technologies of IEEE 802.11ax, such as PHY technologies based on OFDMA, uplink MU-MIMO, SR technology, etc. [13] outlined the SR technology based on OBSS power detection (OBSS_PD) in IEEE 802.11ax. A power control algorithm is proposed to control the dynamicly changing of the clear channel assessment (CCA) threshold according to the state of the channel. The performance improvement is verified by simulating IEEE 802.11ac. The results of theoretical calculation model and actual simulations in [14] prove that optimizing the CCA threshold can increase the spatial utilization and improve the network performance. These related works provide deep analysis for the performance requirements and potential technologies of the IEEE 802.11ax. However, few of them focus on the analysis of the SR technology in IEEE 802.11ax and verify the performance improvement for IEEE 802.11ax.

In this paper, the SR of IEEE 802.11ax is fully analyzed and discussed in detail. After that, to verify the performance, we build the system & link level integrated simulation platform for IEEE 802.11ax and achieve the SR. Finally by the integrated platform, authors simulate the effect of changing the OBSS_PD level on the network throughput of IEEE 802.11ax with SR and select an OBSS_PD value that can maximize the network throughput; then we simulate the multi-BSSs scenarios and show the distribution of the network throughput of each BSS; moreover, authors use the integrated platform to evaluate the network throughput of the two schemes: IEEE 802.11ax without SR and IEEE 802.11ax with SR from uplink transmission, through the comparisons and analysis of the simulation results, under the 32 (8x4) BSSs scenario, the network throughput of uplink transmission is improved by about 34.3% by using SR technology for IEEE 802.11ax.

The main contributions of this paper are as followed:

(1) To the best of our knowledge, this is the first work to introduce and evaluate the SR technology for IEEE 802.11ax.
(2) According to the requirements for simulation platform requested by task group of IEEE 802.11ax (TGax) in evaluation methodology, authors build the system & link level integrated simulation platform for IEEE 802.11ax and achieve SR technologies on the platform. Based on the integrated simulation platform, the authors simulate two schemes: IEEE 802.11ax with SR and IEEE 802.11ax without SR in office scenarios and evaluate the performance improvement of uplink transmission caused by SR technology.

The reminders of this paper are arranged as follows: Sect. 2 introduces SR technologies of IEEE 802.11ax in detail and analyzes the implementation of SR through BSS color mechanism, Two NAV mechanism and OBSS_PD mechanism; Sect. 3 mainly introduces the architecture of the integrated platform and the function of modules forming the integrated simulation platform; In Sect. 4, based on the integrated simulation platform, the authors simulate two schemes: IEEE 802.11ax with SR and IEEE 802.11ax without SR in office scenarios and evaluate the performance improvement of uplink transmission caused by SR technology.

2 Introduction of IEEE 802.11ax SR Technology

Aiming at the high dense scenarios, technology requirement and performance target [4] in PAR, IEEE 802.11ax has put forward a series of key technologies: enhanced PHY technologies, such as new coding strategy to further improve the transmission rate and using the more finer subcarrier division technology to improve the spectrum utilization; multiple access technology based on OFDMA and UL MU-MIMO; MU-MAC enhancement technology, introducing MU-MAC technology to improve the efficiency of WLAN and parallel data transmission; SR technology, IEEE 802.11ax standard regards SR technology as the core technology to improve the spectrum utilization and manage signal interference among BSSs [15].

Because IEEE 802.11ax mainly focuses on high dense scenarios, it is a key problem how to improve the network performance, the SR technology in IEEE 802.11ax is used to improve the network performance in the high dense scenarios. Therefore, this paper analyzes the SR technology of IEEE 802.11ax and evaluates the performance improvement caused by the SR. The followings will introduce the SR in detail.

2.1 BSS Color Mechanism

The principle of SR technology in IEEE 802.11ax is to implement different operations for packets coming from different BSSs. In order to implement SR technology, firstly the received packet should be judged from which BSSs they come. Therefore, IEEE 802.11ax proposes the BSS color mechanism. The BSS color mechanism is concretely implemented as follows: for each packet the color field is inserted into the SIG field of PHY header and the range of value in the color field is $1 \sim 63$ with 8 bits, the value in the color field is used to distinguish different BSSs. When AP or STA receives a packet, it can be judged by the value of the color field if the packet is from the other BSSs (inter_BSS) or from this BSS (Intra_BSS).

2.2 Two NAV Mechanism

IEEE 802.11ax proposes a two NAV mechanism to alleviate the confusion of TXOP end. Figure 1 is shown as the single NAV mechanism, the Link2 is successfully built between STA1 and AP1 while STA3 is transmitting data to AP2; when STA1 ends up transmitting, it has to send CF_END frame to cancel TXOP duration, STA2 receives the CF_END frame and cancels NAV duration that is set by the Link1 to contend channel access again, packets from STA2 can interfere with the packets that STA3 is sending to AP2, so the Link1 is built failed. Figure 2 is shown as the two NAV mechanism, STA3 is transmitting data to AP2 while the Link2 is successfully built between STA1 and AP1; when STA1 ends up transmitting, it has to send CF_END frame to cancel TXOP duration, STA2 receives the CF_END frame and cancels Basic_NAV duration but the Intra_NAV is still busy, STA2 cannot contend channel access again, so the Link1 is built successfully. The specific implementation of the two NAV mechanism is as followed: each STA or AP needs to maintain two NAV period: Intra_NAV is used to record the period of the NAV carried by the packet from this BSS, the Basic_NAV is used to maintain the period of the NAV carried by the packet from other BSSs or some other unknown BSSs. When AP or STA receives a packet, it chooses to update Intra_NAV or Basic_NAV according to the color value carried by the packet. On the contrary, when AP or STA receives the CF_END frame, according to the color value, AP or STA determines to cancel Intra_NAV period or Basic_NAV period.

2.3 OBSS_PD Mechanism

OBSS_PD mechanism: this technology is used to increase the possibility of simultaneous transmission among BSSs and improve the network throughput. Figure 3 is shown as the traditional CCA mechanism, the Link1 is firstly successfully built, STA1 sends packets to AP1 and STA2 also receives the packets, if the received power is larger than CCA threshold (-82 dBm), the channel state is busy, so STA2 cannot contend channel access, the Link3 cannot be built. Figure 4 is shown as the OBSS_PD mechanism, the Link1 is firstly successfully built, STA1

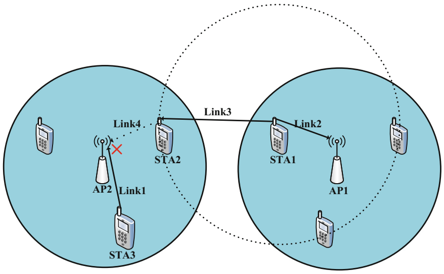

Fig. 1. Single NAV mechanism

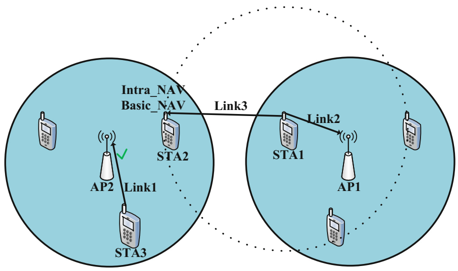

Fig. 2. Two NAV mechanism

sends packets to AP1 and STA2 also receives the packets, if the received power is smaller than OBSS_PD level (OBSS_PD level is more larger than −82 dBm), the channel state is idle, so STA2 can contend channel access, the Link3 can be built successfully. The implementation of the OBSS_PD mechanism is that each STA or AP needs to maintain two CCA thresholds: one CCA threshold is the traditional CCA threshold value (−82 dBm) and the other CCA threshold value adopts a higher CCA level which is described as OBSS_PD level for channel sensing. When AP or STA successfully receives a packet and determines from which BSSs the packet come through the BSS color, if the packet comes from this BSS, the traditional CCA threshold (−82 dBm) is used to judge if channel is busy or idle; if the packet comes from the other BSSs, channel state is judged by the OBSS_PD Level. In general, the value of OBSS_PD level is larger than the traditional CCA threshold (−82 dBm), so that can greatly increase the possibility of simultaneous transmission among BSSs.

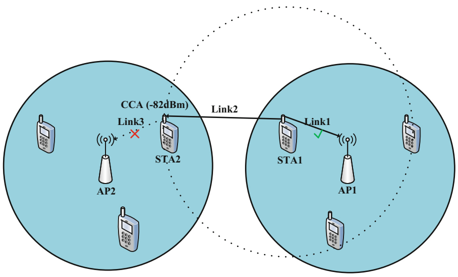

Fig. 3. Traditional CCA mechanism

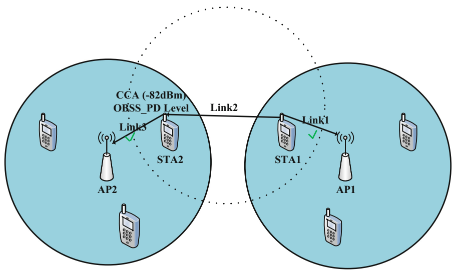

Fig. 4. OBSS_PD mechanism

3 The Integrated Simulation Platform

In order to evaluate the throughput improvement caused by SR technology, this chapter mainly introduces the system & link level simulation platform based on network simulation version 2.0 (NS2). The simulation platform is built according to the requirements of TGax in evaluation methodology. Figure 5 is shown as the architecture of the integrated simulation platform, the simulation platform mainly includes system level simulation module, link level simulation module and integrated entity module. The modules are introduced as followed:

The system level simulation module mainly includes the application layer, the transport layer, the network layer and the IEEE 802.11ax MAC layer, which simulates the transmission of packets and achieves the two NAV mechanism. The application layer is mainly responsible for generating and destroying packets; the transport layer achieves binding packet with related port; the main function of the network layer is to find the next hop IP address; the IEEE 802.11ax MAC layer is mainly responsible for the implementation of the 802.11ax MAC protocol, including the queue module, the channel access module, channel state module and so on.The link level simulation module focuses on IEEE 802.11ax PHY layer and modeling for wireless channel. The PHY layer of IEEE 802.11ax mainly includes the power management module of resource unit (RU) and channel, channel sensing module and calculating SNR and PER module. Channel carrier sensing module mainly implements the OBSS_PD mechanism.

The integrated entity module is responsible for the integration of system level simulation and link level simulation, consisting of two modules: link level discretization and unified system & link level interface. The link level discretization module mainly manages all discrete events generated in network simulation. The unified system & link level interface module is regarded as the unified interfaces to deliver information between MAC layer and PHY layer.

4 Performance Evaluation

This chapter mainly focuses on using the simulation platform to evaluate the performance improvement caused by SR technology. In simulation, two schemes: IEEE 802.11ax without SR technology and IEEE 802.11ax with SR technology are simulated. Compared with the simulation results, the performance improvement of IEEE 802.11ax caused by SR technology can be clearly demonstrated. This paper simulates the two schemes from uplink transmission.

4.1 Simulation Parameters Setting

Simulation scenarios settings still follow the simulation scenarios document exported by TGax [16]. The specific parameter settings are shown in Table 1

4.2 Network Performance In High Dense Office Scenarios

In high dense office scenarios, this paper evaluates the performance improvement of IEEE 802.11ax caused by SR technology from uplink transmission

(1) The effect of changing OBSS_PD level on network throughput.

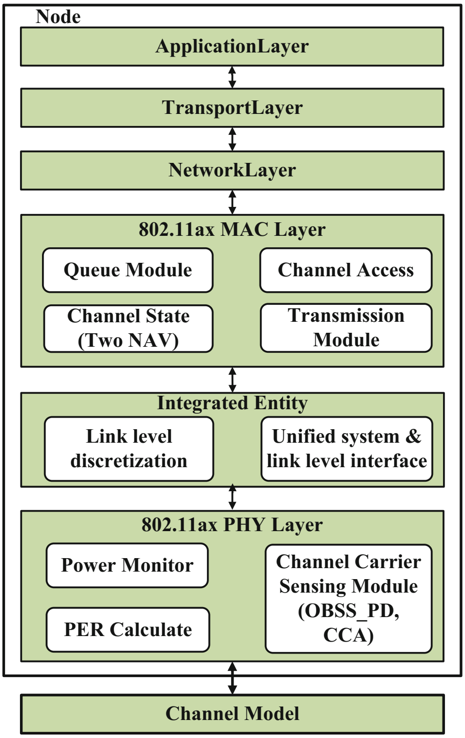

Fig. 5. Integrated simulation platform architecture

Table 1. Parameter setting for the simulation platform

Parameter type	Parameter description
Traffic type/rate	CBR, 0.05 Mbps 3 Mbps
BSS number	4, 8, 18, 24, 32
STA number in BSS	64
STAs position	Uniform random distribution
MCS	0, 1, 2, 3, 4, 5, 7, 8, 9, 10, 11
Bandwidth	20 MHz
Frequency	5.57 GHZ
CCA Threshold	OBSS_PD level Traditional CCA level-82 dBm

Figure 6 shows the effect of changing OBSS_PD level on network throughput in the high dense office scenarios. It can be seen from the graph that changing OBSS_PD level has great influence on the network throughput. When the value of OBSS_PD level is changed from −82 dBm to −70 dBm, the network throughput is increasing and the maximum network throughput can be obtained at

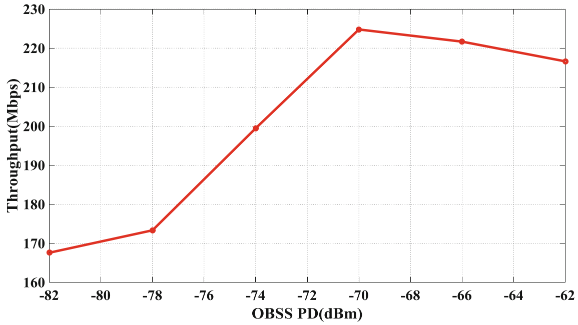

Fig. 6. The effect of changing OBSS_PD level on network throughput

about −70 dBm, however, when the OBSS_PD level is changed from −70 dBm to −62 dBm, the network throughput is decreasing. The reason is that if OBSS_PD level is too small, the probability of SR is decreased; conversely, the interferences between simultaneous links are increasing, which causes the increased packet loss. Through the simulation, the authors can get the OBSS_PD level value: −70 dBm that can maximize the network throughput.

(2) Network performance of uplink transmission

Figure 7 shows the saturated network throughput of both schemes: IEEE 802.11ax with SR and IEEE 802.11ax without SR in different scenarios, including 4 BSSs (2 × 2), 8 BSSs (4 × 2), 16 BSSs (4 × 4), 24 BSSs (6 × 4) and 32 BSSs (8 × 4). It can be clearly seen that when the number of BSSs is less, the probability of SR is very small and both of network throughput are almost same; with the number of BSSs increasing, such as 16 BSSs and 32 BSSs, the probability of SR is improved. In particular, in the case of 32 (8 × 4) BSSs, the network throughput of the uplink transmission is improved by about 34.3% by using SR technology for IEEE 802.11ax.

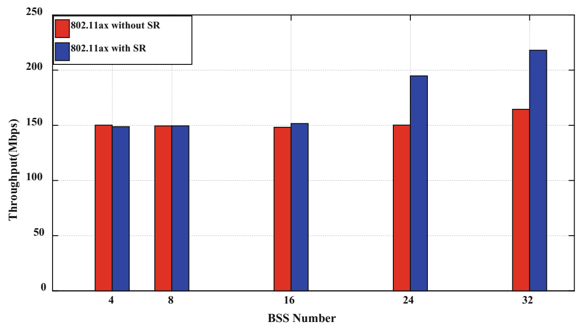

Fig. 7. Network throughput of uplink transmission in office scenarios

(3) The network performance of STA in office scenarios

Figure 8 shows the distribution of BSSs index. Figure 9 shows the distribution of the network throughput of each BSS in 32 (8×4) BSSs scenarios. From the simulation results, the more the BSS is near the center of the network scenario, the smaller the network throughput is; the more it is far away from the BSS in the center of the network scenario, the higher the network throughput is. Namely, the BSS is on the edge of the network scenario, the interference from other BSSs is relatively smaller; on the contrary, the interference is higher.

24 BSS	25 BSS	26 BSS	27 BSS	28 BSS	29 BSS	30 BSS	31 BSS
16 BSS	17 BSS	18 BSS	19 BSS	20 BSS	21 BSS	22 BSS	23 BSS
8 BSS	9 BSS	10 BSS	11 BSS	12 BSS	13 BSS	14 BSS	15 BSS
0 BSS	1 BSS	2 BSS	3 BSS	4 BSS	5 BSS	6 BSS	7 BSS

Fig. 8. The distribution of BSS index

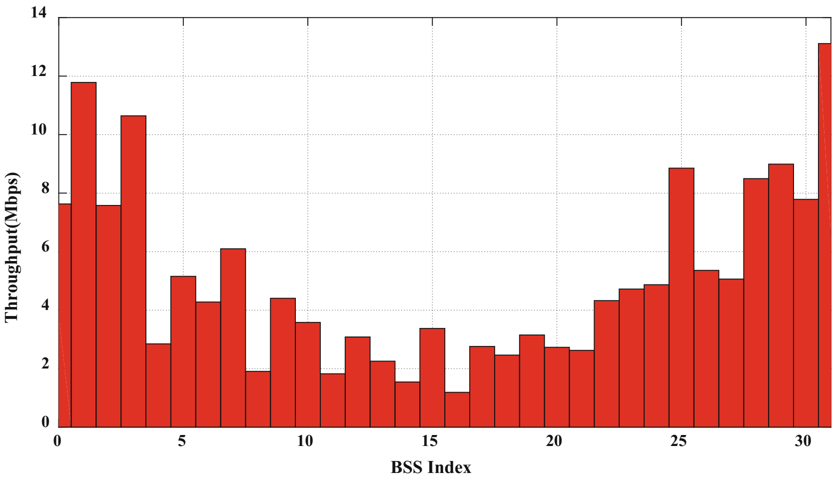

Fig. 9. The network performance of each STA in office scenarios

5 Conclusion

This paper firstly introduces the scenarios, key technologies and current researches for IEEE 802.11ax, discusses the SR technology in IEEE 802.11ax in detail and analyzes the shortcomings of the researches on SR technology of IEEE 802.11ax.

Based on the above studies, according to the technologies requirements of IEEE 802.11ax draft 2.0 for MAC layer and PHY protocol, we build a system & link level integrated simulation platform for IEEE 802.11ax and achieve the SR. Under the high dense office scenarios, firstly authors simulate the effect of changing the OBSS_PD level on the network throughput of IEEE 802.11ax with SR and select the OBSS_PD value that can maximize the network throughput; secondly authors simulate the multi-BSSs scenarios and show the distribution of the network throughput of each BSS; finally authors use the integrated platform to evaluate the network throughput of the two schemes: IEEE 802.11ax without SR and IEEE 802.11ax with SR from uplink transmission, through the comparisons and analysis of the simulation results, the network throughput of the uplink transmission is improved by about 34.3% by using SR technology for IEEE 802.11ax. It can be clearly demonstrated that the SR technology introduced by IEEE 802.11ax can significantly improve the network throughput.

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