# Grouping Based Beamform Training Scheme for the Next Generation Millimeter Wave WLAN

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**Abstract.** The application of wireless local area network (WLAN) technology can make devices connected to the network move. On this basis, the millimeter wave WLAN protocol and beamforming (BF) technology enables wireless communication to support the transmission of services with ultra-high data rates. But the problem of conflict when station (STA) nodes perform BF training during the associated beamforming training (A-BFT) period is still unsolved. Therefore, this paper proposes a grouping based BF training scheme for the next generation millimeter wave WLAN to reduce conflict. The simulation results show that this scheme can effectively reduce the collision probability of STAs during BF training. Finally, it can improve the efficiency of information transmission and can be used in future improvements for the millimeter wave WLAN protocol.

**Keywords:** Millimeter wave WLAN · BF training · A-BFT period · Grouping based BF training · Collision probability of STAs

## 1 Introduction

With the development and application of millimeter wave technology [1], BF technology plays a major part in improving the quality of millimeter wave communications. Although BF technology enables millimeter waves to overcome high path loss, for STAs located within the beam coverage of the same sector, their conflict during BF training is still a crucial problem to be solved.

Based on the physical characteristics of millimeter wave and communication service requirements, WiGig Alliance first proposed the 802.11ad standard draft in 2009 and officially released it in 2013 [2,3]. In the same year, Chen Q proposed a new media Access Control (MAC) layer protocol for the directional multigigabit (DMG) transmission problem in IEEE 802.11ad [4]. In 2016, Assasa H implemented a model for IEEE 802.11ad and BF training technology in the network simulator ns-3 [5].


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In IEEE 802.11ad standard [6,7], nodes (AP and STAs) get best transmission sector ID between nodes through the Beacon Transmission Interval (BTI) and Association Beamforming Training (A-BFT) by BF training [8,9]. However, in A-BFT period, multiple STAs may select the same A-BFT slot for BF training, which causes STAs to collide. This paper mainly proposes a new grouping based BF training scheme to improve the problem and reduce the collision probability and time overhead of BF training.

This scheme proposes that in A-BFT period, an access point (AP) divides STAs that belong to a same sector group into designated A-BFT slots, and these slots can only respond to BF training of the STAs. This method is called grouping based A-BFT slot response (G-ABFTRes). And AP sector scan mode is grouping based sector sweep from wide to narrow for carrying G-ABFTRes. The simulation results show that this scheme can successfully reduce the collision probability of STAs of BF training process in A-BFT period, and it is finally reflected in improving communication Throughput and Packet-Error-Rate (PER).

The rest of the paper is organized as follows: Section 2 introduces the basic theory of millimeter wave and BF training. Section 3 describes the mathematical logic analysis and flow chart of new scheme. For examining the proposed algorithms, results under different simulation environments are given in Sect. 4. And Sect. 5 summarizes the research questions, results, and innovations. Finally, acknowledgement and reference.

## 2 Background

### 2.1 802.11ad Frame Structure

In IEEE 802.11ad, Channel access process is mainly performed in Beacon Interval (BI), and sub-segments of the BI are called the access period. There are 4 periods: Beacon Transmission Interval (BTI), Association Beamforming Training (A-BFT), Announcement Transmission Interval (ATI), and Data Transfer Interval (DTI). They have different access rules and coordinate access time through schedules. This paper mainly studies a improvement schemes in A-BFT period for BF training (Figs. 1, 2, 3 and 4).

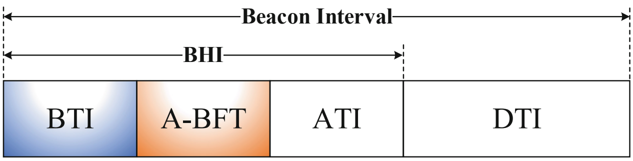


**Fig. 1.** IEEE 802.11ad BI structure

### 2.1.1 BTI

During BTI period, it is mainly realized that APs send directional multi-gigabit beacon (DmgBeacon) frames to STAs. The purpose is to enable STAs to obtain the best sending sector ID of APs and prepare to access A-BFT period.

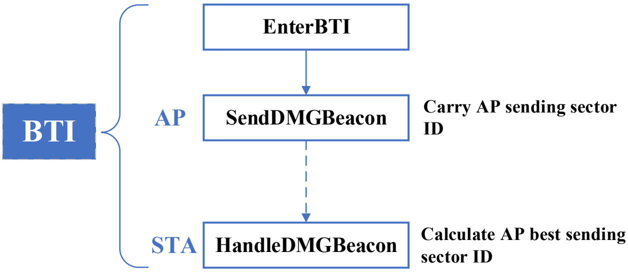


**Fig. 2.** BTI period

### 2.1.2 A-BFT

During A-BFT period, The main work is BF training. In IEEE 802.11ad, STAs randomly enter the pre-allocated A-BFT slots. In each A-BFT slot, a STA performs Sector Level Sweep (SLS) with all APs, and finally obtains the best sending sector/beam ID information of itself.

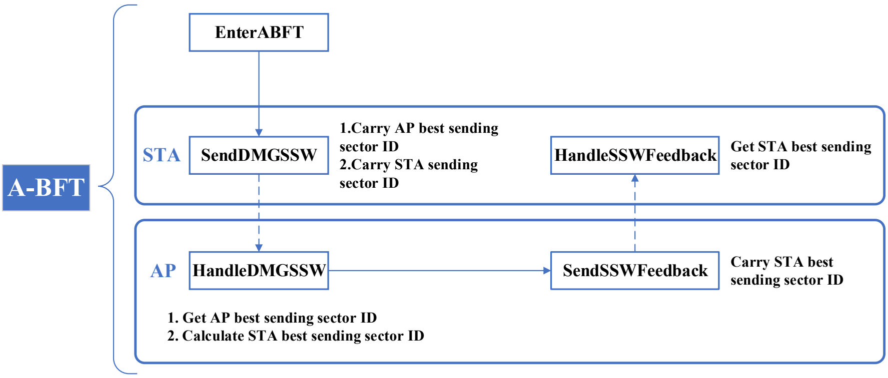


**Fig. 3.** A-BFT period

However, since different STAs may enter a same A-BFT slot. But only one STA can complete BF training in this slot. And other STAs affected by conflict only wait and enter the next A-BFT slot with the STAs that completed BF training. There are two scenarios to solve this problem:

1. Increasing the number of A-BFT slots. STAs will have a greater probability of entering different A-BFT slots. Scenario 1 can reduce the conflicts, but it will increase the time of BF training.
2. Using G-ABFTRes. STAs are divided into groups in advance. We stipulate that AP has multi-beam receiving capabilities, that is, AP can receive information frames from multiple sectors at the same time. And then, AP divides STAs that belong to a same group into designated A-BFT slots, and these slots can only respond to the BF training of this group. By comparison, scenario 2 is better than 1.

## 2.2 Beamforming Training

IEEE 802.11ad standard used BF training to solve the problem of high transmission loss in millimeter waves. Before antennas send data packets directionally, performing periodic BF training between initiator and responder nodes to find the best sending and receiving beams ID and achieve antenna alignment. This can effectively enhance the signal energy in the direction of demand link, and also suppress interference signals from other links.

In terms of workflow, BF training is divided into two stages: SLS and Beam Refinement Phase (BRP). Since BRP is not in this improvement, the following will mainly introduce SLS stage and sector sweeping method.

### 2.2.1 Sector Level Sweep

In SLS stage, transceivers (include AP and STAs) transmit control frames, which mainly contain information for adjusting antenna parameters of transceivers. When transceivers receive frames, they will adjust their antenna parameters, so as to optimize the beam direction.

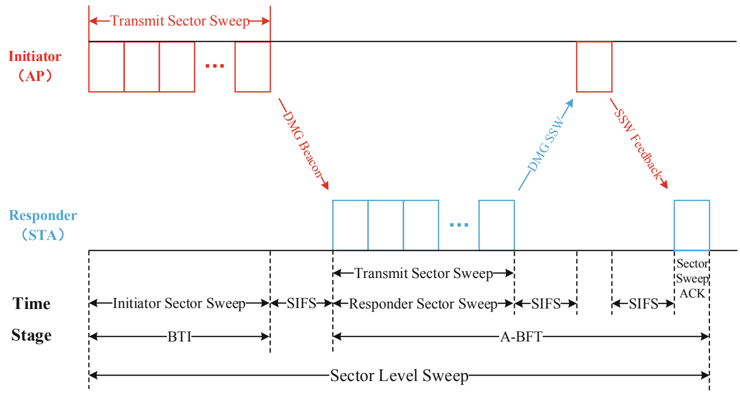


**Fig. 4.** Framework of SLS stage

When BF training initiator sends an information frame, the responder is in an omnidirectional receiving state; when initiator has finished sending, responder feeds back to initiator the best sending sector/beam ID information of initiator.

#### 2.2.2 Sector Sweeping

In SLS, sector sweeping uses an exhaustive method in which initiator sweeps sectors from initial sector one by one until all sectors are swept.

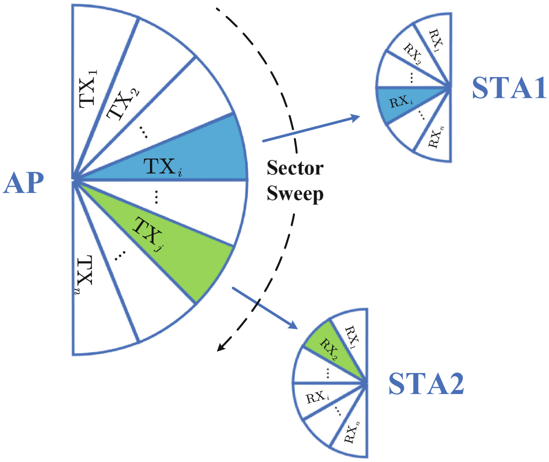


**Fig. 5.** Sector sweeping by exhaustive method

As shown in Fig. 5: AP uses $n$ sectors/beams to cover cell. In SLS stage, AP sweeps sectors from the $TX_1$ to the $TX_n$ in turn, and sends different sector/beam information. At the same time, STAs receive and measure signal energy emitted by different sectors/beams, and feeds back relevant information to AP. According to the feedback information of STAs, AP determines the best transmission sector/beam ID aimed at STAs. The best AP sector/beam ID pairs corresponding to STA1 and STA2 are ($TX_i$,$RX_i$) and ($TX_j$,$RX_2$).

## 3 Methodology

### 3.1 Overall Scheme

New scheme is mainly aimed at BF training in A-BFT period.

As shown in Fig. 6: in A-BFT period, this scheme uses G-ABFTRes to reduce the collision probability of STA and adopts G-SSW to perform sector grouping in BTI period.

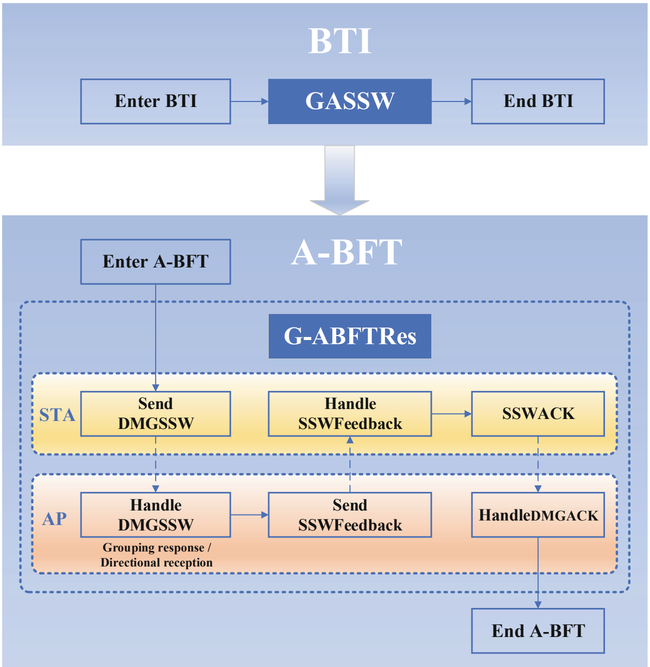


**Fig. 6.** New framework in overall scheme

## 3.2 Grouping Based A-BFT Slot Response

### 3.2.1 Theory

For G-ABFTRes, we stipulate that A-BFT slots are $k$, STAs in A-BFT period are $l$ and all STAs are divided into $m(1 < m < l)$ sector groups. AP has multi-beam receiving capability, and STAs of non-adjacent sector groups can simultaneously access a same A-BFT slot.

When without using G-ABFTRes scheme, the probability of BF training collision between one STA and other STAs in A-BFT slot is $(l-1)/l$; when using G-ABFTRes scheme, the number of STAs in each sector group is $l/m$, and the probability of BF training collisions for STAs is:

$$\frac{\frac{l}{m}-1}{\frac{l}{m}} = \frac{l-m}{l}, \tag{1}$$

where $1 < m < l$,

$$\therefore \quad \frac{l-m}{l} < \frac{l-1}{l}. \tag{2}$$

As a result of using G-ABFTRes, the collision probability of STA is reduced in the A-BFT slot. In addition, because AP has multi-beam receiving capability, and STAs of non-adjacent sector groups can access a same A-BFT slot at the same time. G-ABFTRes avoids STAs in adjacent sector groups from causing mutual interference during BF training.

### 3.2.2 Framework Design

During A-BFT period, different sector groups access different A-BFT slots as required. In a same A-BFT slot, there are multiple STAs belong to non-adjacent sector groups performing BF training, and they will not collide.

Figure 7 shows G-ABFTRes in 1AP6STA simulation topology, where (a) is the result of sector grouping, (b.1)/(b.2) are G-ABFTRes execution stages in A-BFT slot. Among them, $GroupTX_A$ and $GroupTX_C$ are not adjacent, and $GroupTX_B$ and $GroupTX_D$ are also not adjacent.

Figure 8 shows that STAi and STAj belong to non-adjacent sector groups, but they can enter a same A-BFT time slot and don't conflict during BF training.

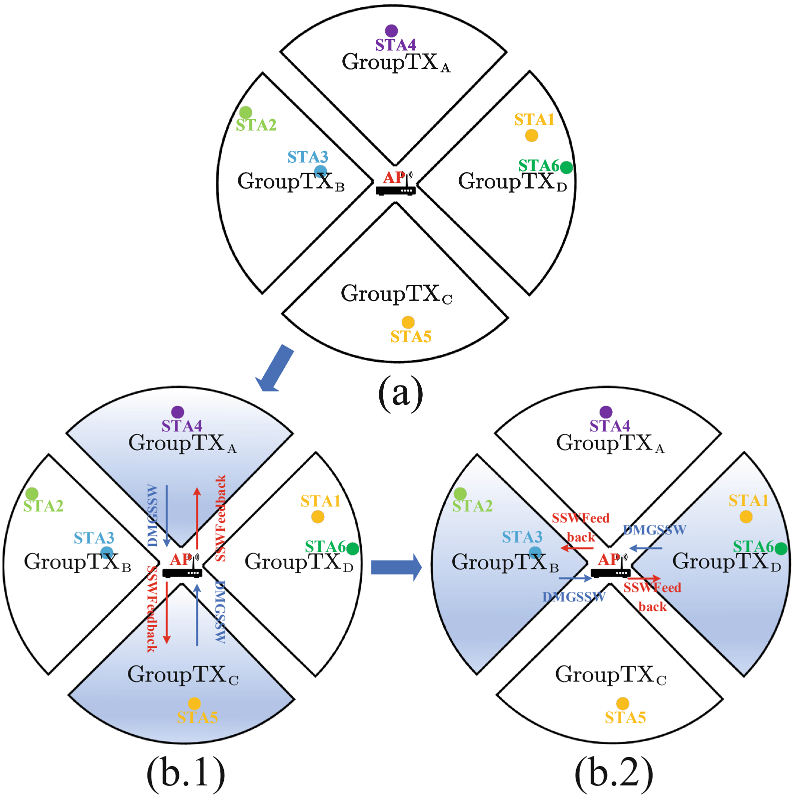


**Fig. 7.** G-ABFTRes in A-BFT period

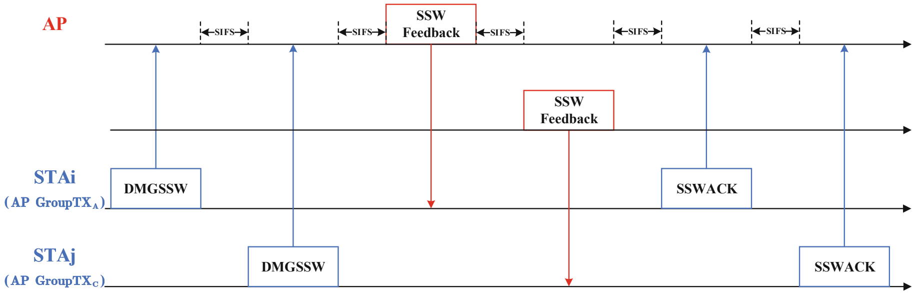


**Fig. 8.** New framework in A-BFT slot

### 3.2.3 Grouping Based Sector Sweep

G-SSW is proposed to assist G-ABFTRes in this paper. It has four phases: group sector division (GSD) phase, extra-group sector sweep (EGSSW) phase, request intra-group sector sweep (ReqIGSSW) phase, and intra-group sector sweep (IGSSW) phase.

Figure 9 shows G-SSW in 1AP6STA simulation topology, where (a) is GSD phase, (b.1)/(b.2) are EGSSW/ReqIGSSW phase, and (c) is IGSSW phase.

We stipulate that AP has $n$ sectors, $m$ group sectors and the number of STAs in BTI period are $l$ and all STAs are divided into $m(1 < m < l)$ sector groups.

When without using G-SSW: each STA receives a total of $n$ information frames containing information about different sectors of AP; when using G-SSW scheme, each STA receives a total of $m + \frac{n}{m}$ information frames from AP.

When

$$m + \frac{n}{m} < n, \tag{3}$$

$$n > \frac{m^2}{m-1}, \tag{4}$$

each STA receives fewer information frames from AP.

As shown in Fig. 10: AP sequentially enter different BTI slot, and interact with all STAs by G-SSW. In a BTI slot, AP first performs EGSSW phase (AP uses group sector to send the WideBeamDmgBeacon frame to each STA), and STAs feed back NarrowBeamRequest frame to AP in sequence. And then, AP judges whether STAs need to perform IGSSW phase through the feedback information. If necessary, AP uses intra-group sector to send a NarrowBeamDmgBeacon frame to STA. If not, skip this stage.

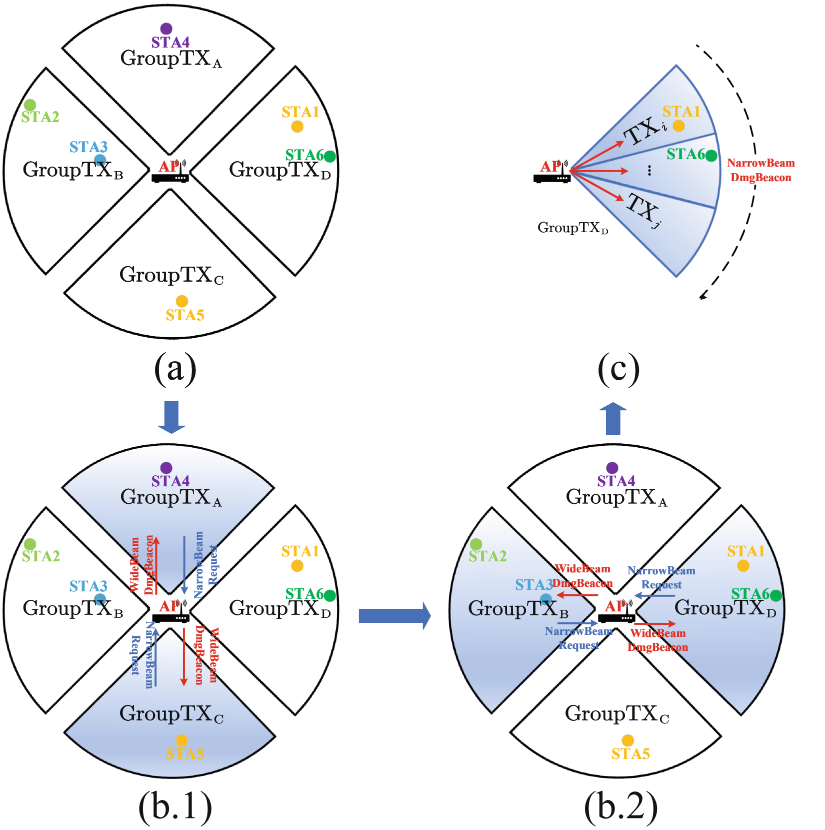


**Fig. 9.** G-SSW in BTI period

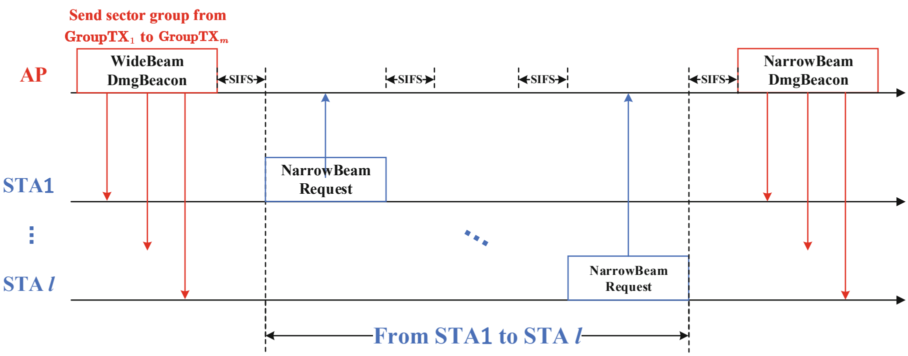


**Fig. 10.** New framework in BTI slot

# 4 Simulation Result

This experiment uses a network simulation platform based on ns-3 in 64 bit Ubuntu 4.4.3-4ubuntu5 operation system and is configured with Intel(R) Core(TM) i7-9750H CPU @ 2.60 GHz, 8 GB RAM. All above algorithms are developed in C++ environment.

## 4.1 Topology and Configuration

### 4.1.1 1AP6STA

In Fig. 11 and Table 1, there is 1 AP, 6 STAs and 6 A-BFT slots, and AP has 4 group sectors and multi-beam receiving capability. The first three A-BFT slots respond to BF training of STAs belonging to $GroupTX_A$ and $GroupTX_C$, and the last three A-BFT slots respond to the BF training of STAs belonging to $GroupTX_B$ and $GroupTX_D$ (refer to Fig. 9).

**Table 1.** 1AP6STA simulation parameters

| Parameters | Configuration |
|---|---|
| Cell number | 1 |
| Number of nodes in cell | 7 |
| Sector number | 12 |
| Degree per sector | 30° |
| Channel model | Calibrated SISO channel |
| Size of conference room scene | 3 m * 4.5 m |
| Channel bandwidth | 2.16 GHz |
| Packet size | 40000 Byte |
| Simulation duration | 1 s |
| Business | Up/Down Link+equal traffic-rate |
| BI duration | 100 ms |
| DTI phase | Only SP |
| SP allocation rules | Priority fairness |
| Threshold of ReqIGSSW | −38 dB |

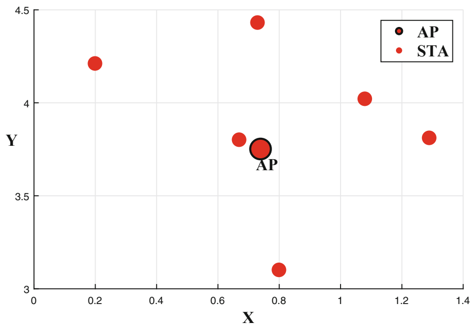


**Fig. 11.** 1AP6STA

#### 4.1.2 6AP36STA

In Fig. 12 and Table 2, there is 6 AP, 36 STAs and 36 A-BFT slots, and AP also has 4 group sectors and multi-beam receiving capability. It is an extended simulation test and no different from 1AP6STA in the implementation of G-ABFTRes and G-SSW schemes.

**Table 2.** 6AP36STA simulation parameters

| Parameters | Configuration |
|---|---|
| Cell number | 6 |
| Number of nodes in cell | 7 |
| Sector number | 12 |
| Degree per sector | 30° |
| Channel model | Calibrated SISO channel |
| Size of conference room scene | 3 m * 4.5 m |
| Channel bandwidth | 2.16 GHz |
| Packet size | 40000 Byte |
| Simulation duration | 1 s |
| Business | Up/down link+equal traffic-rate |
| BI duration | 100 ms |
| DTI phase | Only SP |
| SP allocation rules | Priority fairness |
| Threshold of ReqIGSSW | −38 dB |

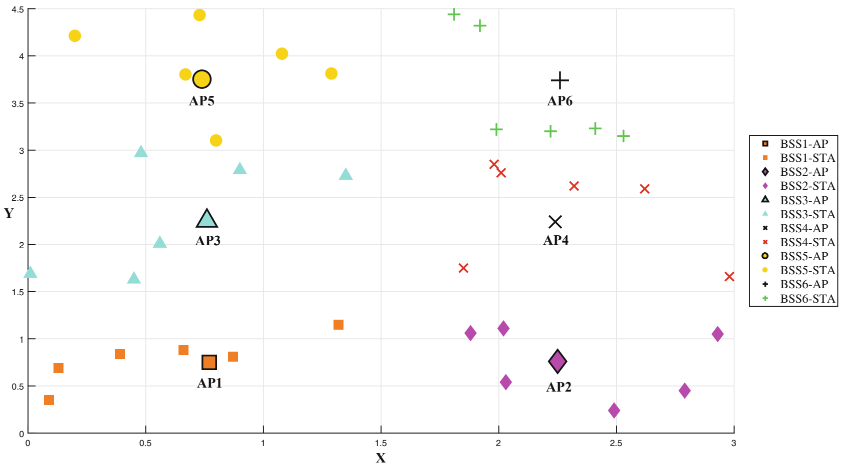


**Fig. 12.** 6AP36STA

## 4.2 Scheme Verification

### 4.2.1 Throughput

$$Throughput = \frac{successfully\ received\ Packets}{simulation\ duration} \tag{5}$$

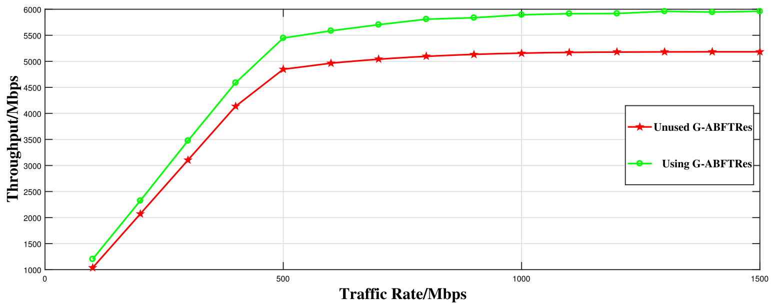


**Fig. 13.** 1AP6STA Throughput comparison

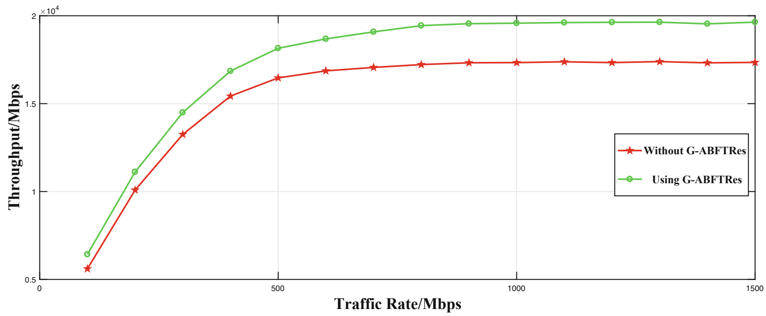


**Fig. 14.** 6AP36STA Throughput comparison

As shown in Fig. 13/14: when Throughput of 1AP6STA/6AP36STA reaches saturation, Throughput after using G-ABFTRes is about 6000/19000 Mbps and higher than unused G-ABFTRes. This is because G-ABFTRes reduces the probability of collisions between STAs in A-BFT slot, thereby reducing the time for re-BF training due to collisions. As a result, the number of successfully received packets are increased and throughput is also improved in same simulation time.

### 4.2.2 Packet-Error-Rate (PER)

$$PER = \frac{Error\ Packets}{Error\ Packets + successfully\ received\ Packets} \tag{6}$$

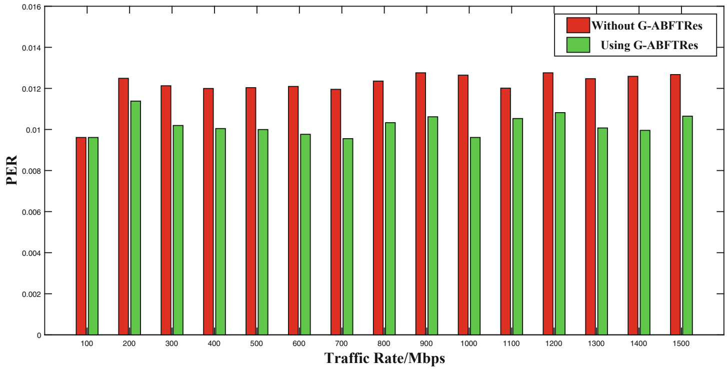


**Fig. 15.** 1AP6STA PER comparison

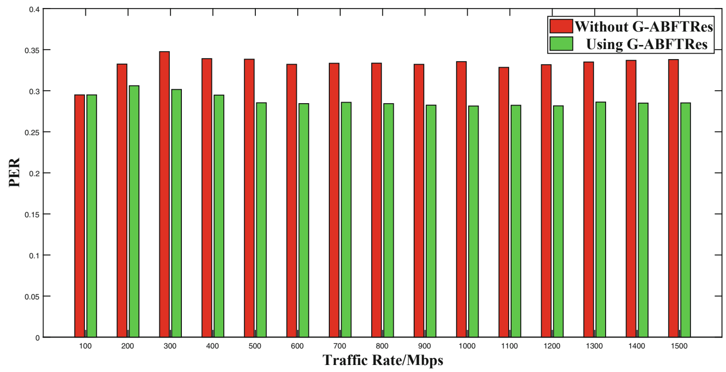


**Fig. 16.** 6AP36STA PER comparison

As shown in Fig. 15/16: when Throughput of 1AP6STA/6AP36STA reaches saturation, PER after using G-ABFTRes is about 0.01/0.29 and lower than unused G-ABFTRes. This is because Error Packets number has not changed and G-ABFTRes increases the number of successfully received Packets. As a result, PER is decreased in same simulation time.

## 5 Conclusion

In this paper, a grouping based BF training scheme has been proposed for solving a conflict problem when STAs perform BF training in A-BFT slot. The scheme can reduce conflict probability and improve Throughput and PER in millimeter wave communication.

Simulation results verify the correctness of G-ABFTRes and G-SSW. It is of some referenced and applicable significance in putting forward standard of next generation millimeter Wave WLAN. However, this scheme is limited to 802.11ad, and does not involve 802.11aj/ay. Hence, a future work would be to provide more analysis in other millimeter Wave WLAN standard.

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