ESR: Enhanced Spatial Reuse Mechanism for the Next Generation WLAN - IEEE 802.11ax

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Abstract. Wireless local area network (WLAN) technology has become mature in the past few decades. However, with the development of social application forms, the situation of high-density deployment of cells has become more frequent in recent years, so the next-generation WLANs face the unprecedented challenge of quality of service (QoS) and quality of experience (QoE) of high-density cell users. In response to this challenge, The Overlapping Basic Service Set Power Detection (OBSS PD) mechanism and Spatial Reuse Parameter (SRP) mechanism are proposed in IEEE 802.11ax (Institute of Electrical and Electronics Engineers) to improve spatial multiplexing capability and certain throughput capabilities. But both of them possess inherent drawbacks. Based on this, this paper proposes an enhanced spatial reuse mechanism, named ESR (Enhanced Spatial Reuse), by limiting the value of the CCA threshold in the SRP mechanism to improve the quality of concurrent links, which further improves the average throughput. Compared to traditional SRP, simulation results show that ESR can increase throughput by 10% and reduce packet loss by 10%.

Keywords: WLAN · SRP · Clear Channel Assessment (CCA) · MAC protocol

1 Introduction

Due to the deep penetration of mobile Internet and the increasing enrichment of wireless network services, wireless communication and quality of service (QoS) requirements have increased dramatically in recent years [1]. Wireless LANs and cellular networks have been recognized as the most important carriers of today's network services due to their high speed, flexible deployment and low cost. According to statistics, from 2016 to 2021, the world's wireless data traffic will increase significantly, with an annual growth rate of 47%. According to the report, by 2021, the percentage of the world's wireless data traffic accounts for the total traffic will increase from 42% in 2015 to 49%. In order to cope with such rapid wireless service growth, the Institute of Electrical and Electronics

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Engineers: IEEE 802.11 will soon release the next generation WLAN (Wireless local area network) standard amendment: IEEE 802.11ax [2].

It is precisely because of the huge increase in wireless demand that the business demand cannot meet the requirements in crowded places, such as companies, shopping malls and residential buildings. The wireless network scenarios that have emerged in recent years are collectively referred to as high-density deployment scenarios the focus of the next generation of WLAN protocol standard. High-density deployment of APs (Access Points) is bound to increase interference [3], and the quality of users' services is more difficult to guarantee.

In response to the above problems, the objective of improving spectrum reuse is proposed in the next generation protocol standard: IEEE 802.11ax. Thus, spatial reuse (SR) [4] is supposed to be a key technology of IEEE 802.11ax, which includes enhanced physical carrier sensing mechanism, enhanced virtual carrier sensing mechanism and power control technology. In the traditional scene, it is always only one transmission link will exist since both the physical carrier sensing and virtual carrier sensing are too conservative. However, allowing multiple links to be transmitted in concurrently with controlled interference will obviously further increase the transmission capacity. Therefore, IEEE 802.11ax [2] introduces two types of SR mechanisms: Overlapping Basic Service Set Power Detection (OBSS PD) mechanism and Spatial Reuse Parameter (SRP) mechanism.

OBSS PD mechanism. The protocol standard indicates that once the node receives the inter-BSS frame, it uses the OBSS PD value to listen to the channel state, which is slightly higher than traditional CCA (Clear Channel Assessment) threshold. If the channel energy is lower than OBSS PD, the node can ignore the virtual carrier sensing mechanism to start backoff and access the channel. The increase of the CCA threshold directly reduces the difficulty of link concurrency. OBSS PD also reduces interference between concurrent links by controlling the transmit power of the links [5]. However, since the current link cannot determine when the concurrent link terminates the transmission, the channel state will become confusing.

SRP mechanism. The protocol standard indicates that once the node receives the TF (Trigger Frame) from inter-BSS, if the SR is allowed, an uncontrollable CCA threshold is used to listen to the channel state for the data frame of the TF source cell. The SRP technology increases the concurrent opportunity by ignoring the interference of the current link to the concurrent link. Then, the current link performs certain control on the transmission power of the concurrent link to ensure that the concurrent link does not interfere with the primary link. However, due to the wide selection of the concurrent link, the problem of interference between concurrent links is serious, and the quality of service is greatly reduced.

For OBSS PD, the concurrent link is unknown and uncontrollable; for SRP, although the interference problem between the current and concurrent links is solved to some extent, the selection of links is really radical and the quality of the link cannot be effectively guaranteed because the physical carrier sensing is uncontrollable when concurrent links receive packets which from current link.

Since both OBSS PD and SRP mechanism possess inherent drawbacks as mentioned above, this paper will apply the idea of adjusting the CCA threshold based on SRP technology. When the node receives the TF, the CCA threshold is fixed from an uncontrollable value indicated in the IEEE 802.11ax to an appropriate value, so that the generation of the concurrent link is no longer the mode of receiving the TF sent by the current AP to continue to backoff and access the channel, but those nodes with low transmission possibilities in neighboring cells can participate in parallel transmission. Through the physical carrier sensing mechanism, the requirements for link concurrency are more strict, so as to further improve the quality of service.

The contributions of this paper can be summarized as follows:

- As far as we know, this is the first work to propose the idea of combining the SRP mechanism with a limited CCA threshold to achieve higher quality of service.
- The simulation results show that the scheme can guarantee a slight increase in throughput under the condition of multi-link parallel, and on the other hand, this mechanism supports SRP to select concurrent links with better quality to reduce packet loss rate.

The reminder of this paper is as follows: Sect. 2 illustrates the motivation and key idea of ESR. Section 3 depicts the simulation platform. Section 4 evaluate the performance. Finally, Sect. 5 concludes the paper.

2 SR Overview for IEEE 802.11ax

2.1 SRP Description

This article only discusses the uplink. The SRP mechanism is to send a trigger frame (TF) with control information before transmitting data, so that neighboring nodes can receive the trigger frame to continue to backoff and access the channel. The corresponding field of the HE-SIG-A in the TF carries a message indicating whether the current link transmission supports the SRP. If supported, the STAs that received the TF can continue to access channel to transmit data during the transmission time of the current link, as shown in Fig. 1.

While allowing the concurrent link, the TF received by STAs also obtain an SRP value, which is a power control information of the current link to the concurrent links, and the value is an adjustable parameter (the simulation of this paper is tentatively set to −65 dBm). P = $SRP - TFP_{RX}$, note that P is the transmit power of the concurrent link after the power control, TFP_{RX} is the received power of the TF. If $P \geq P_{\min}$($P_{\min}$ is the value of the minimum transmit power for the concurrent link, the value is tentatively set to 10 dBm), the station is allowed to start the SRP backoff process, otherwise it will continue to hang. If the channel is successfully accessed, its actual transmit power is $min(P, P_{\max})$ ($P_{\max}$ is the maximum transmit power of the concurrent link, tentatively set to 15 dBm). After power control, the concurrent link will only appear outside the

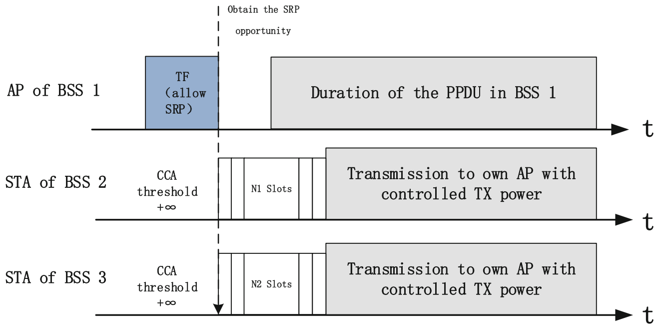

Fig. 1. SRP transmission mechanism.

area with the primary AP as the origin and d as the radius (d is the distance from the position where the dynamic transmission power equal to 10 dBm to the primary AP), as shown in Fig. 2, the STAs that can participate in the link are displayed in green, which ensures the quality of the primary link transmission.

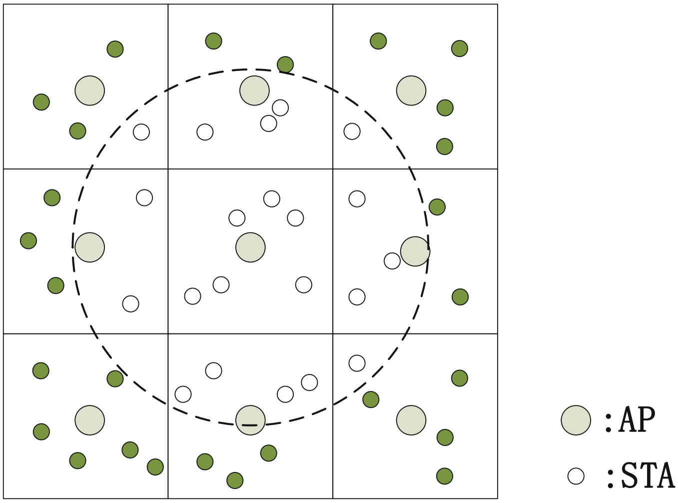

Fig. 2. SRP scene diagram. (Color figure online)

2.2 Description of SRP Problem

In the SRP model, the communication of current link is guaranteed through the power control. However, in the context of the concurrent link, although the dynamic transmission power causes the situation that STAs farther away from the AP, the transmission power is larger, but in a high-density deployment scenario, multiple users accessing the channel at the same time are more common, resulting in a large increase in interference between concurrent links. As shown in Fig. 3, STAs marked with red indicate those STAs with same backoff value. Because the cells are too close together, the simultaneous transmission of packets makes the data packet transmission probability failure, which is the main reason for the high packet loss rate of the SRP mechanism.

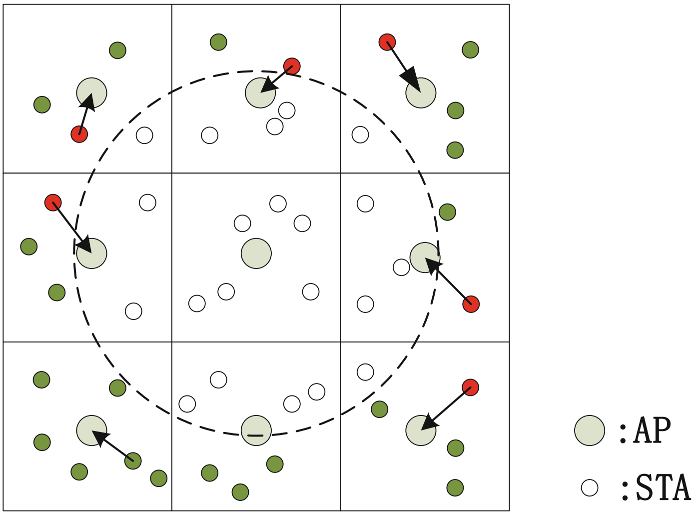

Fig. 3. SRP scene diagram. (Color figure online)

3 Introduction of ESR

3.1 Problem Solved

Considering that the value of the CCA threshold directly reflects the integrated transmission state of the neighboring cell, the more complex the application scenario, the setting of the CCA threshold is more important. If the scene in which the simultaneous transmission occurs is described as a problematic scenario, the following will give a solution to deal with the problematic scenario under an appropriate CCA_SRP.

As shown in Fig. 4, in the SRP mechanism, STA1 and STA2 can participate in parallel after receiving the TF from the current link. If STA1 and STA 2 get the same backoff value, these two transmissions are likely to fail because the two cells is too close. If the CCA threshold is set to SRP_CCA after the two STAs receive the TF, STA1 which is closer to current link will judge that the current state of the channel is busy because the physical carrier sense detects that the channel power accumulation exceeds the SRP_CCA threshold (−62 dBm). STA1 is unable to participate in this parallel transmission. However, STA2 is far away from the current link, the power accumulation of the channel does not exceed

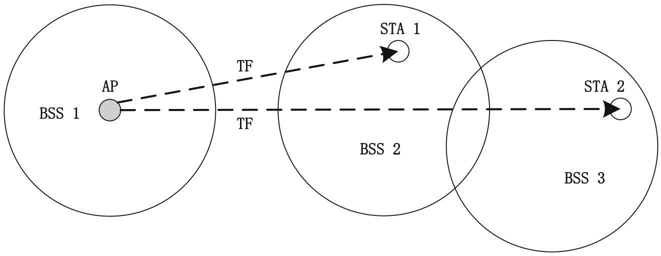

Fig. 4. Concurrent link interference scenario.

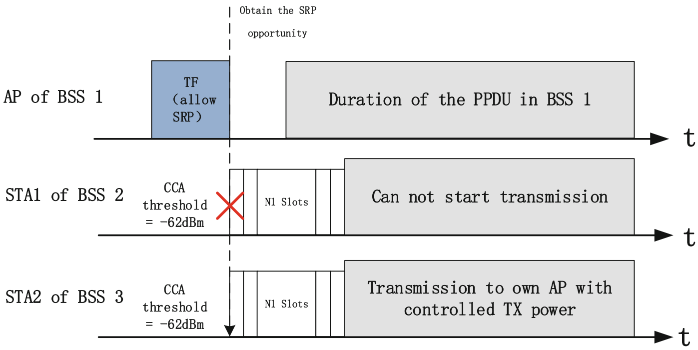

Fig. 5. ESR interference scene transmission mechanism.

the CCA_SRP threshold, and the state is idle. It can participate in this parallel transmission, thus avoiding the interference of multiple STAs simultaneously accessing the channel. As shown in Fig. 5.

Of course, the channel interference described in this scenario mainly comes from the current link. In a complex scene, multiple links affect the channel state, so the role of the CCA threshold is more significant.

3.2 Process

The design process of this paper is as follows:

- Step 1. STAs that can transmit data under power control in other cells receive the TF from the current link.
- Step 2. Set the CCA threshold from an uncontrollable value specified in traditional SRP to CCA_SRP.
- Step 3. The STA detects the channel status. If it is busy, it sets the NAV and cannot send data. If it is idle, ignore the NAV and continue to backoff.
- Step 4. If a new TF with the information that SR is not allowed during the backoff, the SR is immediately stopped and the CCA threshold is reset to the initial value until the arrival of the new TF frame allowing SR.

3.3 Frame Format

Because the CCA threshold set for the transmission of the primary link in the SRP mechanism is uncontrollable, that is, the current link cannot be detected effectively by physical carrier sensing in the concurrent cell, so the innovation of this paper is combined with the adjustment of the CCA threshold to improve the quality of concurrent links. This paper uses the new threshold CCA_SRP to represent the traditional CCA threshold when STAs receive the TF that allows SRP.

In this paper, four bit lengths are added to the Common Info field in the TF frame to indicate different SRP_CCA values. The frame format is shown in Fig. 6. The SRP_CCA value table is shown in Table 1.

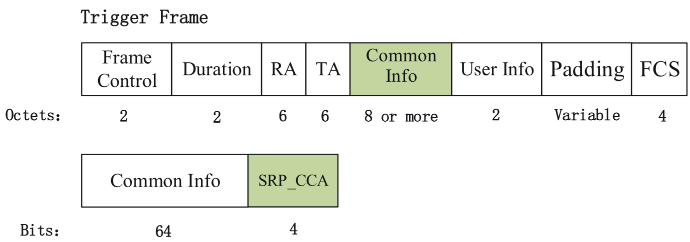

Fig. 6. Trigger frame format.

Table 1. SRP_CCA subfield encoding

SRP_CCA subfield value	Meaning
0	SRP_CCA_DISALLOW
1	−77 dBm
2	−72 dBm
3	−67 dBm
4	−62 dBm
5	−57 dBm
6	−52 dBm
7	−47 dBm
8–15	Reserved

4 Performance Evaluation

4.1 Simulation Design

In order to evaluate the performance of the above design and verify the expected effect, this paper is based on the NS-3 simulation platform [6].

The simulation configuration is designed according to the high-density deployment scenario, and the configuration is shown in Table 2 [7].

Table 2. ESR Scene configuration

Scene configuration	Value
Cell topology	4 ∗ 8
Distance between cells	15 m
Number of users per cell	10
Traffic type	Uplink
Traffic rate	10 Mbps
Traffic packet size	1500Byte
Data MCS	VHTMCS7
Control frame MCS	VHTMCS0
Maximum transmission duration of A-MPDU	5.484 ms
Simulation time	15 s

4.2 Result and Analysis

This paper simulates the trend of system performance as SRP_CCA continues to increase. The average cell throughput is shown in Fig. 7. The average cell packet loss rate is shown in Fig. 8.

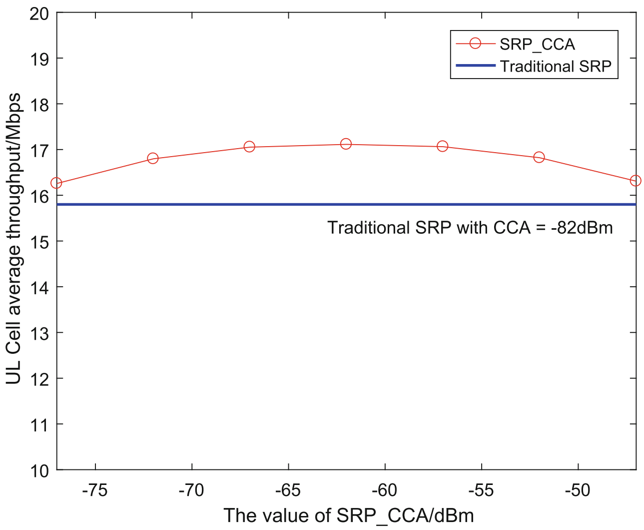

Fig. 7. Average throughput of the SRP_CCA mechanism.

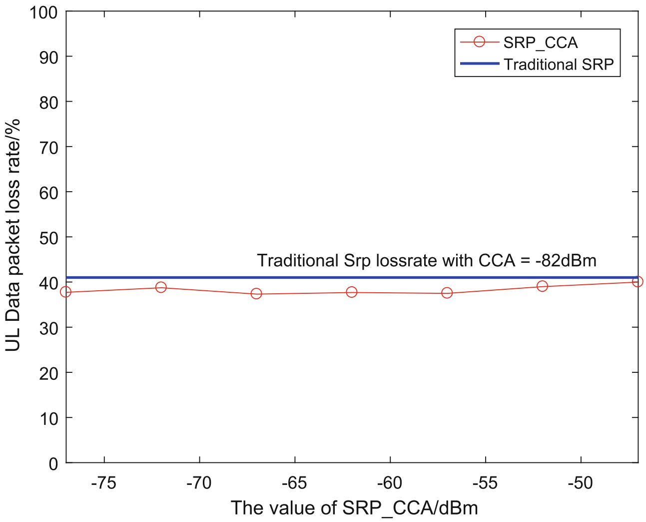

Fig. 8. Average packet loss rate of the SRP_CCA mechanism.

It can be seen from the results that as the SRP_CCA increases, the effect of the current link becomes less and less. It can be seen from Fig. 7 that when SRP_CCA = −62 dBm, the throughput reaches a maximum value. Then, with the SRP_CCA continues to increase, the throughput has a downward trend, and gradually tends to the traditional SRP baseline. According to the packet loss rate curve shown in Fig. 8, it can be seen that the packet loss rate is slightly lower than the traditional SRP mechanism after using the limited SRP_CCA, and as the SRP_CCA increases, the curve tends to the traditional SRP baseline.

In summary, according to the two curves, the increase of SRP_CCA controls the interference between concurrent links. Once the concurrent link responds to the interference of the current link, the problem scenario shown in Fig. 5 can be effectively solved., and as the SRP_CCA increases, the probability of concurrent links will gradually increase, and the problematic scene will also appear, slowly evolve into a traditional SRP model.

The transmission power of the current link is 20 dBm, and the maximum transmission power of the concurrent links is 15 dBm. After the power control, the node position that can participate in parallel are approximately in the area 30 meters away from the primary AP. The energy of the packets which are from the current link has been greatly attenuated [8,9] when these packets arrive in those areas and it is almost impossible to exceed the SRP_CCA value, so when SRP_CCA is higher than −42 dBm, it is almost identical to the traditional SRP model. This is also an important reason for the throughput and packet loss rate to go to the traditional SRP baseline.

5 Conclusion

Combined with the simulation results and analyses in the previous section, it can be considered that the change of the CCA threshold in the SRP mechanism can alleviate the serious problem of concurrent link interference. According to the above simulation results of different SRP_CCA values, at least the following conclusions can be summarized: (1) The value of the CCA threshold will directly affect the possibility of the node sending data. (2) Physical carrier sensing reflects the comprehensive judgment of different nodes on the transmission of neighboring cells. Especially in high-dense deployment scenarios, the effect is more obvious.

This paper only proposes the concept of flexible application of dynamic physical carrier sensing threshold to improve the quality of service in SRP. The author believes that the enhanced physical carrier sensing technology will be more widely used in the future wireless network environment.

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