



An Adaptive Beamtracking Method for the Next Generation mmWave WLAN

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Abstract. With the development of next generation mobile communication and short distance communication, mmWave is becoming more and more critical. The transmission rate and bandwidth of mmWave are greater than that of low frequency band. mmWave can effectively provide large-flow and low-latency service over short distances. Next generation WLAN, such as 802.11ad/ay, already uses mmWave. mmWave uses the directional gain antenna, and beamtracking is performed to determine the new working beam when one end of the communication is displaced. The beamtracking method is designed in detail in 802.11ad /ay: beamtracking is performed after data is sent. This method takes the delay into account, but it is easy to lose packets when nodes move quickly. To address this issue, we design an adaptive beamtracking method (ABT), which adjusts the order of sending data and performing beamtracking according to the number of consecutive beamtracking request. It can take both throughput and delay into account. The simulation results show that the adaptive beamtracking method can achieve the same delay as the beamtracking method in 802.11ad/ay, and the throughput is greater than the beamtracking method in 802.11ad/ay.

Keywords: Next generation WLAN · mmWave · Beamtracking · 802.11ad/ay

1 Introduction

In recent years, with the development of automatic driving, industrial Internet and virtual reality, people's demand for large bandwidth services and low latency services has gradually increased [1]. WLAN such as 802.11ax works in 2.4 GHz and 5 GHz frequency band, with a maximum bandwidth of 160 MHz and a theoretical rate of 9.6 Gbps. This frequency band is also the operating frequency of Bluetooth and Radar, so the channel is very crowded. In order to avoid the disadvantages of low frequency band, in 2013, the WIFI Alliance launched 802.11ad, which operates at 60 GHz, has a maximum bandwidth of more than 1 GHz and a maximum rate of 8 Gbps. It uses mmWave to greatly improve the bandwidth

and rate of short distance communication. The next generation mmWave WLAN 802.11ay is improved on the basis of 802.11ad. By introducing MIMO, channel bonding and other technologies, the maximum bandwidth is 8.64 GHz and the theoretical rate is 100 Gbps [2].

mmWave is easy to fade and the communication distance is short. Directional antenna is needed to improve the gain. Because the beam has direction, the beam alignment should be carried out first in mmWave communication. When displacement or occlusion occurs in the communication process, the communication quality will be affected or even communication cannot be achieved. Therefore, beamforming (BF) and beamtracking (BT) are very important processes in mmWave communication. In future communication scenarios, such as autonomous driving and virtual reality, etc. [3], mobility becomes an important feature, and communication with directional transmission is more sensitive to movement. Therefore, Beamtracking has become the focus of academia and industry. It means that when one end of the communication is moving, the other end can find in timely and perform beamtracking, determine the new work beam pair and notify the other side.

The beamtracking process specified in 802.11ad/ay is as follows [4]: If the RSSI (Received Signal Strength Indication) of the data packet is lower than a certain threshold, beamtracking will be performed. In the next transmission, beamtracking is performed after data is sent, and the beam pair with the largest RSSI is selected as the new working beam pair and notified to the other side. However, there is a certain lag in this way. Beamtracking is performed after the packet is sent, when the move speed of node is very fast, the packet will often fail to be transmitted. If the node moves continuously and uses this beamtracking method every time, each data packet will be lost.

For a long time, people are trying to reduce the overhead of beamtracking from MAC layer, physical layer and channel. In reference [5], starting from the channel and aiming at the problem that the channel model of the current beamtracking algorithm is too simplified, Markov multi-beamtracking algorithm is introduced to maintain multiple beams for tracking at the same time. In reference [6], starting from the physical layer, Extended Kalman Filter is used to track the channel on the static antenna, the error variance estimated by Extended Kalman Filter is used to calculate the array vector error, and the minimum mean square error beamformer is used to update the beamforming weights. Reference [7] proposed a multi base station cooperative beamforming method to improve the communication quality at the cell boundary. Although these papers improve the efficiency of beamtracking from the physical layer and channel, they do not analyze it from the MAC layer. By changing the order of sending data and performing beamtracking, we can reduce the packet loss rate when node moves fastly.

To reduce the lag of beamtracking method in 802.11ad/ay, we design an adaptive beamtracking method (ABT), which adjusts the order of sending data and performing beamtracking according to the number of consecutive beamtracking request. It can take both throughput and delay into account. Post-beamtracking

means sending data before performing beamtracking. Pre-beamtracking means sending data after performing beamtracking. Record the number of consecutive post-beamtracking. If the number reaches the threshold, it indicates that the current movement of the node is intense and the post-beamtracking method is likely to fail. In this case, we should switch to pre-beamtracking. In the pre-beamtracking period, the change value of beam before and after beamtracking is recorded. If it is less than a certain threshold for n consecutive times, it indicates that the node is moving slowly and can be converted to post-beamtracking. Simulation results show that the throughput and delay of the proposed scheme are better than beamtracking method in 802.11ad/ay, and no extra overhead is introduced.

The remainder of this paper is structured as follows: Sect. 2 introduces the beamtracking method in 802.11ad and the problem of post-beamtracking. Section 3 introduces the detailed design of adaptive beamtracking. In Sect. 4, the performance of beamtracking method in 802.11ad/ay and adaptive beamtracking is verified by simulation, and the difference in throughput and delay between them is analyzed.

2 Related Works and Problem Analysis

2.1 The Beamtracking in IEEE 802.11ad/ay

mmWave uses the directional antenna. According to the width of the directional beam, the horizontal plane of the device is divided into different sectors, and each sector has a specific sector ID. The best transmitting beam and the best receiving beam are required for transmission. In this paper, we assume that each sector contains only one beam, and one sector ID corresponds to one beam. In 802.11ad/ay, the transmission is made up of beacon interval one by one. The following figure shows the structure of a beacon interval (see Fig. 1). The BHI is used for beam training at the beginning of each beacon interval, and the DTI is used for data transmission [4].

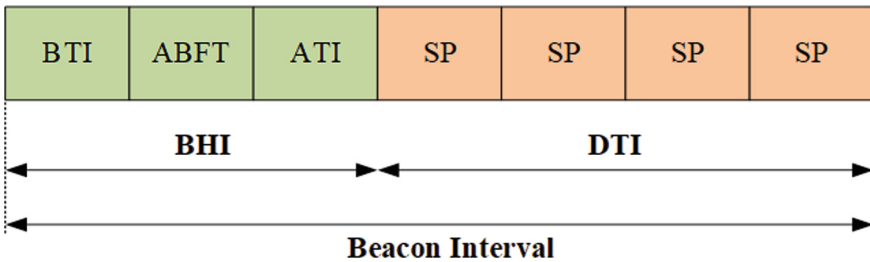


Fig. 1. The structure of a beacon interval.

In BHI, the best transmitting beam TX_1 and the best receiving beam RX_1 to be used in this superframe are determined. If no movement or occlusion occurs

in the DTI phase, TX_1 and RX_1 can be used in this beacon interval all the time. Otherwise, the beamtracking is triggered, which is used to find the best transmitting beam TX_2 and the best receiving beam RX_2 . The figure below shows the beamtracking process (see Fig. 2).

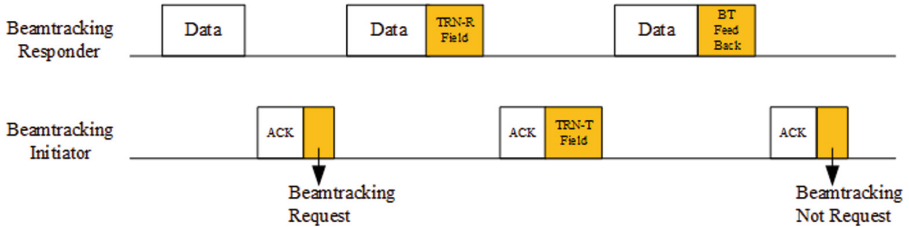


Fig. 2. The beamtracking process in 802.11ad/ay.

The beamtracking process is divided into the following steps:

Step1: If a station receives a data which RSSI is higher than -68 dBm and less than -60 dBm, it will carry a beamtracking request when it sends an ACK. The station that sends the beamtracking request is called the beamtracking initiator.

Step2: The station that receives an ACK carrying the beamtracking request is called the beamtracking responder. When beamtracking responder sends data, TRN-R field is appended. The TRN-R field is used to perform a responder sector sweep after data is sent. When the sweep is complete, the initiator will know the best send sector of responder.

Step3: The initiator receives data, replies with an ACK, TRN-T field is appended. The TRN-T field is used to perform a initiator sector sweep after ACK is sent. Each sector sweep frame carries the result of the best send sector of responder in step2.

Step4: The responder receives the ACK and knows its best send sector. We can also know the best send sector of initiator after TRN-T. When responder sends data again, Beamtracking Feed Back field is appended, which contains the best send sector of initiator.

Step5: The initiator receives the Beamtracking Feed Back, changes its sector and sends an ACK using the new sector. This ACK will finish a beamtracking process.

2.2 Problem Analysis

The beamtracking in 802.11ad/ay has the following problems. Firstly, the beamtracking is triggered by the RX. Secondly, beamtracking is performed after the data is sent. Thirdly, when node moves fast, beamtracking in 802.11ad/ay will lose packets.

As shown in the following figure (see Fig. 3), the blue area is the coverage area of the current beam pair, the purple area is the coverage area of the next beam pair. The STA moves fast and the AP is fixed. When the STA is about to leave the coverage area, one data packet is sent and received by the AP. We assume that RSSI is greater than -68 dBm and less than -60 dBm. As mentioned above, the AP will send the ACK with beamtracking request. Since STA moves fast and has fewer packets, when the STA sends the data with TRN-R field appended, it has left the coverage area and the data packet is lost.

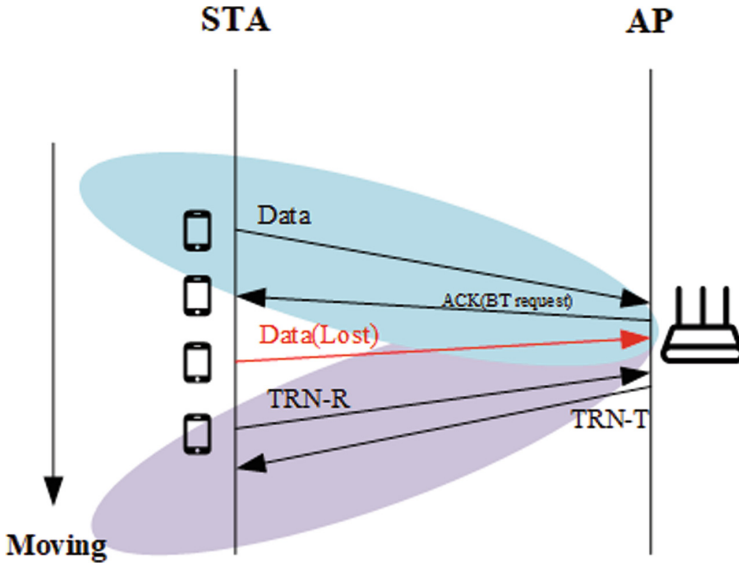


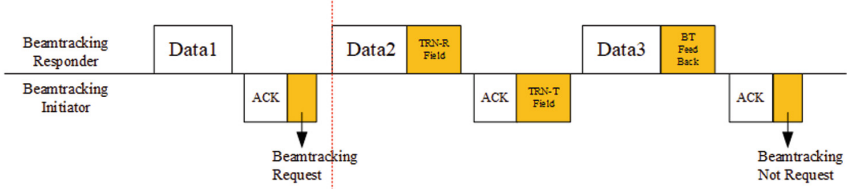
Fig. 3. The scenario that beamtracking process in 802.11ad/ay will drop packet.

3 Adaptive Beamtracking Process

3.1 Basic Idea

The order of sending data packet and performing beamtracking affects packet delay and throughput. If beamtracking is performed after data packet is sent, the packet delay is not affected by beamtracking, but the probability of packet loss is increased. If beamtracking is performed before data packet is sent, data packet will be sent successfully, however, the beamtracking takes time, and packet is affected by the beamtracking, which increases the packet delay. The following figure compares the post-beamtracking with the pre-beamtracking (see Fig. 4). It can be found that the pre-beamtracking avoids packet loss but also introduces certain delay. If we can take two methods into account, the packet loss rate of beamtracking in 802.11ad/ay can be reduced while the packet delay is guaranteed.

802.11ad/ay Beamtracking



Adaptive Beamtracking

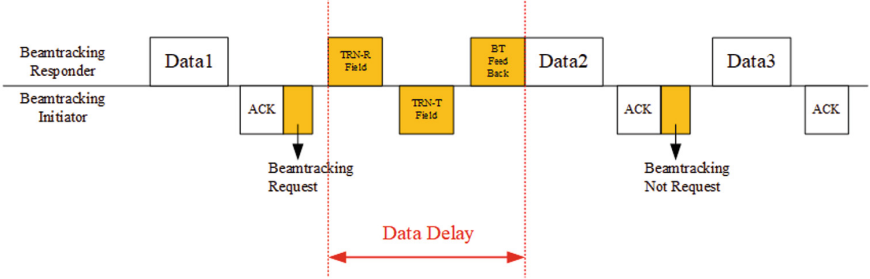


Fig. 4. The difference between 802.11ad/ay beamtracking and adaptive beamtracking in packet Delay.

The adaptive beamtracking follows the frame structure of ACK and DATA in 802.11ad/ay, and only changes the process. After beamtracking is triggered, the order of sending data packet and performing beamtracking is adjusted according to the number of consecutive beamtracking request. The specific process is as follows.

3.2 Detail Design

Firstly, two counters are introduced:

Post Counter: During the post-beamtracking phase, the number of consecutive post-beamtracking is recorded. This counter sets to 0 if the RSSI received is greater than -60 dBm. When this counter is greater than or equal to n_P , we should switch to pre-beamtracking.

Front Counter: During the pre-beamtracking phase, we should record the times that the beam difference before and after the beamtracking is less than or equal to Δ . If the beam difference is greater than Δ , this counter sets to 0. When this counter is greater than or equal to n_F , we should switch to post-beamtracking.

By maintaining these two counters, adaptive beamtracking can be achieved. The process is as follows. When sending data, the station should check whether the beamtracking is requested. If beamtracking is not required, sets Post Counter and Front Counter to 0. If beamtracking is required, according to the current

beamtracking mode(default mode is post-beamtracking), we'll go through a different process. During post-beamtracking phase, the beamtracking is performed after data packet is sent, and Post Counter plus one. If the Post Counter is greater than or equal to n_P , we should switch to pre-beamtracking. During pre-beamtracking phase, we will follow the rules of the Front Counter and record the corresponding variables until the Front Counter is greater than or equal to n_F , we should switch to post-beamtracking. The specific flow chart is as follows (see Fig. 5).

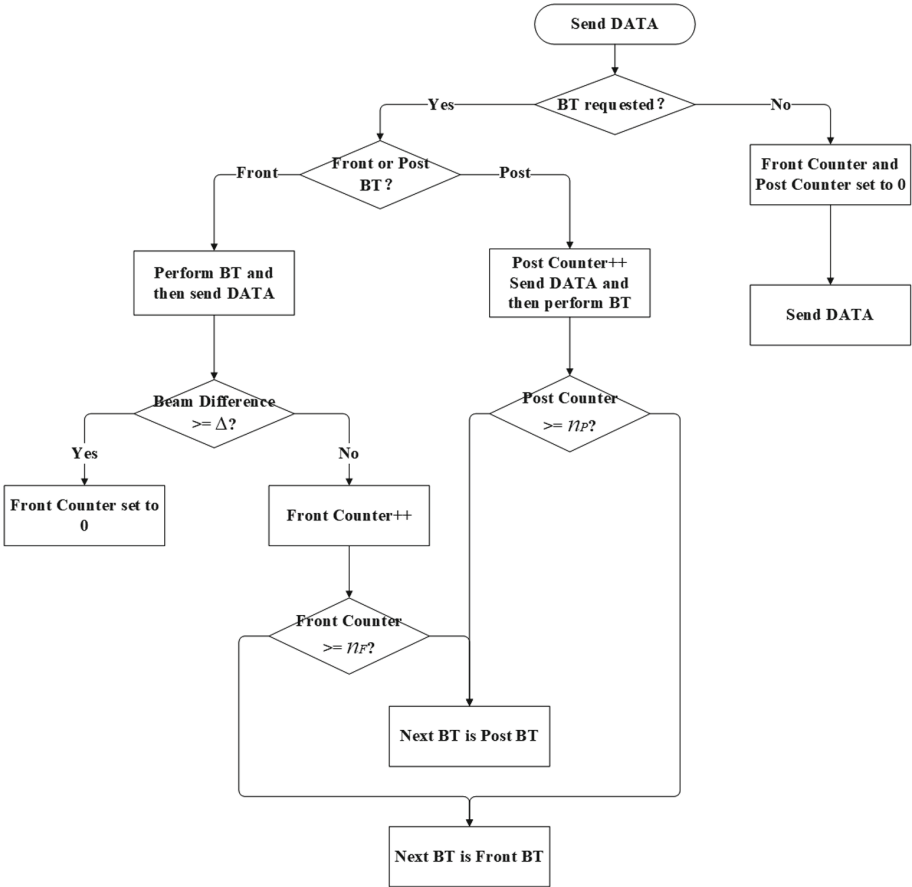


Fig. 5. The adaptive beamtracking flow diagram.

4 Performance Evaluation

4.1 Simulation Scenario and Parameter Configuration

The simulation platform of this paper is designed according to TCP/IP model (Table 1).

Table 1. Parameter configuration.

Parameter	Value
BSS Number	1
STA Number	1
AP Number	1
Traffic Rate	400 Mbps to 4000 Mbps
Packet Size	80000 bytes
AMPDU Size	1, 2, 4, 8, 16, 32
BI Duration	0.1 s
CCA threshold	-68 dBm
BT threshold	(-68 dBm, 60 dBm)
Simulator Duration	200 s

4.2 Simulation Results

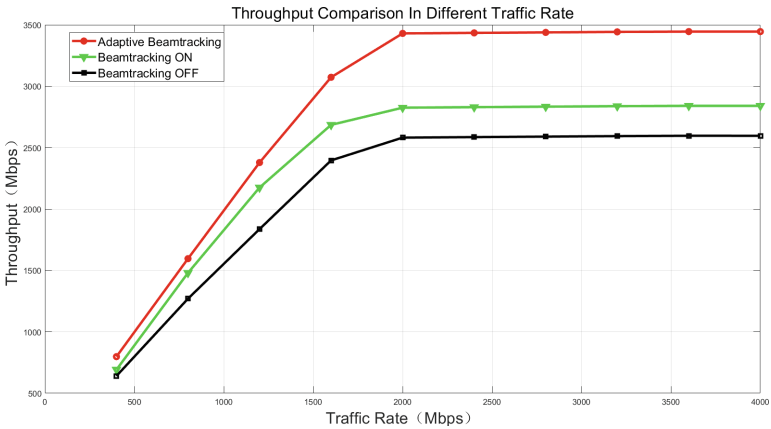


Fig. 6. Throughput comparison between ABT & beamtracking in 802.11ad/ay in different traffic rate.

When beamtracking is disabled, the throughput is the lowest. The beamtracking in 802.11ad/ay can correct sectors, reduce packet loss rate, and improve the throughput. The adaptive beamtracking method further avoids packet loss and has the highest throughput (see Fig. 6).

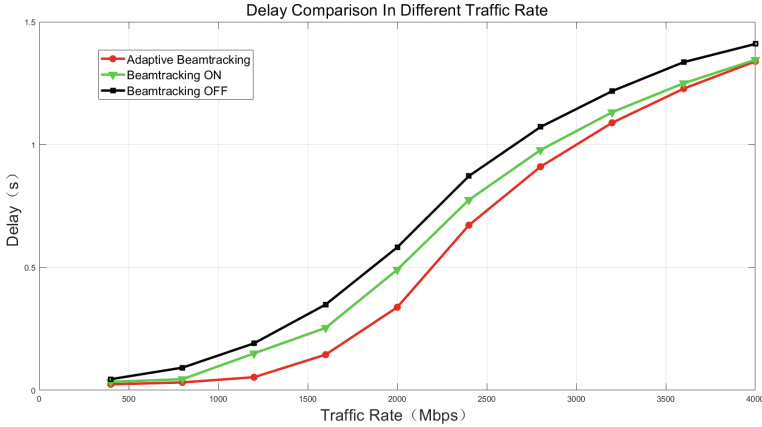


Fig. 7. Delay comparison between ABT & beamtracking in 802.11ad/ay in different traffic rate.

When beamtracking is disabled, the average latency is the highest. The beamtracking in 802.11ad/ay can correct sectors, reduce packet loss rate, and decrease the average delay. The adaptive beamtracking method further avoids packet loss and has the lowest average delay. With the increase of traffic rate, the delay difference of adaptive beamtracking and the beamtracking in 802.11ad/ay increases first and then decreases (see Fig. 7).

When the aggregate number changes, the advantage of the adaptive beam tracking method becomes more obvious. The throughput of the same mode increases when the aggregate number increases. The throughput of the adaptive beamtracking method is always higher than that of the beamtracking in 802.11ad/ay under the same aggregate number (see Fig. 8).

When beamtracking is disabled, the average latency is the highest. The beamtracking in 802.11ad/ay can correct sectors, reduce packet loss rate, and decrease the average delay. The adaptive beamtracking method further avoids packet loss and has the lowest average delay (see Fig. 9).

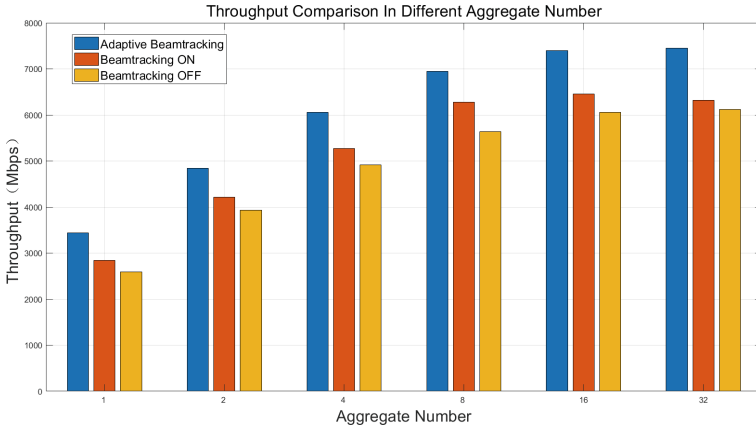


Fig. 8. Throughput comparison between ABT & beamtracking in 802.11ad/ay in different aggregate number.

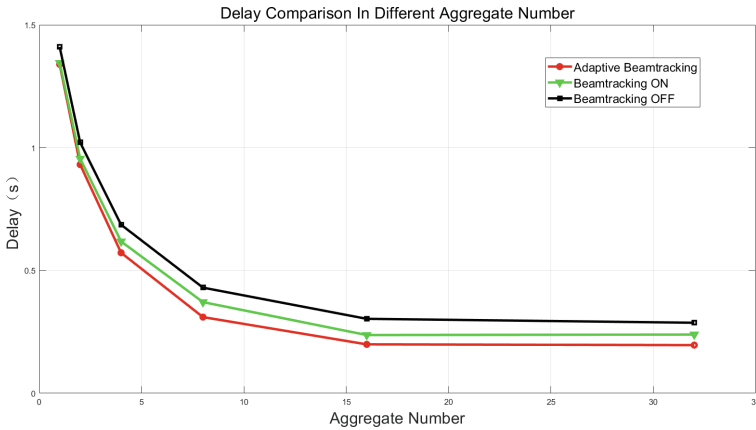


Fig. 9. Delay comparison between ABT & beamtracking in 802.11ad/ay in different aggregate number.

5 Conclusion

In this paper, aiming at the lag of beamtracking in 802.11ad/ay, we design an adaptive beamtracking method. According to the number of consecutive beamtracking request, the order of sending data packet and performing beamtracking is adjusted. In this way, both throughput and packet delay can be taken into account. Simulation results show that adaptive beamtracking method improves the throughput compared with the beamtracking in 802.11ad/ay, and the packet delay of the two methods is similar. In different traffic rate and different aggregate number, the throughput of adaptive beamtracking is higher than the beamtracking in 802.11ad/ay.

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