Multi-cell Cooperative Transmission for the Next Generation Millimeter-Wave WiFi Network

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Abstract. In this paper, we study the directional data transmission of multi-cells. In a high-density cell scenario, if nodes of multi-cell perform data transmission randomly in the Scheduling Period (SP) phase, there may be a large interference between the links of cells using the same frequency. In order to reduce the interference, improve the throughput of the network, and reduce the delay of the network and packet loss rate, we propose a multi-cell cooperative transmission scheme. In our proposed scheme, one cell is set as the primary cell, and one cell is the secondary cell, and a special new frame is proposed. When the nodes of the primary cell starts SP, the data sender of the cell sends the frame to synchronize between cells. The node of the other cell that received the frame performs data transmission at the appointed time point. Through our proposed scheme, the impact of other cells transmitting data on the acknowledgement (ACK) of the cell is greatly reduced. The simulation results show that the proposed scheme improves the anti-interference performance of the network including improving the network throughput and reducing the packet loss rate and packet transmission delay of the network compared with AP Clustering.

Keywords: Service period · Directional antenna · mmWave · Interference mitigation

1 Introduction

With the rapid growth of HD video, virtual reality and other ultra-high-speed services, traditional wireless LANs have become increasingly difficult to meet these needs. Since the 2.4 GHz and 5 GHz bands are used in the traditional WLAN, and the unlicensed spectrum resources in this band are less, the maximum information rate that can be provided is very limited. In recent years, the 60 GHz millimeter wave band WLAN with 5 GHz to 9 GHz unlicensed spectrum

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resources has become a research hotspot in academia and industry. As mentioned above, the current WLAN development is difficult to meet these requirements. In the 60 GHz millimeter wave band, there are a large number of unlicensed spectrum resources, which can carry larger data information and can be used indoors, offices, etc. Therefore, it's a good solution to the current demand for Spectrum resource due to ultra-high-definition video and virtual reality. The wireless LAN protocol that more commonly used for the millimeter wave band is the 802.11ad standard.

In IEEE 802.11ad/ay, although the bandwidth of the millimeter wave and the transmission rate are very advantageous, the transmission loss is very serious due to the self-characteristic of the millimeter wave. Therefore, when the millimeter wave is used, the millimeter wave is oriented, and the directional beam can reduce the transmission loss in certain degree. This is why IEEE 802.11ad/ay specify that the MAC process is divided into two parts in a wireless LAN, we called Beacon Interval. The interior divided into two parts, Beacon Header Interval and Data Transmission Interval. The Beacon Header Interval (BHI) includes Beacon Transmission Interval (BTI), Association Beamforming Training (A-BFT), and Announcement Transmission Interval (ATI). Data Transmission Interval (DTI) is used for data transmission including Scheduling Period (SP) and Contented based access period (CBAP) [1–3]. This basic set of superframe structure is still used in 802.11ay (Fig. 1).

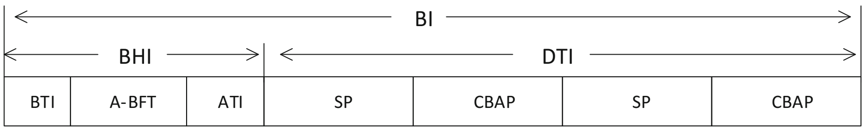

Fig. 1. A typical superframe structure.

In the existing IEEE 802.11ad standard and 802.11ay draft, if different cells are in the same SP phase, the senders don't randomly back off when transmitting data packets, which may result in interference from other cells in the same SP phase during transmission. It is not clearly stated in the standard whether there are Clear Channel Assessment (CCA) in the SP phase. If there is CCA, the links in different cells will be suppressed. If there is no CCA in SP, there will be great interference in the links in different cells [4,5].

The method for interference reduction of multi-cell in the existing protocol is mainly AP Clustering. AP Clustering interleaves the BTI or BHI phases of different cells to ensure the successful transmission of the beacon frame and the beam training is done correctly.

The work done in this paper: for the SP phase interference of multi-cell, an method is proposed based on the AP Clustering of the existing protocol standard. We propose a new frame called SPBeginBroad frame. This new frame can synchronize the transmission progress of different cells in SP phase. If the transmission progress can be synchronized, the interference to receiver can be reduced greatly. At the beginning of the SP, the initiator of the link directly broadcasts a new frame, which can reduce the interference in links of different cells. Specifically, we design a multi-cell cooperative transmission MAC protocol flow, and verify its performance through simulation. The simulation results show that the MAC protocol flow can improve throughput of the network and service quality of edge users.

The rest of this paper is organized as follows. In Sect. 2, we find the problems in the high-density cell scenario of the existing IEEE 802.11ad/ay protocol. In Sect. 3, a new algorithm is proposed to solve the problems. The Sect. 4 set the simulation configuration and gives the simulation results. Finally, Sect. 5 concludes this paper.

2 Motivation

In multiple cells, there are interferences between the cells using the same frequency band. We use AP Clustering principle to reduce the interference in the beam training phase and ensure that STAs can receive DMG Beacon frames. This paper uses distributed AP Clustering, which interlace the BHI period between multiple cells. While the nodes in a cell carries out information sending and beam training in BHI period, the nodes in other cells are in a special SP, Beacon SP, to keep silent, in order to ensure that the cell can successfully complete the information transmission and beam training [6,7].

In IEEE 802.11ad/ay, SP is introduced for scheduling transmission in the cell. When a AP assigns a certain SP to a certain STA for downlink transmission or uplink transmission, the SP of the cell can only be used for downlink transmission or uplink transmission with this STA. In SP phase nodes does not randomly back off to reduce interference from other cells. This leads to the interference of the same frequency channel between the cells specially when the multi cell are in same SP phase and the beam direction coincidence degree is high. In addition, if there are CCA in SP, when each cell uses the opposite direction of the beam, it will cause the STA to fail to send packet to complete link transmission process.

In order to solve the problems of the SP phase in the multi cell scenarios, firstly we set that the nodes in the SP do not carry out CCA. The data packet sender of the SP phase detects the specific packets from other cells. If the specific packets from other cells are received, the data transmission in this cell is synchronized with the other cell transmission according to the information in the specific packet. Thus, the interference in links which belong to different cells in the same SP is reduced, the concurrency of links in the high density scene of multi cells is improved, the anti-interference ability of multi cells is improved and the service quality of the edge users can be improved.

3 Method Description

3.1 Problem Description

AP Clustering guarantees the effectiveness of beam training and Beacon frame transmission. The concept of protection SP phase is proposed in 802.11ad protocol for multi-cell scenario. It means that when one cell is in the SP phase, other cells around it are not in the SP phase but in CBAP phase. If there is interference between two cells which are in SP phase and CBAP phase, respectively, the time required to access the channel of SP phase is short than CBAP phase, due to EDCF being used in CBAP phase and SP phase is scheduling [8]. It means that the data transmission in SP phase can be guaranteed more effectively than in CBAP phase [9,10].

Fig. 2. An example of multi-cell topology.

This paper proposes a new SP phase process based on the AP Clustering. For example, as shown in Fig. 2, the cell where the AP1 is located (the cell is the primary cell, and the information transmission of the cell is the highest priority) starts SP phase. Firstly, the STA in transmission state sends a broadcast frame named SPBeginBroad Frame to inform other cells. Other cells are secondary cells, and guarantee the information transmission of the self cell as much as possible. The SPBeginBroad contains the packet transmission start time and the size of the data packet and etc. After receiving the SPBeginBroad Frame, the STAs of other cells send the data packet synchronously with the cell where the AP1 is located, until the end of the SP phase belongs to itself. If the STAs of other cells do not receive the SPBeginBroad Frame, it means other cells do not interfere with the primary cell, so normal data transmission may be performed in these cells. In this paper, only the uplink is discussed.

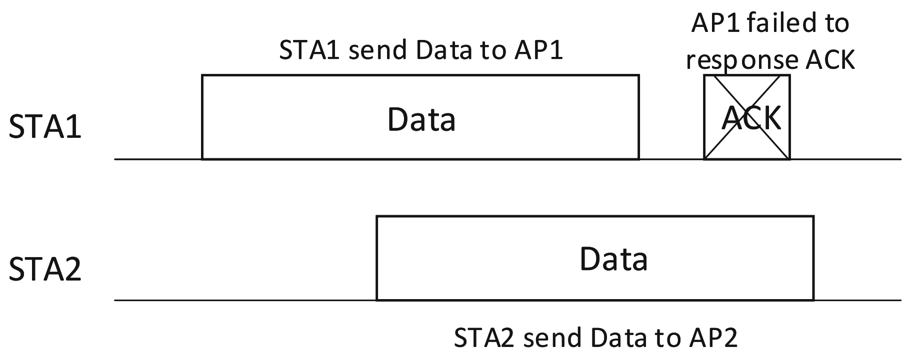

Fig. 3. The transmission failure in SP.

As shown in Fig. 3, in the SP phase of multi-cell, the transmission between cells is not controlled, and there is no CCA in the SP phase. The phenomenon shown in the figure will appear, and there may happen that one link is successfully transmitted, and the other links are always in a failed state. For example, when the STA11 sends a data packet, the data packet from the STA21 is received, and the data packet end time is after the ACK frame. Therefore, the STA11 fails to receive the ACK frame, and it is impossible to determine whether the Data is successfully received by the AP1, and then STA11 enters the retransmission state.

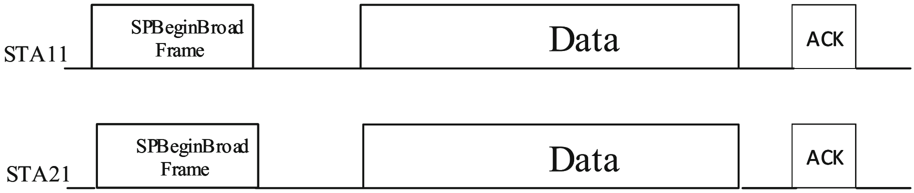

Fig. 4. The transmission progress in our method.

As shown in Fig. 4, we use the flowchart to describe the SP phase of multi cells. In combination with the topology of Fig. 3, after the cell of AP1 sending the SPBeginBroad Frame, STA11 starts the data transmission process after 2*SIFS, and STA21 receives this special frame. After receiving the frame, the STA 21 specifies the data transmission start time of the cell in which the AP1 is located, and starts the link data transmission process of the current cell after 2*SIFS; the data transmission process remains synchronized between the cells.

3.2 Frame Structure

Figure 5 is the SPBeginBroad frame structure. There are 4 parts of the frame: SPBegin Header, SPBegin MAC Header, Payload and FCS. We mainly need SP PacketSize, MCS ID and SP Duration to achieve synchronization of multiple cells.

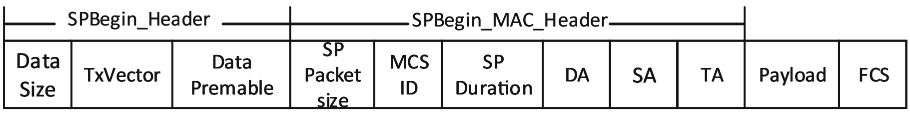

Fig. 5. SPBegin frame structure.

The cooperative transmission process ensures concurrency of different cells in the SP phase, effectively reduces interference and delay between cells, improves cell throughput.

4 Simulation and Discussion

4.1 Simulation Design and Implementation

We use the ns-3 simulation platform for the simulation, and ns-3 is one popular network simulation tool in the current. Based on the existing ns-3 simulation platform, the high frequency WiFi part is added for function development [11].

The simulation topology is set to a straight line. AP1 and STA11 on the left in Fig. 6 belong to the same cell, and AP2 and STA21 on the right belong to the same cell. AP1 is 0.5 m from STA11, AP1 is 1 m from AP2, and AP2 is 0.5 m from STA21. The simulation duration is 10s, the beacon interval is 100 ms, and the DTI phase is divided into 8 SPs, excluding Beacon SP. The simulation service adopts a uniform rate service. In this paper, the uniform rate service is used for performance discussion. The main simulation parameters are showed in Table 1.

Fig. 6. Simulation topology.

Table 1. Simulation parameters.

The number of AP	2	BI length	100 ms
The number of STA in one cell	1	Data MCS	DMGMCS10
Position of AP1	(1.5, 1, 0)	Management MCS	DMGMCS0
Position of AP2	(2.5, 1, 0)	Mobility model	Stationary
Position of STA11	(1, 1, 0)	Length of simulation time	10 s
Position of STA21	(3, 1, 0)	CBAP	no CBAP
Packet length	4096 bytes	SP	no RTS/CTS

There is no RTS/CTS in the process of transmitting data packets in the SP phase and we set that there is no CCA in SP. The MCS of data frame is DMGMCS10, and the MCS of management frame is DMGMCS0. The beacon interval of the two cells are staggered from each other, and Beacon SP is added to protect the BHI phase. As shown in Fig. 7, when AP1 is in the BHI phase, the cell where AP2 is located is in a silent state, does not interfere with the cell where AP1 is located. The SP is used in the DTI phase, and STAs send data to APs in SP.

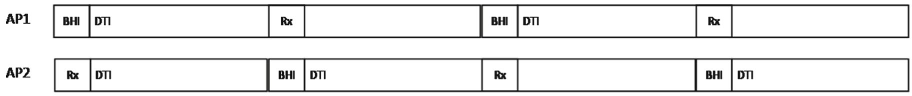

Fig. 7. Basic protocol framework.

In the SP phase, the STA broadcasts the SPBeaginBroad Frame before transmitting the data packet, and carries the information packet and the packet transmission start time of the SP. After broadcasting the SPBeginBroad Frame for 2*SIFS, the STA11 starts to send the Data packet. In ns-3, STA21 enters the scheduling timing after receiving the frame, and waits for 2*SIFS to perform synchronous transmission with the cell where AP1 is located. Since the specified data packets of the two cells are the same size, the two links can ensure a good synchronization effect in this SP phase.

4.2 Performance Evaluation

We analyzes the simulation results in this section.

In Fig. 8, we compare the throughput of the multi-cell cooperative transmission scheme and AP Clustering scheme. It can be seen from the figure that the throughput of the AP Clustering scheme is not much different from the multi-cell

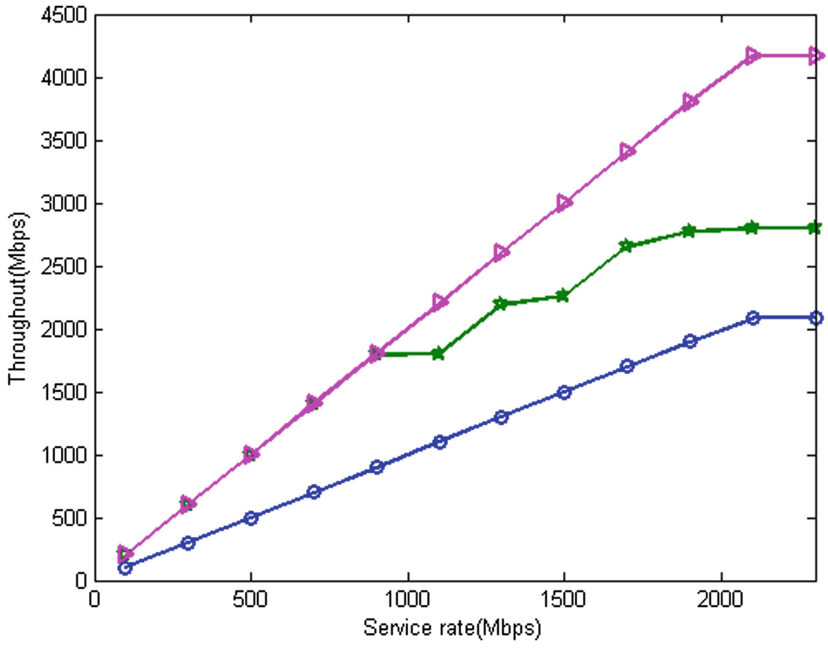

Fig. 8. Throughput of the network.

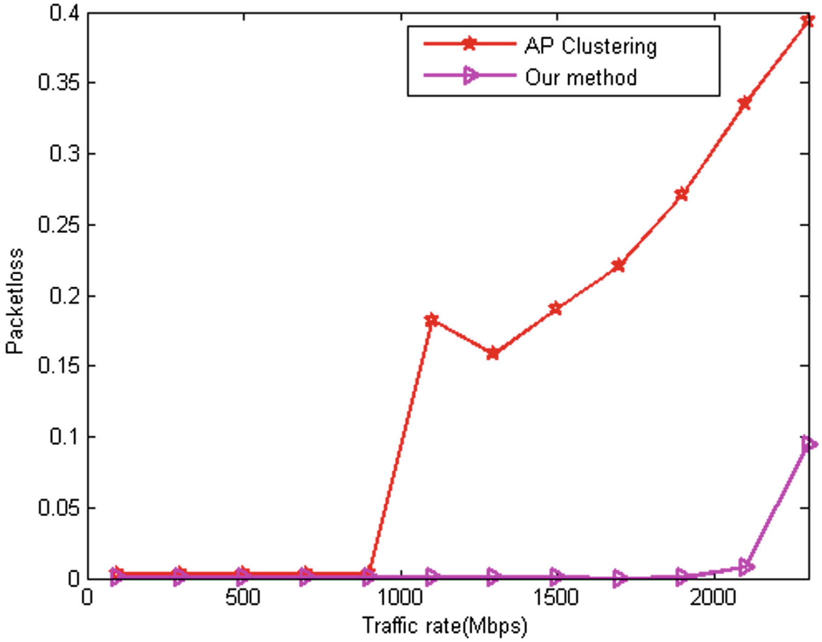

Fig. 9. Packet loss of the network.

cooperative transmission scheme when the traffic rate is low. As the service rate increases, the conflict between AP Clustering links increases, the trend of the throughput increases slowly, and the multi-cell cooperative transmission scheme shows better throughput gain. If the service is not a uniform rate service, the throughput performance gain is significant when the service is saturated.

In Fig. 9, we compare the packet loss of the multi-cell cooperative transmission to the AP Clustering schemes. It can be seen from the figure that when the service rate is low, the packet loss rate of the two schemes is not much different. As the service rate increases, the packet loss of the AP Clustering scheme increases significantly, and the packet loss rate of the multi-cell cooperative transmission scheme increases slowly.

5 Conclusions and Future Work

In this paper, based on AP Clustering protocol flow, a new multi-cell cooperative transmission MAC flow is proposed. Through principle analysis and ns-3 simulation verification, it shows that in the two-cell topology, when full traffic rate, the multi-cell cooperative transmission has a greater advantage than AP Clustering in throughput packet loss, delays and other aspects. This paper only discusses the uplink service in the two cells, and the multi-cell complex scenario is to be studied later.

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