PSR: Probability Based Spatial Reuse Mechanism for the Next Generation WLAN

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Abstract. Wireless local area network (WLAN) technology can be seen everywhere in people's lives, and technology itself is constantly developing, the coming new WLAN standard IEEE 802.11ax is excepted to increase the per-user throughput by 4 times than existing WLAN standards in residential, enterprise and other dense deployment scenarios. One of the key technologies of 802.11ax is spatial reuse (SR) technology, which improves area throughput by allowing concurrent links, and spatial reuse parameter (SRP)-based SR mechanism is introduced in 802.11ax. But in fact, the SRP mechanism lacks the ability to adapt to the scenario, and does not guarantee full gain from SR in any dense deployment, even exhibit a negative gain in some scenarios. This paper proposes a probability based SR (PSR) mechanism to achieve the full gain from SR with a probability value that reflects the scenario condition. Simulation results indicate that the PSR mechanism is a practical solution for SR in next generation WLAN (NGW).

Keywords: WLAN · IEEE 802.11 · Spatial reuse · Dense deployment · Next generation WLAN

1 Introduction

Wi-Fi is a common technology to access wireless local area network (WLAN) in people's daily life. In order to meet the communication needs of a large number of wireless network devices, outdoor and dense deployment scenarios [1] can also provide users with a good experience, the Wi-Fi community set up the next generation of WLAN IEEE 802.11ax working group in 2014 [2]. With the release of Draft 2.0 [3], the work of IEEE 802.11ax was nearing completion. The latest study demonstrates the per-user throughput of IEEE 802.11ax is up to 4.74 times of IEEE 802.11ac operating in the same band [4].

In WLAN, the adjacent links inevitably interfere with each other due to they are sharing the same wireless media, each link reduces the communication quality of other links, or even leads to failure; on the other hand, if the concurrent links can tolerate the interference caused by each other and transmit successfully,

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then the gain can be obtained from the number of links to enhance the area throughput. In legacy IEEE 802.11, the carrier detection threshold is relatively conservative, on the one hand to ensure link quality, on the other hand, because the application scene is usually single cell with single access point (AP), and there is no gain in concurrent links; But in NGW, in order to pursue higher area throughput and frequency spectrum utilization under dense deployment, it is a very clear direction to obtain the gain from link numbers by controlling the interference between links through certain means. Therefore, a variety of spatial multiplexing (SR) techniques and two SR mechanisms are proposed in IEEE 802.11ax [3], and it has been proved by latest study that it can bring obvious gain in multi-BSS indoor scenarios [4]. The space reuse parameter(SRP)-based SR mechanism (SRP mechanism) is based on the combination of various technologies such as CCA enhancement, NAV enhancement, transmission power control and BSS Color mechanism, which effectively increases the number of concurrency links with controlled interference, and improves the area throughput and utilization of frequency spectrum.

Although the SRP mechanism controls the interference of the concurrent link to the current link by limiting the transmission power, it ignores that (1) the current link with default transmit power has greater interference with concurrent links; (2) collision problem caused by allowing STAs to access channel; (3) problem of hidden terminal [5] in multi-BSS scenarios. These problems will lead to too radical SR under the SRP mechanism and fail to achieve the desired results, or even destroy the transmission of the current link.

In order to solve the above problems, this paper proposes a probability based SR (PSR) mechanism, which adjusts the concurrent link access probability in SR according to the different scenarios, the number of concurrent links in the WLAN is maintained at a reasonable level so that the area throughput gain from SR is stable at a better level. The simulation results show that the PSR mechanism has stronger adaptability and is expected to give full play to the gain from SR in dense deployment scenarios. To the best of our knowledge, the probability based mechanism is first integrated into the SR mechanism in this study, and try to solve the problem that the existing SR mechanism cannot deal with the dense deployment scenarios with complicated channel conditions.

The reminder of this paper is as follows: Sect. 2 illustrates the motivation of this study. Section 3 details the key idea of PSR. Section 4 deploys several simulations and verifies the performance. Finally, Sect. 5 concludes the paper and plans the future work.

2 Motivation

2.1 Introduction to SRP-based SR Mechanism

In 802.11ax, uplink is triggered by trigger frame (TF) transmit by AP [6], assuming that all sites support SRP mechanism, then SRP mechanism flow is shown in Fig. 1. AP can set up whether to allow SR and control the interference from concurrent link power by configuring the SRP subfield in SIG-HE-A of TF. The SRP subfield containing 4 bits and encoded as shown in Table 1.

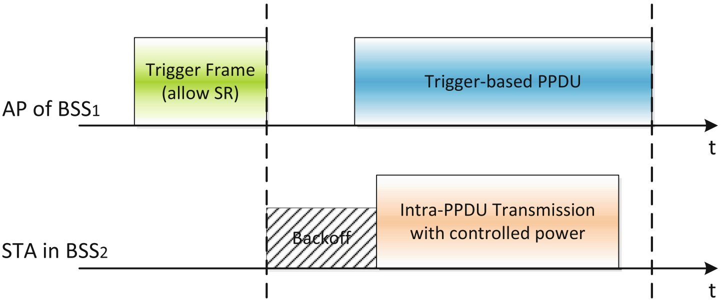

Fig. 1. SRP-based SR mechanism flow.

Table 1. SRP subfield encoding

Value	Meaning	Value	Meaning
0	SR disallow	8	SRP=−44dBm
1	SRP = −80 dBm	9	SRP = −41 dBm
2	SRP = −74 dBm	10	SRP = −38 dBm
3	SRP = −68 dBm	11	SRP = −35 dBm
4	SRP = −62 dBm	12	SRP = −32 dBm
5	SRP = −56 dBm	13	SRP = −29 dBm
6	SRP = −50 dBm	14	SRP = −26 dBm
7	SRP = 470 dBm	15	Reserved

STAs in overlapping BSS (OBSS) can obtain the SRP after receiving the TF. If SR is allowed, the STA in OBSS can ignore CCA and NAV of current link and execute its backoff procedure until other concurrent link is detected, otherwise, it can start a transmission as the concurrent link if the backoff timer reaches 0. In addition, the following conditions need to be met from the concurrent link: (1) the concurrent link must end before the current link; (2) the transmission power must be controlled, that is, the transmission power of concurrent link is $P_{TX} \leq SRP - P_{RX}$, where P_{RX} is the receiving power of TF.

2.2 Problem Statement

(a) The interference of the current link to the concurrent link is brought by the sender of the current link, which is brought by the STA, but because the information that the concurrent link can obtain comes from the AP of the current link, the interference from the current link to the concurrent link is unpredictable, which will cause the concurrent link to be in a relatively fragile state.

(b) In the target indoor scenario defined by Task Group ax (TGax) for 802.11ax [7]. Due to the characteristics of dense deployment, there are often a large number of STA, such as enterprise scenario shown in Fig. 2. There are 32 offices, each office is a BSS, and 64 cubicles per office, each cubicle has more than one STA. The uplink transmission is triggered by TF in 802.11ax, so usually only AP will access the channel. But the SRP mechanism allows STA to access the channel, and the intensity of competition is difficult to predict, fierce competition will lead to the collision of the contention window and resulting in unexpected concurrent links if there are a large number of STA.

(c) In the multi-BSS scenario, the classical problem of hidden terminal may also lead to unexpected concurrent links, thus making the interference of current link higher than expected.

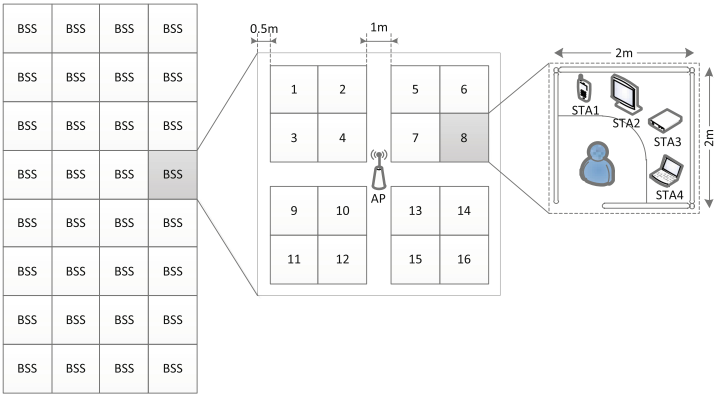

Fig. 2. Enterprise scenario.

In a word, the SRP mechanism has limited the concurrent link, but in fact, its ability to adapt to the scenario is weak, and there are serious drawbacks in the control scheme of the concurrent link, and the gain of SR cannot be fully obtained in any dense deployment scene.

3 Key Idea

3.1 Overview

In order to solve the problems of the SRP mechanism in the Sect. 2, this paper proposes a probability based SR mechanism. Within the PSR mechanism, each

AP maintains a probability of SR p, and it need to be carried in each TF, the STAs that receive the TF perform SR competition by probability p, it means there are some STAs that are not allowed to obtain the opportunity of SR at random. In general, the probability p reflects the intensity of SR competition, that is, the quantity information of STA in OBSS. The information can be generated by statistics of the transmission success rate of the BSS by AP, and can also be interacted through inter-AP communication. In addition, the transmission power of concurrent link still need to be controlled.

3.2 Mechanism

This section illustrates the workflow of the PSR mechanism through examples, and points out its source of gain. Figure 3 shows the common situations and problems encountered by SRP mechanism in the dense deployment: AP of BSS_1 send a SR allowed TF, and STA_1 in OBSS obtain this opportunity of SR because its backoff timer reaches 0; other STAs in OBSS (e.g. STA_2) pause their backoff process due to CCA mechanism; but in dense deployment scenario with a large number of STA, there is a greater possibility that contention window will collide, if there is an unexpected concurrent link just like the transmission from STA_3, it will cause uncontrollable interference to the other two links and reduce the benefit.

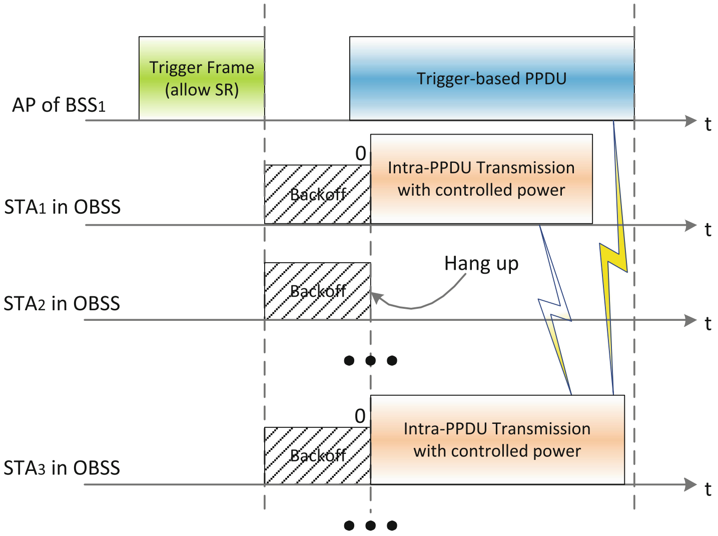

Fig. 3. The workflow of SRP mechanism under dense deployment.

In the same dense deployment scenario, the workflow of the PSR mechanism is shown in Fig. 4. The SR probability is p carried in the TF, and p roughly reflects the number of surrounding STA in OBSS. The STAs that receive the TF perform SR competition by probability p, it means the collision probability of contention window is directly related to p, so the SR probability p take an appropriate value can make the gain from SR fit the expectation.

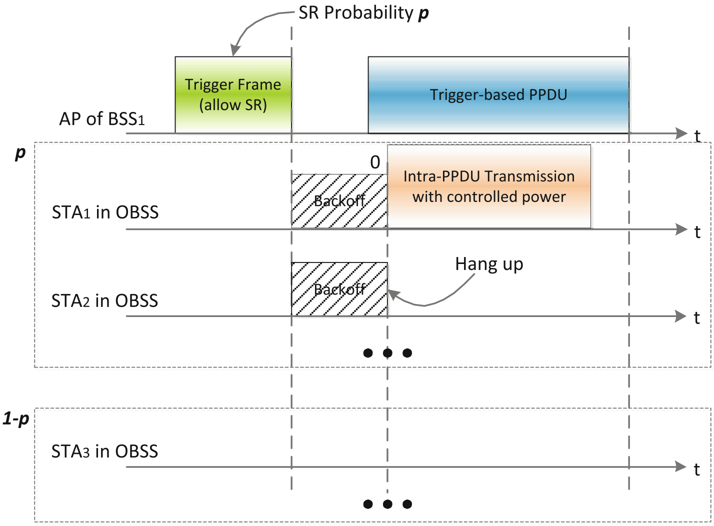

Fig. 4. The workflow of PSR mechanism under dense deployment.

4 Simulation

4.1 Simulation Environment

To test and compare the gain from SR with the SR probability p take different values by simulation, we use the NS-3 simulator [8]. The configuration of the simulation parameters is shown in Table 2. Link adaptation for STAs is allowed. The SR probability pp is fixed, the PSR mechanism will be degenerated to the SRP mechanism when p is taken as 1, and SR disallowed when p is taken as 1.

4.2 Performance Evaluation

Figure 5 illustrates that the gain from SR changed as the number of STAs in each BSS increased. When the number of STA in each BSS is small, especially 5–10, the gain from SR is obvious, up to more than 80%, but it is difficult to judge the optimal value of p; however, as the number of STA in each BSS increases, the gain from SR decreases, and the rate of decline is positively related to p; the SRP mechanism ($p = 1.0$) exhibit a negative gain with 25–30 STAs in each BSS, but considerable gain can still be achieved with PSR mechanism and set p equal to 0.2.

Table 2. The configuration of the simulation parameters

Parameter	Value
Service type	CBR (constant bit rate)
Traffic model	Poisson Model
Traffic rate	10 Mbps
Packet size	1472 octets
Trigger frame size	36 octets
Default data frame MCS	VHT MCS 7
Control frame MCS	VHT MCS 0
AP transmit power	20 dBm
Default STA transmit power	15 dBm
Lowest STA transmit power	5 dBm
SR probability	0, 0.2, 0.4, 0.6, 0.8, 1

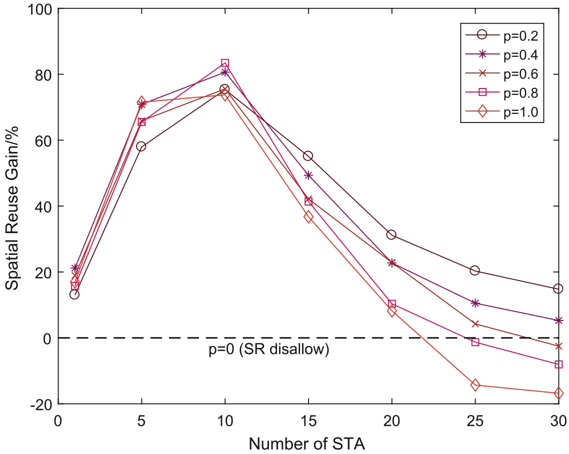

Fig. 5. Spatial reuse gain performance of PSR at different number of STA in each BSS.

Figure 6 illustrates that the collision probability changed as the number of STAs in each BSS increased. When SR is disallowed, only AP can access the wireless channel, so the collision probability is independent of the number of STA in each BSS and is maintained at a lower level; the collision probability increases with the increase of the number of STA in each BSS when SR is allowed. In general, the greater the p, the higher the collision probability.

From the simulation results above, it is observed that SR probability p has a significant impact on the gain from SR. The gain from SR varies with the changes in scenario, and the SRP mechanism is sometimes difficult to adapt to the changes, which can lead to the decrease of the gain or even exhibit a negative

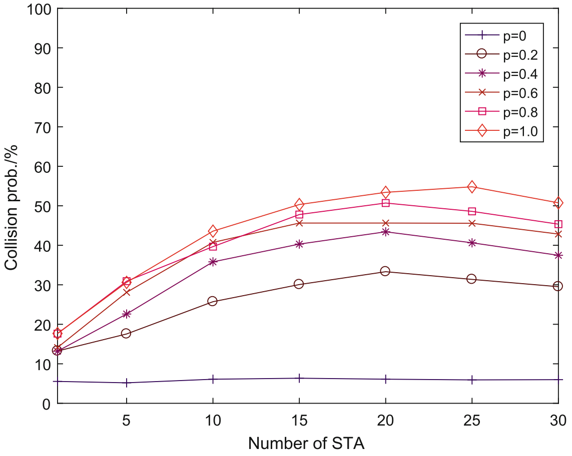

Fig. 6. Collision probability performance of PSR at different number of STA in each BSS.

gain. In this case, the use of the PSR mechanism with an appropriate value of p can effectively solve the problem.

5 Conclusions and Future Work

This paper proposes a PSR mechanism to increase the gain from SR under indoor scenario, and solve the problem that the existing SRP mechanism cannot dynamically adapt to the scenario changes, the simulation results show the feasibility of the scheme. In the future, we plan to make dynamic optimization strategies for SR probability in PSR mechanism based on the key idea described in Subsect. 2.1; we also plan to study the theoretical model of PSR mechanism and give a more perfect solution to obtain the fullest gain from SR.

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