Dynamic Time Slot Adjustment Based Beamform Training for the Next Generation Millimeter Wave WLAN

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Abstract. In recent years, people have put forward higher and higher requirements for high-speed communications within a local area. Millimeter-wave WLAN has attracted much attention from academia and industry by virtue of its ultra-large bandwidth and short-range coverage. Beam training is a key technology of millimeter wave WLAN. The quality of beam training is related to communication performance and even communication. However, as the number of nodes continues to increase, the beam training efficiency of the traditional millimeter wave WLAN is very low, which affects system performance. This paper proposes a beamforming training method based on dynamic time slot adjustment for the next generation millimeter wave WLAN. The beam training slot in the subsequent beacon interval (BI) can be adjusted according to the completion of the beam training in the previous BI, thereby improving the efficiency of beam training. The simulation results prove that the method proposed in this paper can effectively improve the beam training efficiency and has a small impact on the performance of the system.

Keywords: Millimeter wave · WLAN · 802.11ad · Beam training

1 Introduction

With the widespread use of WLAN, the unlicensed spectrum in the low frequency (LF) frequency band has been close to saturation. Therefore, the most commonly used 802.11 WLAN (such as 802.11n, 802.11ac, etc.) cannot meet the constantly updated wireless The data rate of the application. In order to provide users with a higher data transmission rate to meet the constantly updated data transmission requirements, in order to adapt to more complex network deployment scenarios, more usable spectrum and more cutting-edge technologies are required. Millimeter wave (mmWave) (i.e. 30 GHz–300 GHz) has more licensable spectrum, which

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can provide more opportunities for emerging broadband applications [1]. Currently, millimeter wave communication has been applied to the fifth generation (5G) mobile communication system and some cutting-edge wireless communication systems (such as IEEE 802.15.3c 802.11ad and 802.11ay, etc.) [2]. Among these abundant unlicensed spectrum, both academia and industry suggest that the 60 GHz unlicensed mmWave frequency band should be given priority. IEEE 802.11ad uses the 60 GHz frequency band (i.e. 57–66 GHz). In the previous work [3], we have extensively evaluated the performance of IEEE 802.11ad, but there are still many problems to be solved under the high-density network deployment in the future.

Because millimeter wave propagation suffers from severe path loss and signal attenuation, it is almost impossible to achieve long-distance communication transmission when using traditional omnidirectional communication. Therefore, beamforming technology that can concentrate the transmit power and receiving area on a narrow beam is commonly used for directional transmission, and beamforming training (BFT) is a key process to realize directional communication. Therefore, the BFT process must be carefully designed in the protocol, and the best transceiver sector must be determined to be fully prepared for directional transmission. If the process of establishing directional communication transmission takes too much time, the communication delay will be too long. Quality of experience (QoE) is reduced [4]. However, because the BFT process in 802.11ad cannot be flexibly configured according to different requirements, this makes the BFT process very time-consuming and inefficient in communication. Therefore, it is very important to design a simple and effective BFT method, especially for WLANs that aim to reduce costs and complexity to provide high-quality services (QoS). The Association Beamforming Training (A-BFT) stage is the key to channel access and BFT, because in high-density user deployment scenarios, the number of nodes continues to increase or changes greatly, causing nodes to collide or not optimize when they enter a fixed number of time slots. Once the STA cannot complete the beam training in the A-BFT, it will not be allocated to the time slot to complete the data transmission, but will wait for another A-BFT in the next beacon interval (BI) to access the training again, which will seriously affect QoE.

At present, there are already some solutions to study the efficiency of BFT of millimeter wave WLAN. For example, some studies have proposed a multichannel A-BFT solution to reduce serious conflicts during A-BFT in high-density deployment scenarios. Other studies have proposed extending the number of time slots to adapt to high-density user scenarios. Although these solutions provide efficient and feasible solutions, they all create additional costs, which will affect the overall performance of the system more or less. Therefore, it is the key to present research to propose an efficient A-BFT scheme that can dynamically adjust the ABFT slots according to the beam training conditions of the nodes in the cell.

To efficiently improve the beamforming training performance, this paper proposes a method based on dynamic time slot adjustment, which dynamically determines the number of A-BFT time slots in the next BI according to the conflict in the A-BFT in the previous BI, thereby re-dividing the A-BFT time slots. And for the node that has completed the training, it is only necessary to save the training result for use in the next BI until the communication quality of the link drops, and then perform beam training for the node access. Save the time allocated for beam training. At the same time, the number of sector sweep frames (SSW frames) in ABFT Slot is reduced by determining the best receiving sector of the STA (obtained in the BTI phase), and using this as the center to do only 180° sector training. The simulation shows that the system greatly improves the efficiency of beam training while ensuring the overall performance is unchanged.

The Section 1 summarizes the research status of 802.11ad, the Sect. 2 introduces the principle and motivation of the method used, the Sect. 3 explains the principle and the frame structure design and program flow design, the Sect. 4.1 configures the simulation platform, and the Sect. 4.2 analyzes the simulation results. Section 5 summarizes the work of this paper.

2 Related Work and Motivation

2.1 BFT in IEEE 802.11ad/ay

In the 802.11ad/ay protocol, the A-BFT phase is allocated in each BI, and a certain amount of ABFT slots are set in the A-BFT phase. Before the beam training starts, that is, after the node receives the DMG beacon frame, the node in the cell randomly selects an ABFT slot It is used for beam training. In the ABFT slot, the AP receives the SSW frame sent by the STA rotating every sector omnidirectionally. Based on the received SSW frame, the AP determines the STA with the strongest transmission energy to send the sector, and sends the information It is stored in the sector sweep feedback frame (SSW-FBCK frame) and returned to the STA. This process completes the beam training of the STA's transmission sector. This process is shown in the following figure (Figs. 1, 2, 3, and 4):

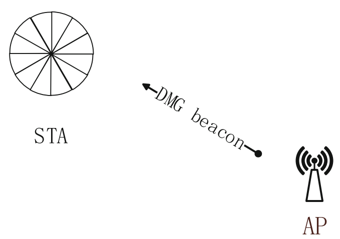

Fig. 1. AP sends DMG beacon frames in all directions

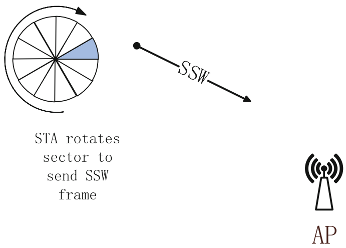

Fig. 2. STA rotates sector and sends SSW frame to AP

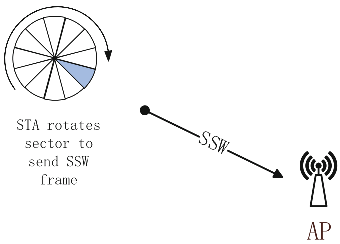

Fig. 3. The AP receives the SSW frame with the strongest signal energy

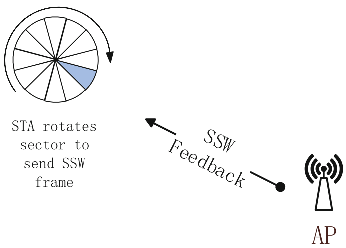

Fig. 4. The AP sends the STA's best sending sector information through the SSWF-BCK frame

In the A-BFT phase, the STA in the cell randomly selects the training time slot, which will cause several STAs to select the same time slot and cannot complete the training. (There are two cases where the training cannot be completed. One is although There are several nodes in the same time slot, but due to STA directional transmission, one node in the time slot finally completed the training, and the other is that all the nodes that choose the time slot cannot complete the training as shown in the figure). The node will try to access the training again in the next BI (Figs. 5 and 6).

In order to avoid such conflicts, it is common practice to preset free ABFT slots before the start of BI to ensure that the number of time slots is greater than the number of nodes. Although this method takes care of the success rate of beam training, it reduces the overall training efficiency. For a system where the nodes in a cell maintain a stable state, the less time the beam training takes, the

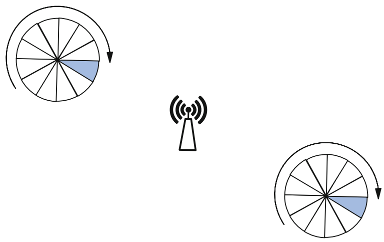

Fig. 5. Complete sector training of a STA in a time slot

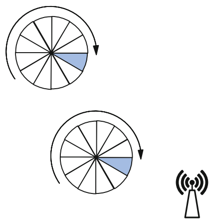

Fig. 6. No node in the time slot has completed sector training

better. Considering this factor, this article introduces a beam training method based on dynamic time slot adjustment. This method only allocates time slots for nodes that have not completed beam training. For nodes that have completed beam training, save and use the trained sectors As a result, a link maintenance mechanism is also introduced to maintain the quality of the management link. If the quality of a link decreases (during the communication, the initiator does not receive an ACK frame or the receiver does not initiate an ACK frame), let the node of the link accesses the ABFT slot again for beam training.

2.2 Related Studies on BFT Improvement

There have been many studies aimed at improving the efficiency of BFT. For example, a multi-channel A-BFT scheme was proposed in [5], which allocates the same A-BFT to the STA on the secondary channel as the primary channel. Configuration to reduce serious conflicts during A-BFT in high-density deployment scenarios. For example, if two or more STAs choose to access the same ABFT slot, they are allocated to different master and slave channels respectively. Such a multi-channel scheme can effectively avoid conflicts. Since 8 ABFT slots are generally set in 802.11ad, in high-density network deployment scenarios, the number of time slots can be expanded to reduce training conflicts. [6] Provides a separate ABFT (SA-BFT) mechanism to expand the original 8 time slots to more, that is, an EA-BFT time slot is added to the DMG Beacon frame, which is expressed as an extended extra The number of time slots, therefore, the total number of time slots in the extended A-BFT is "A-BFT length+EA-BFT length". [7] and [8] can also effectively avoid the collision problem of A-BFT. Since A-BFT is divided into multiple time slots, when one STA performs receiving sector scanning in one of the time slots, other STAs can remain silent. In order to improve the efficiency of A-BFT, Akhtar and Ergenthe [9] proposed an intelligent monitoring (ILA) mechanism during A-BFT to reduce the BFT overhead between STAs. When a STA accesses the ABFT time slot for receiving sector scanning, other STAs keep listening in the quasi-omnidirectional mode instead of remaining idle. They will learn the approximate beam direction of the training STA by completing the training result of the beam training node. After a certain number of nodes have completed training, other STAs can infer the best sending sector direction of their peers. Therefore, STAs do not need to rotate 360° to send SSW frames to APs, which can significantly reduce the BFT overhead between STAs.

2.3 Motivation

The motivation of this paper is to solve the problem of training conflicts and the decrease of beamforming training efficiency due to the increase of the number of nodes during beamforming training. The beamforming training method in the A-BFT phase of the current 802.11ad protocol is not flexible enough, because it is usually necessary to set up enough ABFT slots in advance to cope with the nodes in the cell. Such a setting cannot meet future high-density network deployment scenarios. As the number of nodes in the cell increases, more and more STAs will inevitably In the beam training phase, conflicts are generated and the training cannot be successfully completed and thus cannot be served, which reduces the training efficiency of the entire A-BFT phase. The following figure shows that beam training conflicts occur with the increase of access nodes under a fixed number of ABFT slots (Fig. 7).

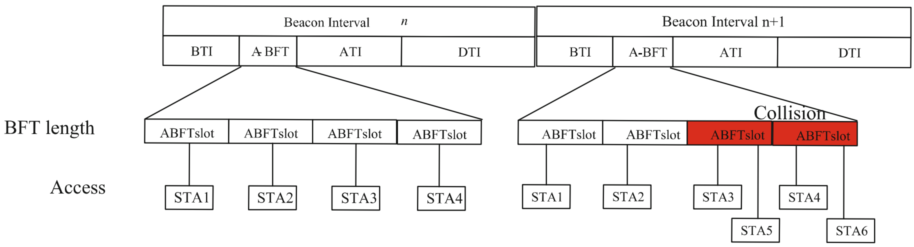

Fig. 7. Increased node access in cell leads to beamforming training collision

3 Scheme Description

The beam training method proposed in this paper dynamically adjusts the number of ABFT slots according to the number of nodes that have beam training conflicts at this stage to meet the training needs of all nodes in the cell. At the beginning of the simulation, an ABFT slot number is preset to perform beam training on the nodes in the cell. The beamforming training is first found The best receiving sector of the STA. Using this as the center, let the sector only scan 180°, then find the node that has completed the training and save the training result of the node, and count the conflicting time slots and conflicting nodes at the same time, and this The sum of the two values is set to the number of ABFT slots in the next BI. Assuming that there are 10 nodes in the cell preset 6 time slots, at most 4 of these 6 time slots will cause training conflicts, and at least 4 nodes will be unable to complete beam training due to conflicts (here the conflict is assumed to be In the first case, one node in the time slot has completed beam training). Then in the next BI, only 8 ABFT time slots need to be allocated to complete the training of all nodes in the cell, and no nodes are trained in the subsequent BI, unless the communication quality of some of the nodes is reduced (the communication quality can be reduced by The link maintenance mechanism detects that the receiving end has not received an ACK or the sending end has not initiated an ACK within a certain period of time). The following figure shows the frame structure design of this scheme (Fig. 8):

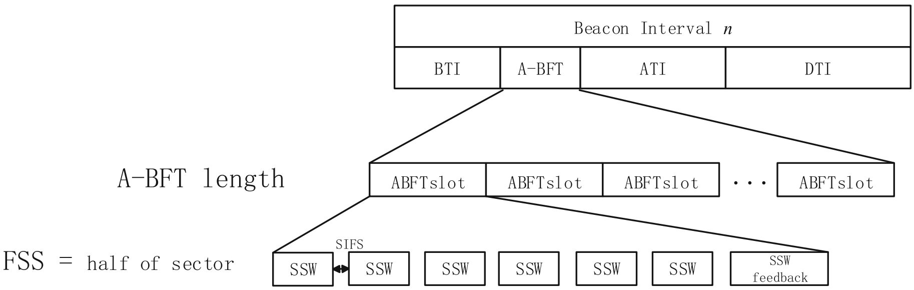

Fig. 8. Dynamic ABFT slot MAC layer frame structure

If in the A-BFT stage of the nth BI, a node has not completed the beam training of the sending sector, that is, a conflict occurs, the ABFT slot is dynamically adjusted according to the conflict situation in the n+1th BI (Fig. 9).

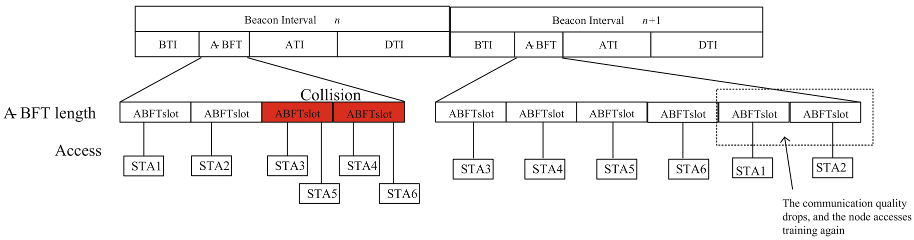

Fig. 9. Dynamically adjust ABFT time slot STA access training

As shown in the following figure, the sequence flow chart of STA performing beam training. First, AP broadcasts a DMG beacon frame to STA. After receiving it, STA in the cell selects an ABFT slot to access in order. After entering ABFT slot, STA rotates to receive the best The sector is the center 180° to send the SSW frame, the AP receives the SSW and makes a decision, selects the strongest energy among them, and returns the sector information to the SSW feedback frame to the corresponding STA. If two or more STAs are simultaneously accessed in the time slot, beam training cannot be completed. Therefore, in the ABFT phase of the next BI, first adjust the number of ABFT slots in the phase according to the conflict situation, and then train the nodes that have not completed beam training in the previous BI, and then consider whether the communication quality of the nodes that have completed the beam training is degraded, When the communication quality drops, beam training is performed for the node to access the time slot (Figs. 10 and 11)

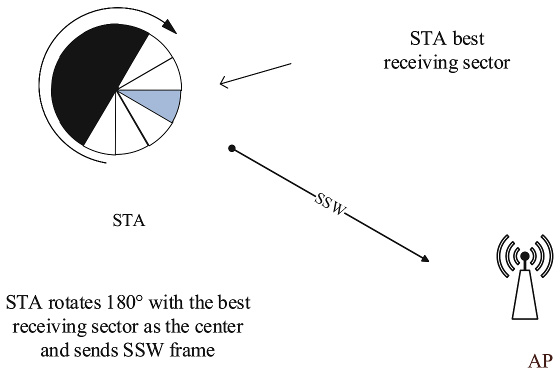

Fig. 10. STA rotates 180° to send SSW frame to AP

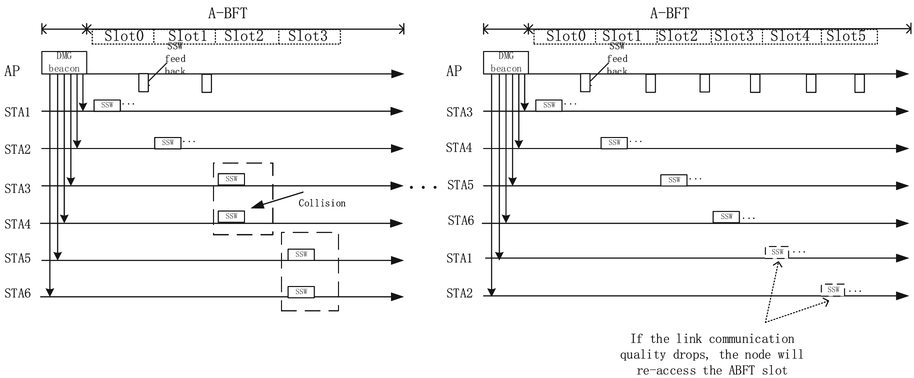

Fig. 11. Beam training sequence flow chart

4 Performance Evaluation

4.1 Simulation Settings

In this chapter, we use the configuration Intel®Core$^{\text{TM}}$i7-8750H CPU@2.20 GHZ main frequency, 8 GB memory and 64-bit Windows-10 operating system, all codes are developed under the NS3 simulation platform. The simulation configuration is a single cell scenario, with 1 AP and 6 STAs in the cell. Create cell congestion by reducing the number of preset ABFT slots to simulate high-density network deployment scenarios (Fig. 12 and Table 1).

Table 1. Parameter setting

Parameter	Configuration
Number of cells	1
Number of STA nodes in a single cell	6
Sector angle	30° (360° is divided into 12 sectors)
Channel model	Calibrated SISO channel
Meeting room scene size	3 m * 4.5 m
Channel bandwidth	2.16 GHz
Packet size	60000 bytes
Simulation duration	3 s
Link adaptation	According to simulation
MCS without link adaptation	DMG MCS24
BI length	100 ms
DTI stage configuration	Only SP
SP distribution principle	Fairness first
Physical layer	Phy Abstraction

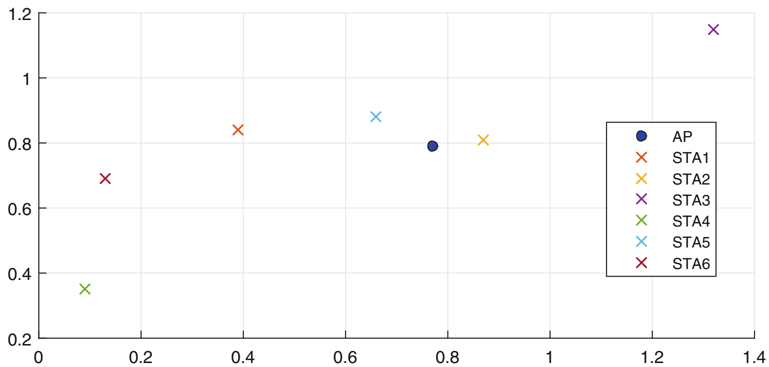

Fig. 12. Network topology diagram

4.2 Simulation Results and Analysis

According to the system throughput and packet loss rate, the simulation compares the script of adding dynamic time slot adjustment method and link maintenance mechanism with the original protocol script. As shown in the figure below, the blue solid line represents the original script without added functions, and the yellow The dotted line indicates the script with dynamic time slot adjustment added, and the red dotted line indicates the script with dynamic time slot adjustment and link maintenance mechanism added (Figs. 13 and 14).

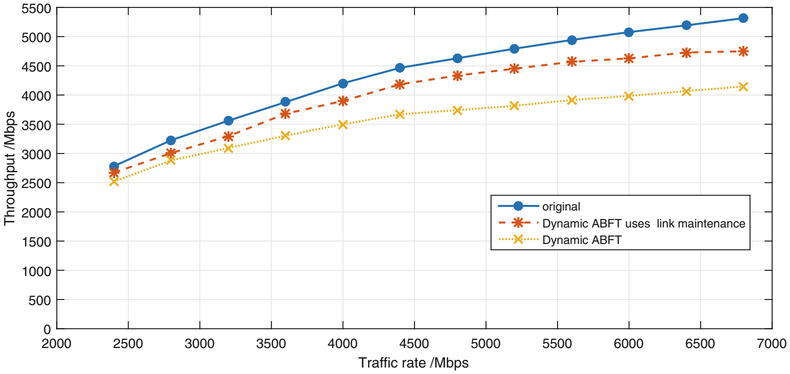

Fig. 13. Throughput comparison of various schemes

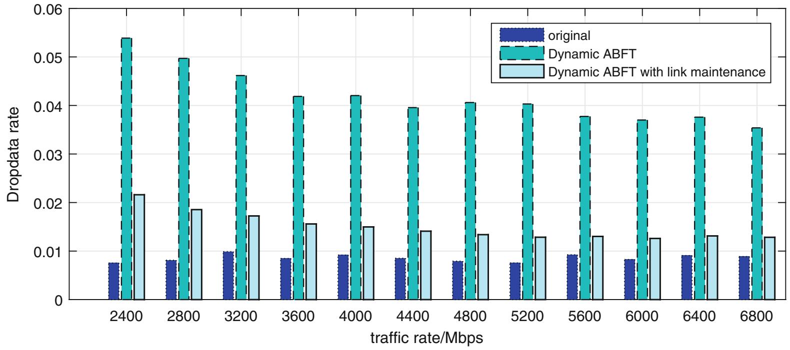

Fig. 14. Comparison of packet loss rate of each scheme

The simulation results show that, from the throughput curve, the performance of the curve with only dynamic time slot adjustment decreases more, and the link maintenance function can be better compensated. From the packet loss rate histogram, the packet loss rate with only dynamic time slot adjustment is higher, and the packet loss is mainly concentrated in the first few BIs. This situation is caused by the failure of the previous training conflict. Generally speaking, The dynamic time slot adjustment of link maintenance can not only improve the efficiency of beam training but also ensure the performance of the system.

5 Conclusions

This paper proposes a beam training method for the next generation millimeter wave WLAN based on dynamic time slot adjustment. In order to adapt to changes in the number of nodes in the cell and reduce beam training conflicts caused by changes in the number of nodes, the original fixed number of ABFT slots are set to a form that can be dynamically adjusted according to the beam training conflicts. The simulation results show that this method improves the efficiency of beam training while ensuring the overall performance of the system, and can better adapt to future high-density network deployments.

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