CRJT: Channel Reservation Based Joint Transmission MAC Protocol for the Next Generation WLAN

Peng Tan, Ding Wang, Mao Yang(✉), Zhongjiang Yan, and Bo Li

School of Electronics and Information,
Northwestern Polytechnical University, Xi'an, China
`tanpeng@mail.nwpu.edu.cn`,
{`wangd,yangmao,zhjyan,libo.npu`}`@nwpu.edu.cn`

Abstract. In the past few decades, the rapid development of wireless local area networks (WLANs) provides great convenience to human lives. However, as the number of users and the complexity of deployment scenarios have increase, the next-generation WLANs face the unprecedented challenge of quality of service (QoS) and quality of experience (QoE) of cell-edge users. In response to this challenge, access point (AP) cooperation is supposed to be a promising solution. In this study, we propose a joint transmission medium access control (MAC) protocol based on channel reservation (CRJT). This protocol can make full use of the wireless channels to complete channel reservations and support joint transmissions effectively between APs. The simulation results show that this protocol provides a robust communication guarantee for edge users.

Keywords: WLAN · Channel reservation · Joint transmission (JT)

1 Introduction

Wireless local area networks (WLANs) are playing an increasingly important role in the global communication network [1]. Their rapid development and widespread application have resulted in a greater focus on the design of related protocols and the performance analysis. With the rapid growth of users' traffic, WLAN has become one of the most important ways of carrying data services. In order to meet the growing needs of users, both the academia and industrial focus on the key technologies for next-generation WLAN.

Quality of service (QoS) and quality of experience (QoE) of edge users are two of the key performance indicators (KPI) [2] of wireless networks. High-density deployment is an important trend for next-generation WLANs. On the one hand, high-intensive deployments increase the interference [3], making it

J.-L. Chen et al. (Eds.): WiCON 2018, LNICST 264, pp. 52–61, 2019.
https://doi.org/10.1007/978-3-030-06158-6_6

more difficult to guarantee the QoS and QoE of edge users. In particular, next-generation WLANs also need to support outdoor deployment scenarios, further aggravating the problem. Therefore, the service performance of the edge users in next-generation WLANs is an important research direction.

In response to these problems, many studies have proposed the idea of access point (AP) collaboration. Adachi and Kumagai [4] proposed the multi-AP cooperative diversity, which is formed between multiple APs in the surrounding area with poor channel quality. APs located in a collaborative diversity provide up link (UL) and down link (DL) traffic for the stations (STAs) simultaneously. The AP collaboration diversity can specify the traffic priorities that can be supported (for example, only high-priority traffic can be supported). Sirait et al. [5] proposed that in a densely deployed multi-AP network scenario, all APs are connected to a control center (CC). Depending on the transmission request of each STA, the beacon signal strength of each AP measured by the STA, and the interference intensity of each AP on each channel, the AP centrally plans the working channel for the AP and allocates the serving AP to the STA. However, this method has a great deal of overhead and complexity in implementation, especially because the AP frequently switches the working channel and the STA frequently switches the associated AP. In addition, to address the problem of inadequate resource utilization in WLANs due to hidden terminal and exposed terminal problems, Nishide et al. [6] proposed a method that can obtain information on hidden terminals and exposed terminals more accurately by cooperation between APs so that the access process can be performed more efficiently and the network performance can be improved. In summary, the existing research on the cooperation between APs is still at a preliminary stage. On the one hand, the information that is exchanged and shared between APs is far from enough to achieve deep cooperation. On the other hand, the achievements through AP cooperation are limited and far from diverse.

Coordinated multiple points (CoMP) is proposed in cellular networks, which is based on different degrees of sharing of the channel state information (CSI) and data information by each base station [7]. Through the cooperation of base stations between cells, the interference originally used by adjacent cells is converted into useful information, thereby improving the performance of users located at the edge of the cell. Cellular networks have X2 interfaces and are extremely time-critical networks. However, WLANs usually do not have X2 interfaces and have a distributed competition mode, whose time planning is not strict. Therefore, it is impractical to directly introduce CoMP into WLANs.

Therefore, in this paper, we propose joint transmission (JT) medium access control (MAC) protocol based on channel reservation, named CRJT, by combining the channel reservation mechanism and JT in the WLAN. The channel reservation guarantees the successful probability of JT. Specifically, in this study, we design the detailed MAC protocol for CRJT and verify its performance through simulation platforms. The simulation results show that the CRJT results in a 42.9% gain due to its maximum signal gain of 3 dB when there are two cooperative APs within the coverage distance of the APs service and when the STAs are located at the same distance from each other and far from each other. At the same time, regardless of the topology, the CRJT always has a lower packet loss rate than the non-CRJT. This gap is even more significant in a topology where the links are far away. This is a significant improvement in the QoS and QoE of the edge cell users.

The contributions of this paper is summarized as follows:

- As far as we know, this is the first work on the combination of channel reservation and JT in the design of the MAC protocol of the next generation WLAN. Meanwhile, the proposed method improves the edge users QoS significantly and guarantees the reliability of the JT.
- The results of this study demonstrate that the proposed protocol improves the QoS of the edge users using a simulation. In the topological structure in which the STAs are at the same distance from two cooperating APs, the distance covered by the AP is increased by 42.9%. At the critical case, the packet loss rate is reduced by more than 70%.

This structure of paper is as follows: Sect. 2 illustrates the proposed CRJT-MAC protocol. Section 3 depicts the simulation platform, Sect. 4 evaluate the performance. Section 5 lists some discussions, and Sect. 6 concludes this paper.

2 CRJT-MAC Description

2.1 Core Ideas

The CRJT is mainly aimed at cell-edge STAs and has the objective of increasing the signal-to-interference-plus-noise ratio (SINR) of the receiving STA through multi-AP JT to ensure the success rate of the reception, thereby increasing the edge users throughput.

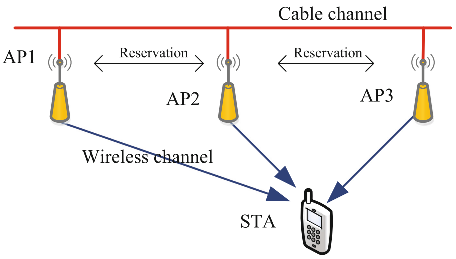


Fig. 1. CRJT scene schematic.

As shown in Fig. 1, the STA is an edge user of a cell and is far from the AP of the cell in which it is located (AP1). In addition to the dense deployment, the STA in this scenario cannot guarantee high throughput. In order to ensure that the AP1's DL traffic is accurately acquired by the STA, the JT MAC protocol based on the channel reservation schedules AP2, AP3, and AP1 for the JT.

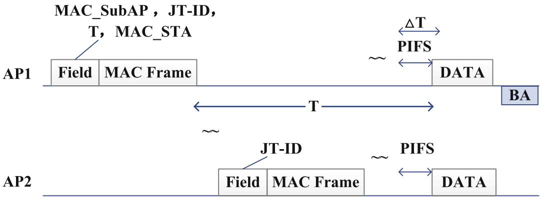


Fig. 2. CRJT flowchart (Scheme 1).

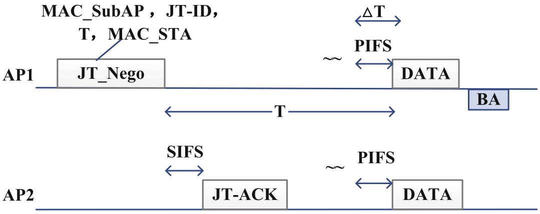


Fig. 3. CRJT flowchart (Scheme 2).

2.2 Protocol Process

The CRJT process is divided into two parts: channel reservation and JT. Figures 2 and 3 show the two implementation processes of the CRJT, whose main difference lies in the different methods of channel reservation.

Figure 2 shows Scheme one. In this scheme, AP1 and AP2 implement the channel reservation by adding a field in the data packet. The specific flow is as follows: (1) the principal AP (AP1) has information that needs to be jointly transmitted; it determines the subordinate AP (AP2) and the object to be transferred (STA) and then establishes an identifier(ID) for this reservation. (2) In the next data transmission of the AP1, the field is added to the data frame and the information such as the address of the AP, the address of the STA, the reservation time T, the reservation ID, etc. is added to the field and is sent along with the data packet. (3) After receiving a packet with a reserved field, AP2 parses the field, determines its own identity (subordinate AP), and determines whether it can participate in this JT according to its own traffic conditions. If possible, APs will add the same reservation ID to its own next packet to determine the reservation. (4) After receiving the reservation signal, AP1 sends the DATA frame to the STA according to the reservation time T. At the same time, AP2 also sends the same DATA. (5) After the STA receives this DATA, it sends an acknowledge packet (ACK) to AP1 to complete the joint transmission.

It should be noted that, in order to ensure that the JT is successfully performed at the scheduled time, the point coordination function interframe space (PIFS) duration is reserved prior to the transmission so that the AP can successfully obtain the channel use right. In addition, the peripheral traffic is set to remain within a period of time ΔT from the start of the PIFS timer to the transmission of the DATA frame to avoid collisions.

Figure 3 shows Scheme 2. In this scheme, AP1 and AP2 make channel reservations through new control frames. The reservation process is as follows: (1) AP1 adds the reservation information to the protocol control frame JT-Nego and sends it out. (2) After AP2 receives the JT-Nego, it determines its own identity (subordinate AP) and responds to the control frame JT-ACK to confirm that it can participate in this JT.

Both schemes can effectively implement the channel reservation. The advantage of Scheme 1 is that there is no need to add a new frame type to the protocol and it will not increase the channel traffic. The disadvantage is that the controllability is poor and the feedback speed is slow. Scheme 2 has good control effects, fast feedback, and high efficiency but the addition of the frame types makes the channel competition more intense.

2.3 Frame Structure Design

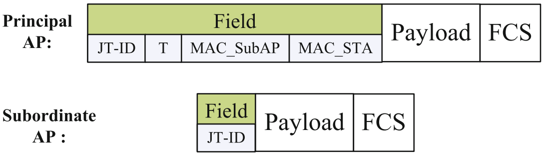


Fig. 4. CRJT frame structure (Scheme 1).

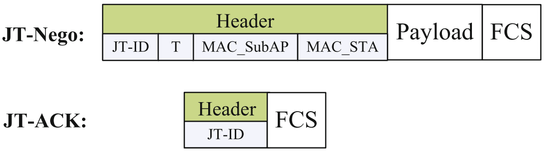


Fig. 5. CRJT frame structure (Scheme 2).

In Fig. 4, the channel reservation of Scheme 1 is shown. It consists of three parts, including the added field, payload, and frame check sequence. The newly added field includes a reservation ID, a reservation time T, the MAC address of the subordinate AP, and the MAC address of the receiving STA.

The channel reservation of Scheme 2 is shown in Fig. 5. Two types of frames are newly added. The JT-Nego frame sent by the principal AP includes information such as the reservation ID, the reservation time T, the MAC address of the subordinate AP, and the MAC address of the receiving STA. The JT-ACK frame returned from the subordinate AP contains the reservation ID.

3 Simulation Design

In order to evaluate the performance of the proposed design and verify the expected results, a simulation based on the NS-3 platform is conducted. NS-3 is a discrete event simulator [8]. Through serial configuration and code implementation, the protocol process design of the CRJT is completed.

3.1 Simulation Configuration

In this simulation, Scheme 2 is used. The design of the process (Fig. 3) is implemented in the NS-3 platform and the following parameters are configured [9]:

- Two cells are set; each cell has one STA and the scene is set as a diamond.
- The simulation time is set to 10 s.
- The modulation and coding scheme (MCS) of the data frame is set to an orthogonal frequency-division multiplexing (OFDM) rate of 36 millions of bits per second (Mbps) and the MCS of the control frame is set to an OFDM rate of 6 Mbps and remains fixed.
- The request to send/clear to send (RTS/CTS) are set to off.

3.2 Simulation Scene Design

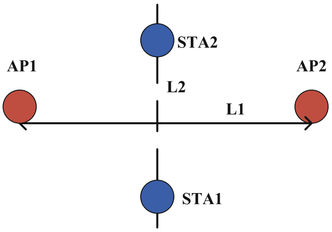


Fig. 6. Simulation scene.

The simulation scenario is shown in Fig. 6. There are two cells and each cell has one STA. A diamond structure is formed in which the distance between the APs is L1 and the distance between the STAs is L2. In the simulation, AP1 acts as a principal AP and has a UL traffic for STA1; AP2 as a subordinate AP needs to participate in the JT of the data frame based on the channel reservation.

In order to verify the effect of the protocol, the throughput and packet loss rate are used as indicators and the link distance and data rate are used as independent variables for the simulation verification.

In the simulation with the link distance as an independent variable, we set L1 as shown in Fig. 6 to be unchanged at 20 m. L2 is incrementally increased from 10 m to 120 m, that is, the link distance is increased from 11 m to 61

m. We set the data rate to 30 Mbps and the packet size to 1000 byte. AP1 is responsible for contracting in CRJT mode and mobilizing the AP2 assistance. We count the number of successfully received packets, calculate the packet loss rate based on the total number of packets sent, and calculate the throughput based on the simulation time.

In the simulation with the data rate as the independent variable, two kinds of topological structures are set. Topology one: L1 is 40 m, L2 is 70 m (link distance is 40 m); topology two: L1 is 40 m, L2 is 80 m (link distance is 45 m). The data rate is set to increase from 2 Mbps to 24 Mbps and the packet size is 1000 bytes. The two topologies are simulated separately to calculate the packet loss rate and throughput.

4 Performance Evaluation

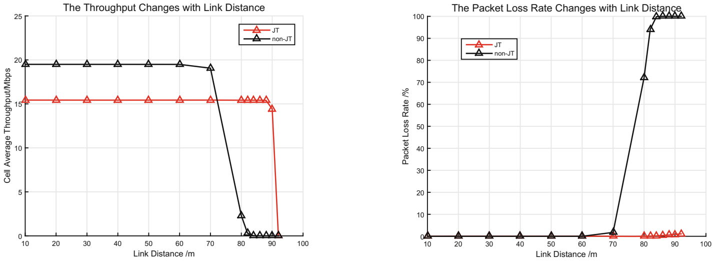
4.1 Performance Trends for Different Link Distances

Figure 7a depicts the trend of the throughput as the link distance increases. The CRJT and non-CRJT exhibit similar trends as the distance increases, that is, the throughput remains stable when the link distance is short and drops sharply as the link distance continues to increase. The differences between the CRJT and the non-CRJT depend on the link distance. (1) When the link distance is short, the CRJT throughput is 79.4% of the non-CRJT throughput because the SINRs of both schemes are relatively high and thus the packet loss is small (Fig. 7b) but the CRJT scheme reduces the throughput due to the introduction of a certain overhead. Of course, with the introduction of frame aggregation technology, the difference between CRJT and non-CRJT will be relatively small. (2) When the link distance is longer, the non-CRJT starts to decrease at 70 m, whereas the CRJT only decreases at 100 m because the JT adds 3 dB of power gain to the signal. This shows that the CRJT results in a 42.9% gain in the coverage distance of the AP.

Figure 7b shows the trend in the packet loss rate as the link distance increases. (1) When the link distance is short, the packet loss rates are very similar for the two schemes and both are low. This is because the SINRs of both schemes are relatively high. (2) When the link distance is long, similarly, if the distance is about 70 m, the non-CRJT packet loss increases sharply; however, at this time, the CRJT still maintains a low packet loss rate. The CRJT shows a significant increase in the packet loss rate until about 100 m. This is also because the JT provides protection for the STAs to successfully receive data packets.

4.2 Performance Trends for Different Data Rates

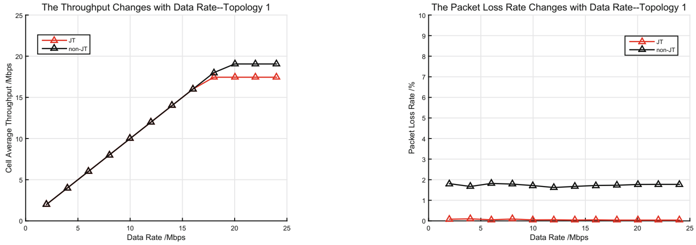
Figures 8a and 9a show the trend of the throughput for different data rates. In terms of the throughput, the CRJT and non-CRJT exhibit a similar trend in the throughput for the different data rates. The differences are as follows. (1) Fig. 8a shows that the maximum throughput achieved by the CRJT in the



(a) (b)

Fig. 7. Performance trends for different link distances

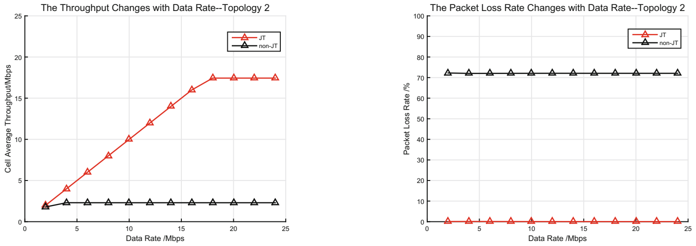
stationary phase is lower than that achieved by the non-CRJT (it is 92.1% of the non-CRJT). This is because the CRJT introduces a certain amount of reservation overhead. Similarly, under the frame aggregation technology, this gap will narrow. (2) For a very low throughput of the non-CRJT in Fig. 9a, the CRJT shows a throughput that is comparable to Fig. 8a. The CRJT has an approximately 7 times higher throughput than the non-CRJT in this topology. This is because in the scenario of topology 2, the link distance is very large. The non-CRJT can no longer guarantee the normal reception of the data packets, whereas the CRJT ensures the successful reception of data packets because of the power superposition. This shows that the CRJT can adapt more robustly to the change in the service rate of the AP and can provide several times the throughput of the non-CRJT in case of a long distance to the link.



(a) (b)

Fig. 8. Performance trends for different data rates (Topology 1)

Figures 8b and 9b show that the packet loss rate changes as the data rate increases. In both topologies, the packet loss rate is lower for the CRJT than the non-CRJT. Figure 8b shows that the packet loss rate of the CRJT is about 1.8% lower than that of the non-CRJT; Fig. 9b shows that the packet loss rate of the CRJT is about 72% lower than that of the non-CRJT. The simulation results indicate that the CRJT can exhibit greater gains with longer link distances.



(a) (b)

Fig. 9. Performance trends for different data rates (Topology 2)

In summary, the CRJT significantly improves the QoS of the edge STAs.

5 Discussion

Based on the simulation results, it can be concluded that the MAC protocol based on the CRJT can play a significant role in the performance improvement of edge users in a high-density deployment environment. In the development of next-generation WLANs, if this protocol is used as a reference and a more appropriate protocol process is designed, the experience of edge users will be significantly improved [10,11]. Of course, this comes at the cost of an increase in the communication between APs, which will undoubtedly require higher data processing capabilities.

6 Conclusion and Future Works

Based on the simulation results for the service rate and link distance, the following conclusions can be obtained:Because of its maximum 3 dB signal gain, the CRJT can indeed exhibit gains in a topology where the STAs are located at the same distance from each other and at a distance from two cooperating APs. The robustness of this gain in the critical state of the normal mode is worthy of recognition.The CRJT results in a certain loss of throughput due to the added overhead of the wired-side data transmission and new frames.In future studies, the author will add simulation designs for more complex topologies, further observe the CRJT performance under non-specific topological structures, increase the number of APs, and discuss the strategies for screening the APs in order to further improve the protocol process.

Acknowledgement. This work was supported in part by the National Natural Science Foundations of CHINA (Grant No. 61771390, No. 61771392, No. 61501373, and No. 61271279), the National Science and Technology Major Project (Grant No. 2016ZX03001018-004, and No. 2015ZX03002006-004), and the Fundamental Research Funds for the Central Universities (Grant No. 3102017ZY018).

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