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An Introduction to Key Technologies of Wi-Fi 7

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Abstract: *Wireless Local Area Network (WLAN) develops from 802.11b from 1999 to today's 802.11be (Wi-Fi 7). This article introduces Wi-Fi 7's key technologies such as 320MHz channel bandwidth, 16*16 Multi-User Multiple-Input Multiple-Output (MU-MIMO), 4K Quadrature Amplitude Modulation (QAM), Multi-Link Operation (MLO), Multi Resource Unit (RU), Preamble Puncturing, and its advantages over Wi-Fi 6. Wi-Fi 7 will bring new experiences for various real-time services such as AR/VR, 8K videos, and Internet of Things (IoTs) for ultra-low latency and very high data throughput.*

Keywords: *Wireless Local Area Network (WLAN), Wi-Fi 7, Quadrature Amplitude Modulation (QAM), Multi-Link Operation (MLO), Multi-User Multiple-Input Multiple-Output (MU-MIMO)*

1. Introduction

Since the 1990s last century, Wireless Local Area Network (WLAN) standards have developed fast, from 802.11b, 802.11a, 802.11g, 802.11n, 802.11ac, to today's 802.11ax, and 802.11be in the near future (as shown in Table 1). As mobile communication moves from 5G to 6G, WLAN accelerates the process from Wi-Fi 6 to Wi-Fi 7. The Wi-Fi 7 standard is IEEE 802.11be. In May 2019, IEEE 802 11be EHT (Extremely High Throughput) working group was officially established to optimize and improve IEEE 802.11ax (Wi-Fi 6) from multiple dimensions such as network throughput, interference suppression, spectrum efficiency, and latency optimization. The working group sets a target of a maximum throughput rate exceeding 40 Gbps and a latency of less than 5 ms (supporting real-time applications) on below 7 GHz spectrum at the beginning of the protocol revision. The release of 802.11be was divided into two versions. Release 1 had completed draft 3 and was released in 2023. Release 2 is expected to be completed by the end of 2024.

Table 1: 802.11 Protocol Family

Protocol	802.11	802.11b	802.11a	802.11g	802.11n	802.11ac Wave1	802.11ac Wave2	802.11ax	802.11be
					WiFi 4	WiFi 5		WiFi 6	WiFi 7
Proposal Time	1997	1999	1999	2003	2009	2013	2015	Officially released in 2019, Release 2 in 2022	2024
Frequency	2.4GHz	2.4GHz	5GHz	2.4GHz	2.4/5GHz	5GHz	5GHz	2.4/5/6GHz	2.4/5/6GHz
Bandwidth Supported	NA	20MHz	20MHz	20MHz	20/40MHz	20/40/80 MHz	20/40/80/160MHz, 80+80MHz	20/40/80/160MHz, 80+80MHz	20/40/80/160/240/320/80+80/160+80/160+160 MHz
MIMO	NA	NA	NA	NA	4*4	8*8	8*8	8*8	16*16
Channels (20MHz)	NA	14	14	14	14/24	24	24	24	160
Highest Order Coding	NA	DBPSK/DQPSK	64QAM	QPSK	64QAM	256QAM	256QAM	1024QAM	4096QAM
Maximum Physical Layer Rate	2Mbps	11Mbps	54Mbps	54Mbps	600Mbps	3.4Gbps	6.9Gbps	9.6Gbps	46Gbps
Key Technology		DSSS	DSSS/OFDM	DSSS/OFDM	OFDM, 4*4MIMO	OFDM, DL MU-MIMO Beamforming		UL/DL MU-MIMO, OFDMA, Spatial Reuse, BSS-Coloring, TWT (Target Wakeup Time)	UL/DL MU-MIMO, OFDMA, Multi-RU, MLO, Preamble Puncturing

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The biggest change in Wi-Fi standards is the increase in transmission bandwidth. Wi-Fi 7 extends the innovative features of Wi-Fi 6/6E, not only achieving faster speeds but also significantly improving responsiveness and reliability to meet applications that require extremely high consistency and accuracy.

Compared with Wi-Fi 6, Wi-Fi 7 has the following advantages [1]:

➢ Wi-Fi 7 is 4.8 times faster than Wi-Fi 6 and 13 times faster than Wi-Fi 5. Wi-Fi 7 increases the maximum speed from 9.6 Gbps of Wi-Fi 6 to 46 Gbps.

➢ Reduces latency by at least 5 times, achieving real-time response.

➢ Supports up to 4096 QAM, with a 20% increase in transmission speed compared to Wi-Fi 6's 1024 QAM.

➢ Supports Multi-Link Operation (MLO) to automatically obtain data in the fastest way possible.

➢ Supports Preamble Punching function, allowing communication to continue even if some frequency bands are interfered with.

Also, the Wi-Fi Alliance has launched Wi-Fi 7 (Wi-Fi CERTIFIED 7™) based on IEEE 802.11be in January 2024. The cutting-edge features of Wi-Fi CERTIFIED 7™ can drive innovation with high throughput, deterministic latency, and more reliable critical traffic [2]. Only devices that have been certified by the Wi-Fi Alliance (IEEE 802.11) are the Wi-Fi we use in our daily lives.

2. Key Technologies of Wi-Fi 7

2.1 320 MHz Channel Bandwidth (High-capacity)

The maximum supported bandwidth of Wi-Fi 7 is 320 MHz, which is twice that of Wi-Fi 6. With the opening up of the 6 GHz frequency band to Wi-Fi applications, Wi-Fi 7 supports a maximum channel bandwidth of 320 MHz on the 6 GHz frequency band, as well as 20/40/80/160 MHz channel bandwidth on the 5 GHz and 6 GHz frequency bands and 20/40 MHz on the 2.4 GHz frequency band.

The "Radio Frequency Division Regulations of the People's Republic of China" [3], which came into effect on July 1, 2023, by The Ministry of Industry and Information Technology of the People's Republic of China, clearly allocate the 700 MHz bandwidth of 6425-7125 MHz in the 6G frequency band to mobile communication, as shown in Figure 1. However, the 500 MHz frequency band of 5925-6425 MHz has not yet been allocated. In the future, similar to the European Union, the 5925-6425 MHz might be authorized for Wi-Fi use in China. When the 6 GHz frequency band is not open, Wi-Fi 7 performs 1.2 times better than Wi-Fi 6 [3].

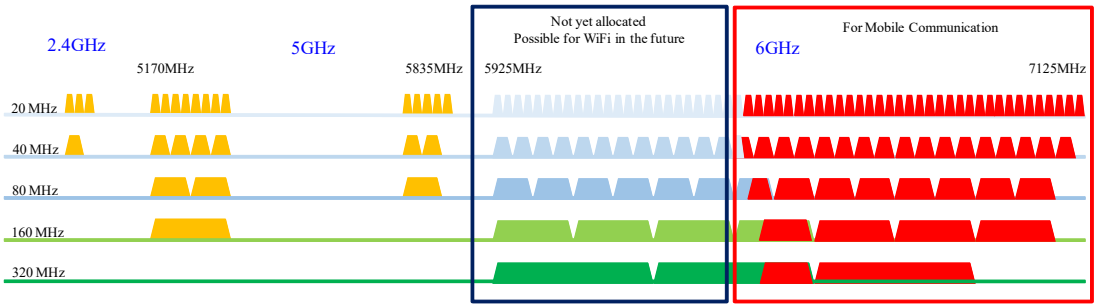

Figure 1: WLAN Channel Plan in China (Source: H3C)

*2.2 16 * 16 Multi-User Multiple-Input Multiple-Output (MU-MIMO)*

To meet the growing bandwidth demands of the increasing number of Wi-Fi devices, the AP continues to increase the number of antennas and improve spatial multiplexing capabilities. Wi-Fi 7 has increased the number of spatial streams from 8 to 16. Therefore, compared to Wi-Fi 6, the theoretical physical transmission rate has doubled. With 16 streams of Wi-Fi 7, each device has sufficient bandwidth to run Internet applications smoothly [5].

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2.3 Higher Order 4096 Quadrature Amplitude Modulation (QAM)

QAM is a widely used Wi-Fi modulation scheme that simultaneously mixes amplitude and phase changes in the carrier wave. Wi-Fi 6 supports up to 1024 QAMs - the constellation points on the left in Figure 2 represent 10 bits of symbols. Wi-Fi 7 supports 4096 QAM - each right constellation point represents 12 bits of symbols. In other words, each QAM modulated point in Wi-Fi 7 can carry 2 more bits of information than Wi-Fi 6, resulting in a 20% increase in speed [4].

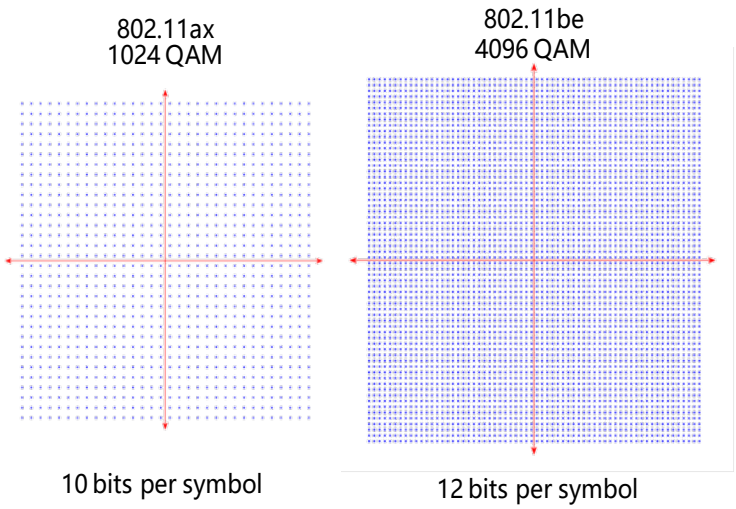

Figure 2: 4096 QAM of Wi-Fi 7 (Source: H3C)

2.4 Multi Link Operation (MLO)

Although traditional APs for Wi-Fi 6 support dual or triple band, the device can only choose one frequency band to access. For example, you can only choose one frequency band between 2.4 GHz and 5 GHz in a Wi-Fi network for data transmission, and the resources of the other frequency band are wasted even though it is idle.

The interference level and spectral characteristics between different frequency bands are inconsistent. If some channel air interface resources are poor, transmitting packets continuously on that channel will result in more packet loss and retransmission. To more effectively integrate and utilize spectrum resources, Wi-Fi 7 directly defines relevant standards for multi-link aggregation from the protocol side, including multi-link architecture, channel access, and data transmission.

MLO refers to a radio frequency unit that has at least two or more radio frequency links connected to the air interface. Compared to single-link devices, it adds redundancy to the radio frequency links. The device switches and collaborates on different links based on usage scenarios and air interface status to ensure more efficient, faster, and low-latency data transmission.

Wi-Fi 7 adopts flexible and diverse channel access modes to further optimize channel transmission efficiency. It includes two modes: asynchronous and synchronous [4], as shown in Figure 3.

- Asynchronous mode: independent channel detection, listening, and data transmission between different RF links, that is, different links can choose to receive or send data at the same time, improving transmission efficiency.

- Synchronous mode: different links must receive or send data simultaneously, avoiding mutual interference between receiving and sending data between different links in asynchronous mode.

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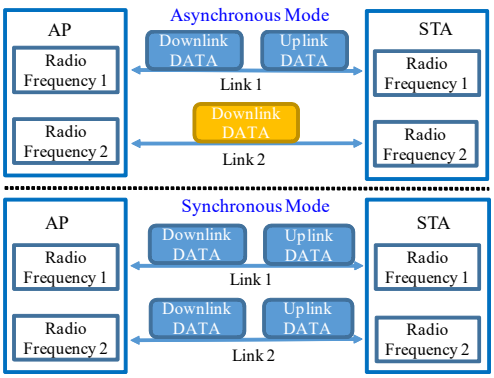
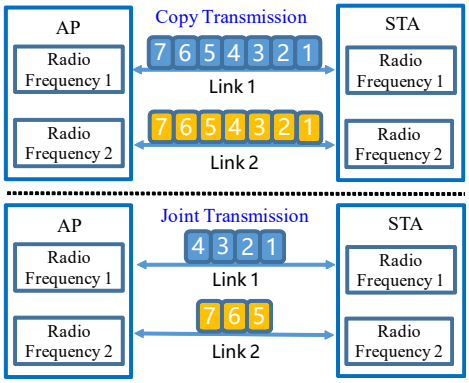


(Source: H3C)

Figure 3: Channel Access Modes of MLO



(Source: H3C)

Figure 4: Transmission Mechanism of MLO

Wi-Fi 7 upgrades the data transmission mechanism to improve the efficiency of air interface transmission, as shown in Figure 4.

➢ Copy transmission: involves transmitting the same data across different links. When there is interference in one of the channel environments, the receiving end can effectively reduce transmission delay based on the "first come first served" principle.

➢ Joint transmission: by reasonably splitting data packets and transmitting data on two RF links simultaneously, it can effectively improve transmission efficiency.

2.5 Multi Resource Unit (RU)

Wi-Fi 7 flexibly allocates wireless resources to improve spectrum efficiency.

Under the Wi-Fi 6 protocol, each user can only send or receive frames on a specified Resource Unit, which significantly limits the flexibility of spectrum resource scheduling. As shown in Figure 5, to address this issue and further improve spectral efficiency, Wi-Fi 7 allows for the allocation of multiple RUs to a single user and can combine different sizes of RUs to improve transmission efficiency, which is suitable for high bandwidth applications [4].

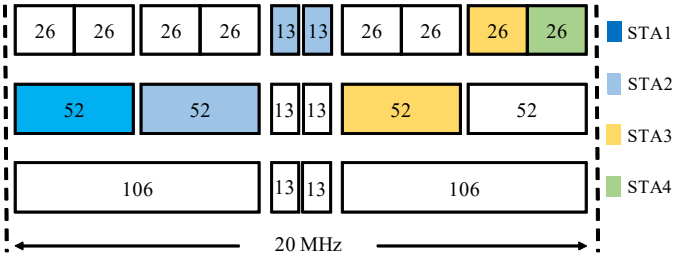


Figure 5: Multi RU of Wi-Fi 7 (Source: H3C)

2.6 Preamble Puncturing

Wi-Fi 7 supports Preamble Puncturing technology. When there is interference in a small bandwidth of a certain frequency band, it can allow communication data to skip the interfered frequency band (will be set to Null status) and continue to transmit normally in the remaining frequency bands (bundled), thereby improving anti-interference ability [5].

3. Summary

With the fast development of electronic information technologies, new applications are emerging into the market, such as 8K high-definition videos, Virtual Reality (VR)/Augmented Reality (AR), video conferences, online games, Internet of Things (IoTs)/Industry 4.0, remote diagnosis and surgery. These applications have higher requirements for wireless communication bandwidth (>20 Gbps), ultra-low latency (<5 ms)/jitter/package loss rate, high reliability, and Quality of Service (QoS). With the continuous innovation of applications, maturity of the industrial ecosystem, and growth of

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consumer demands, Wi-Fi 7 will undoubtedly become an important component of wireless communication in the future [6].

Wi-Fi Alliance estimates that Wi-Fi 7 will rapidly become popular in a wide ecosystem, with over 233 million devices expected to enter the market by 2024 and growing to 2.1 billion devices by 2028 [2].

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