# Full Duplex Enabled Next Generation mmWave WiFi Network

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**Abstract.** The full-duplex technology with the same frequency and the same time has developed rapidly in the wireless communication field. Compared with the traditional half-duplex technology, full-duplex technology can obtain the double spectral efficiency and throughput. However, in low-frequency asymmetric full-duplex communication, AP has full-duplex, and STA only has half duplex. And the interference between STAs results that we still cannot reach the theoretical multiple throughput. In this paper, we use the feature of directional propagation of mm wave to eliminate the interference between STAs in asymmetric full-duplex communication, and the full-duplex is applied to the WIFI high-frequency field for the first time. This paper introduces the BI frame of MAC architecture of IEEE 802.11 ay protocol in mmWave WIFI network, and designs the SP period of BI frame. So in SP period, the AP has full-duplex function and STAs still are half-duplex. We use Matlab to simulate, and get the theoretical multiple throughput.

**Keywords:** Full-duplex · IEEE 802.11ay · Triangle communication · Matlab

## 1 Introduction

Full-duplex (FD) communication is a new technology proposed in recent years, but it develops rapidly and is widely concerned in academia and industry. Traditional half-duplex (HD) cannot receive and send wireless signals at the same time and frequency, resulting in a waste of wireless spectrum resources [1]. And full-duplex can receive and send wireless signals at the same time and frequency, yet fundamentally avoid the waste of spectrum resources in half-duplex communication due to the orthogonality between the signal to send/receive. Theoretically, FD can exponentially improve the network capacity and spectrum efficiency. Full-duplex communication has great potential to improve spectrum resource utilization and user data throughput.

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In wireless communication networks, the biggest technical challenge to the full-duplex is the interference. In fact, due to the nodes sending and receiving antennas are too close, sending signals will be leaked into receiving channel resulting in interference or even drowning the useful signal it wants to receive (Fig. 1) [2]. The full-duplex sender can know the relevant parameters of the signal it sends. In theory, it can eliminate the interference of the sending signal to the receiving signal, that is, self-interference elimination. In recent years, Self-interference canceling technology has also made great progress, which can gradually support full-duplex communication. Different levels of self-interference elimination technology have great influence on the capacity of full-duplex system, which is proportional to each other [3]. Next generation wireless network requires realize full-duplex both for AP and STA in order to improve the network throughput. But the cost of the STAs realization is too high, so we think it should be the AP is full-duplex mode, the STA still is half-duplex mode, which resulting in full-duplex mode is asymmetric full-duplex communication in the implementation [4]. In this model, as shown in Fig. 2, the AP sends and receives signals at the same time, and the STA only sends or receives signals. In low frequency wireless network communication, the AP and the STA often adopt omnidirectional communication. As a result, there is a serious problem in the asymmetric full-duplex communication: because of the low frequency omni-directional communication signals would radiate in all directions. When AP and STA2 are for uplink transmission, STA1 for downlink receiving will receive STA2s signal interference for uplink transmission. Therefore, in the asymmetric full-duplex communication, the full-duplex effect cannot reach the expected the twice network capacity, only has about 1.5 times in the current research [5,6].

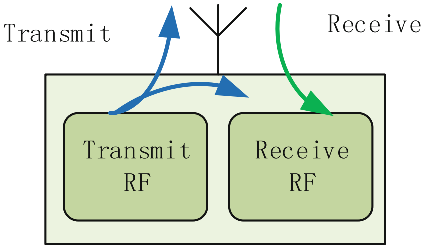

**Fig. 1.** Full duplex self-interference.

In the mmWave band, the beam is directional. In view of the problem for low frequency asymmetric full-duplex communication cannot gain twice the desired capacity, this paper puts forward that use of high frequency mmWave beam transmission characteristics to reduce the STA1s interference for STA2 to improve network capacity, expected to close to the theoretical spectrum gain of 2 times. The IEEE 802.11 ay protocol works in the ultra-high speed and low-interference 60 GHz frequency band, which means that in a cell, STA and AP can communicate with each other through directional beam realising point to

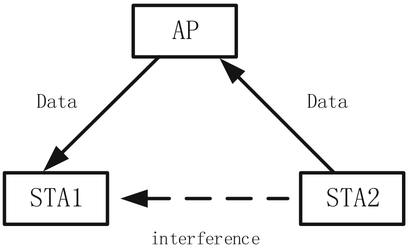

**Fig. 2.** Full duplex triangle communication self-interference.

point communication, with uplink and downlink functions [7]. Therefore, based on the IEEE 802.11 ay communication model, the design and simulation of high frequency full-duplex communication are carried out in this paper.

As far as we know, this paper will introduce the full-duplex into mmWave WiFi network for the first time, and provide the full-duplex communication MAC protocol support for the next generation mmWave WiFi network– the IEEE 802.11, and gain much better than the low frequency WiFi system. In low frequency, there must be different sectors for full-duplex. However, the intra-sectors and inter-sectors can both support full-duplex function in high frequency, especially the intra-sectors, which is of great significance.

The structure of this paper is as follows: Sect. 2 introduces the IEEE802.11ay high frequency directional communication MAC Layer; Sect. 3 introduces the implementation scheme of asymmetric full-duplex communication in high frequency directional communication. Section 4 presents the simulation results. Section 5 is the conclusion of this paper.

## 2 System Model

The IEEE 802.11 ay specification, based on the IEEE 802.11 standard, defines the physical layer PHY and the media access control layer MAC to provide wireless high-speed connectivity at the 60 GHz frequency band. Based on the IEEE802.11 ay communication model, the paper designs the MAC layer of high frequency.

The channel access process of IEEE 802.11 ay protocol is mainly carried out within Beacon Interval, and the sub-segment divided within Beacon Interval is called access period. Different access periods within beacon intervals have different access rules and are coordinated through schedules. The schedule is generated by STA as a PCP/AP, after which PCP/AP communicates with the device through Beacon and notification frames. The Non- PCP /AP device receives the time coordination information sent by PCP/AP and accesses the access channel according to the access mechanism of the corresponding stage within the coordinated time [8].

The channel time of IEEE 802.11 ay is in terms of hyperframe, called beacon interval, including four different access periods [9]: BTI: Beacon transmission interval, A-BFT: Association beamforming training, ATI: Announcement transmission interval and DTI:Data transfer interval, as shown in the figure. On the whole, it can be divided into BHI period and DTI period, beam training in BHI period and data transmission in DTI period. DTI is divided into competition based access period (CBAP) and Service period (SP).

During the beacon transmission period (BTI), the PCP/AP device sends one or more beacon frames containing location information, synchronization information, scheduling arrangements in this frame, etc. Non-PCP/AP devices synchronize with PCP/AP upon receipt of beacon frames and occupy channel as scheduled to communicate. During the BTI period, the beam will be trained to obtain the best transmission beam of PCP/AP (Fig. 3).

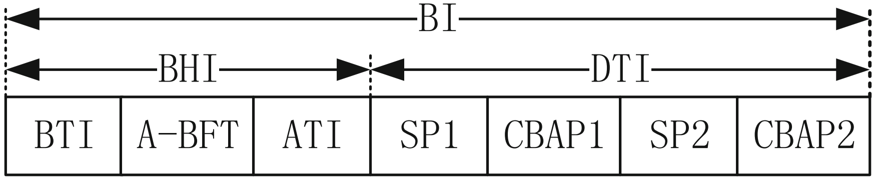

**Fig. 3.** Beacon interval frame structure.

After BTI, PCP/AP needs to wait for MBIFS time before starting the A-BFT process. The training process of beam forming in A-BFT includes the receiving sector sweep (RSS) and sector feedback sweep (SSW feedback). The best STA sending sector was obtained during the a-bft beam training.

ATI is usually done after A-BFT. During the ATI period, PCP/AP polls non-pcp /AP devices, which can send requests to obtain the allocation of time slot SP. After the A-BFT stage waiting MBIFS, PCP/AP sent Request frames to all STA, and before sending, it was necessary to check whether the CCA was idle. STA needs to reply after receiving the Request frame. If there is data to be transmitted, a Response frame is returned to PCP/AP after SIFS. If there is not data to be transmitted, an ACK frame is returned to PCP/AP after SIFS [10].

Beam refinement is between ATI and DTI, and the PCP/AP and non-pcp/AP devices in BRP stage interact many times to train their respective optimal receiving sectors.

Data exchanges between equipment during DTI period. Each beacon interval has one DTI. Non-pcp /AP devices communicate with others on CBAP they have competed and assigned SP in accordance with PCP/AP scheduling. PCP/AP presets a fixed start time and a fixed duration for each time slot, which is realized through the timing synchronization function. A time slot configuration can be a time slot SP where the ownership of the channel is granted to a single device. Or it could be a competing access time slot CBAP, where the right to use the channel is acquired through device competition.

# 3 mmWave Asymmetric Full-Duplex Scheme

**Question:** In general, at each SP stage, an AP only dispatches one STA to carry out uplink or downlink transmission with it. Not belonging to this SP, STA cannot communicate with AP within this SP time period, as Fig. 4.

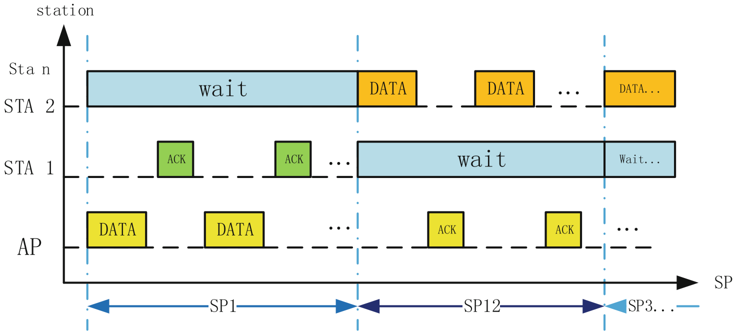

**Fig. 4.** Data transmisiion flow chart in SP period when half duplex.

**Solution:** In 802.11 ay, beam has directivity, so in SP stage, AP can consider scheduling multiple STA for uplink or downlink transmission. Respectively, the best sending or receiving sector for STA and AP must have different angles. In this case, the throughput for a SP stage will be multiplied. In this model, suppose AP has strong self-interference canceling ability.

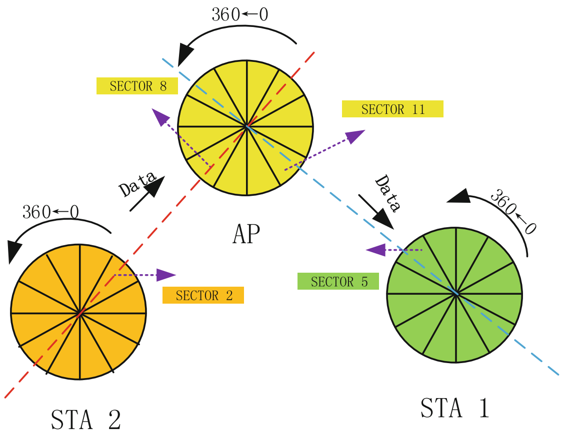

**Fig. 5.** Scenario 1.

*Scenario 1: Inter-sector.* The most common scenario is AP and the STA 1, STA 2 constituting asymmetric full-duplex communications, as Fig. 5: AP uses sector 8 communicating with the STA 1 with sector 2 for downlink transmission, at the same time, the AP uses sector 11 communicating with the STA 2 with 5 sectors for uplink transmission. STA 1 and STA 2 are visual for each other. In the low frequency they can interfere with each other, but in the high frequency mm wave, the beam directivity results that when STA 1 is in downlink receiving, interference of STA 2s upward transmission is nearly zero for the STA 1 direction.

Considering an extreme simple of scenario 1: the topological diagram location of the AP, STA 1, STA 2 as Fig. 6: AP and STA have 12 sectors respectively, and each sectors width is 30°. When AP and STA 1 are in downlink transmission, AP dispatch STA 2 into uplink transmission simultaneously. As shown in the figure, in the same SP stage, STA 1 with sector 1 transmits downlink with AP, while STA 2 with sector 7 transmits uplink and AP. The AP with the sector7 has downlink transmission with STA 1, at the same time AP with sector 2 has uplink transmission with the STA 1. Because of the two sectors of AP are facing, in the simulation the back of the interference of sectors are generally default as 0. Therefore, there is no interference between STA 1 and STA 2.

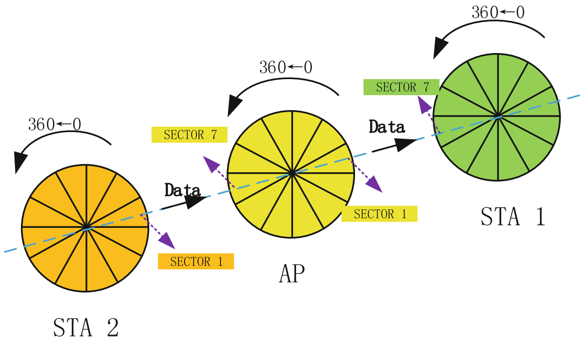

**Fig. 6.** Extreme simple of scenario 1.

*Scenario 2: Intra-sector.* In asymmetric full-duplex communication, when the two transmission paths between AP and STA 1 AP and STA 2 are very close to each other, it can be seen that AP-STA 1-STA 2 are on the same line. At this point, AP is equivalent to sending and receiving signals with the same beam, which improves efficiency on the basis of improving throughput. Although the sending and receiving sectors of STA 1 and STA 2 are in the same direction, the sending sector of STA 2 is on the back of STA 1, so there is little interference to STA 1.

*Data Transmission Flow Chart.* As shown in the Fig. 7, in SP1 period, the AP simultaneously schedules two STA for uplink and downlink transmission, no

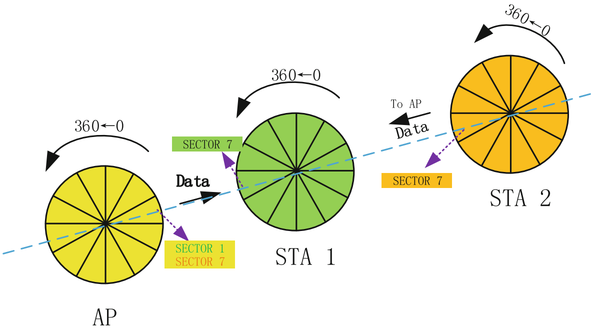

**Fig. 7.** Scenario 2.

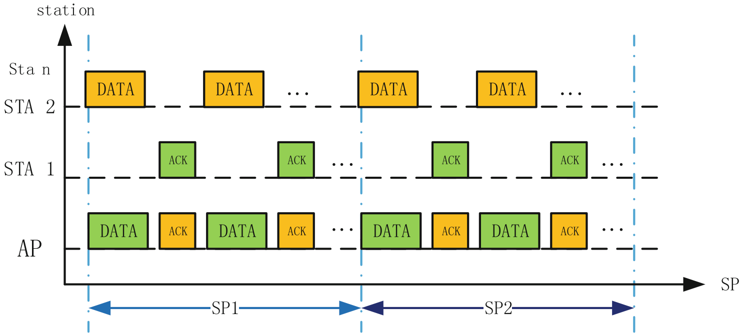

**Fig. 8.** Data transmission flow chart in SP period when full duplex.

matter in which scenario. The DATA for uplink or downlink both has the same transmission time and moment. The ACK time may not be the same. When STA 1 receives the downlink DATA packet from AP and AP receives the uplink DATA packet from STA 1, that is, there are two non-interference DATA packets transmitted at the same time in the SP1 stage, which improves the network capacity [11] (Fig. 8).

Integrated three scenarios, in asymmetric full-duplex communication, the interference between STA 1 and STA 2 becomes smaller because of the beam directivity characteristics of high frequency. The downlink receiving packets will not be affected, we can gain twice throughput of asymmetric full-duplex.

## 4 Simulation

The simulation scenario is STA intensive community. During the simulation, the size of DATA packets transmitted in the uplink or downlink is the same size and the ACK size is the same. The time interval between DATA and ACK is SIFS. In BI frame, BHI stage has completed beam training and has determined the best sending sector and the best receiving sector of STA and AP. The SP and CBAP

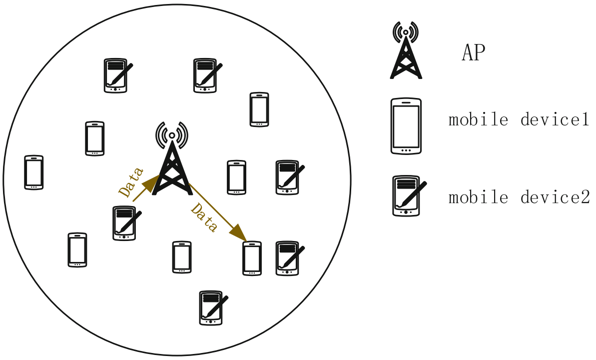

**Fig. 9.** AP schedule two STA simulation scene.

stages both transmite data through the best sector. In the DTI period, AP in SP stage dispatches two STA for full-duplex transmission, and CBAP keeps the original mode unchanged.

**Simulation: Relationship Between SP Throughput and DateRate.** The topology diagram of ap–sta 1–sta 2 is shown as Fig. 9. In a single-cell multi-sta intensive scenario, AP schedules one and two STA respectively. In SP period,

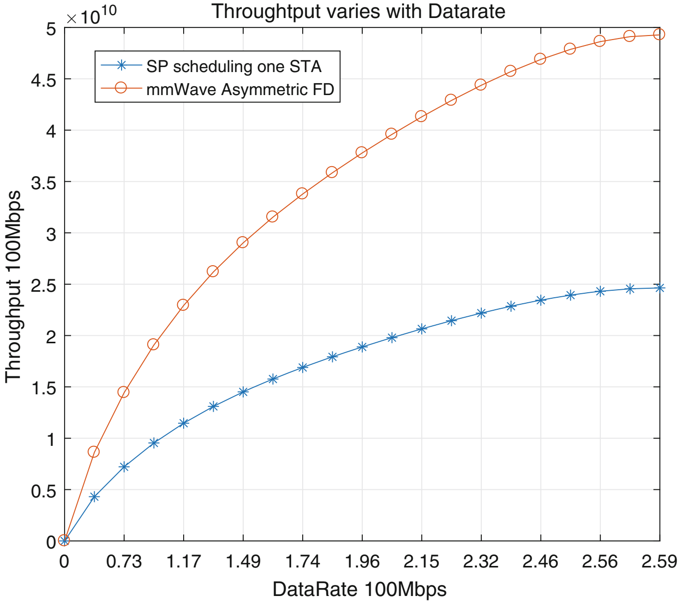

**Fig. 10.** Relationship between SP throughput and DateRate both on full or half duplex.

simulation time is 4s; packet is 8 Mbit; ACK is 304 bit, SIFS is 2.5/Ms, header is 416 bit. In SP period, throughput varies with the DateRate.

**Analysis:** From the simulation results, it can be seen that as the DataRate increases from 0, the throughput of the entire SP stage also increases under the two simulation conditions. When the DataRate reaches a fixed value 2.56, the increase trend of the throughput slows down and gradually increases to a value that remains basically unchanged, that is, the channel reaches saturation. The throughput of two STA scheduling in SP is always higher than that of one STA scheduled by AP, and is approximately twice as high as expected (Fig. 10).

## 5 Conclusions and Future Work

This paper mainly introduces the asymmetric full-duplex mode of high frequency mm wave WIFI network, and introduces full-duplex to high frequency mm wave WIFI network for the first time. According to the high frequency mm wave property and IEEE 802.11 ay MAC protocol, the data transmission of all asymmetric full-duplex communication in SP period is given, and we use MATLAB simulation tool to get the graph of the relationship between the throughput and data rate of all asymmetric full-duplex communication and semi-duplex communication in the high frequency WIFI network. The simulation results show that the asymmetric full-duplex of high frequency mmWave WIFI network solves the interference between low frequency asymmetric full-duplex STA very well, and gains the theoretical doubled throughput. This paper provides MAC protocol support for full-duplex communication for the next generation of WIFI IEEE 802.11ay, but the scheduling mode of participating in full-duplex when the AP schedus STAs in the SP stage needs to be improved and the efficiency needs to be improved.

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