Wi-Fi 6 Technology and Evolution White Paper

Contents

List of Figures

List of Tables

1 Overview

1.1 Purpose

From 802.11, which was released in 1997, to 802.11ax, which was introduced in 2019, the 802.11 family of Wi-Fi standards has gone through six generations. Wi-Fi technology has since undergone remarkable development and widespread adoption. The launch of 802.11ax is a further advancement of the Wi-Fi technology. In October 2018, the Wi-Fi Alliance (WFA) decided to name Wi-Fi generations in “Wi-Fi + number” format. In September 2019, it unveiled the Wi-Fi 6 certification program to promote the application of Wi-Fi technology in devices and various industry sectors. This document will introduce the background, advantages, key technologies, and application scenarios of Wi-Fi 6 (802.11ax), as well as the possible development directions of the next-generation Wi-Fi technology.

1.2 Terms, Definitions and Abbreviations

1.2.1 Terms and Definitions

Table 1.1 lists some terms used in this document and their definitions.

Table 1-1 Terms and Definitions

Term	Defintion
Beacon	The beacon frame is an 802.11 management frame.

1.2.2 Abbreviations

Table 1-2 lists some abbreviations used in this document.

Table 1-2 Abbreviations

Abbreviation	Full Spelling
ACK	Acknowledgement
A-MSDU	Aggregation-MAC Service Data Unit
AP	Access Point
AR	Augmented Reality
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BSS	Basic Service Set
CCA	Clear Channel Assessment
DCM	Dual Carrier Modulation
DL	Download
ER	Extended Range
FER	Frame Error Rate
FFT	Fast Fourier Transform
GI	Guard Interval
HARQ	Hybrid automatic Repeat Request
HEW	High-Efficiency WLAN
ICI	Inter-Carrier Interference
LDPC	Low Density Parity Check
MCS	Modulation and Coding Scheme
MIMO	Multiple-Input Multiple-Output
MPDU	MAC Protocol Data Unit
MSDU	MAC Service Data Unit

Abbreviation	Full Spelling
MU-MIMO	Multi-user Multiple-Input Multiple-Output
NAV	Network Allocation Vector
NDP-A	Null Data Packet Announcement
OBSS	0verlapping Basic Service Sets
OFDMA	Orthogonal Frequency Division Multiple Access
ONT	Optical Network Terminal
PD	Power Detect
PPDU	PLCP Protocol Data Unit
QAM	Quadrature Amplitude Modulation
RTS	Request to Send
RU	Resource Unit
SINR	Signal to Interference plus Noise Ratio
SNR	Signal Noise Ratio
SR	Spatial Reuse
SU-MIMO	Single user-Multi input, multiple output
STA	Station
TPC	Transmit Power Control
TRS	Triggered Response Scheduling
TWT	Target Wake Time
UL	Upload
Wi-Fi	Wireless Fidelity
WFA	Wi-Fi Alliance
WLAN	Wireless Local Area Network

2 Introduction to IEEE802.11 Standards

2.1 Development of IEEE802.11 Standards

Wi-Fi is a short-range wireless access technology that converts signals from wired to wireless based on the IEEE 802.11 series protocols. It has become the preferred way for users to access the Internet both in the home and at work. The WFA forecasts that by 2022, nearly 400 million Wi-Fi devices be serving the world, carrying more than half of the global data traffic. Such achievements are not possible without the continuous evolution of the Wi-Fi technology.

802.11b was the first widely accepted Wi-Fi standard, followed by 802.11a, 802.11 g, 802.11n and 802.11ac.The evolution of these five Wi-Fi generations mainly revolved around increasing the theoretical rate, that is, the throughput in a high Signal Noise Ratio (SNR) environment, to meet the growing bandwidth demand. As new services such as smart homes, video conferencing and AR/VR gain popularity, Wi-Fi networks begin to see congestion thanks to the increasing number of smart devices. That makes boosting spectral efficiency more of an issue than increasing the theoretical rate for the next Wi-Fi generation, 802.11ax, to address as it seeks to provide access for more Stations (STAs).

In terms of increasing the theoretical rate, 802.11ax inherits the 8x8 Multiple-Input Multiple-Output (MIMO) technology of 802.11ac while also providing higher-order 1024-QAM modulation and supporting long Orthogonal Frequency Division Multiplexing (OFDM) symbols to improve throughput. To improve spectral efficiency, 802.11ax innovatively introduces the Orthogonal Frequency-Division Multiple Access (OFDMA) technology while still using 8*8 MU-MIMO to implement spatial diversity. Although the theoretical rate of 802.11ax is only 37% higher than that of 802.11ac, the per-user throughput of 802.11ax in dense environments is expected to be at least four times higher than that of 802.11ac due to more efficient spectral utilization and because of improvements designed for intensive deployment. As for the design of its operating bands, 802.11ax adjusts the applicable bands from 1-6GHz to 1-7.125GHz. While compatible with the existing 2.4GHz and 5GHz bands, it also adds the 6GHz band with seven 160

MHz channels, thus opening up more possibilities for the development of Wi-Fi technology in the future.

*The 6GHz certification specifications of the WFA have not been formulated.

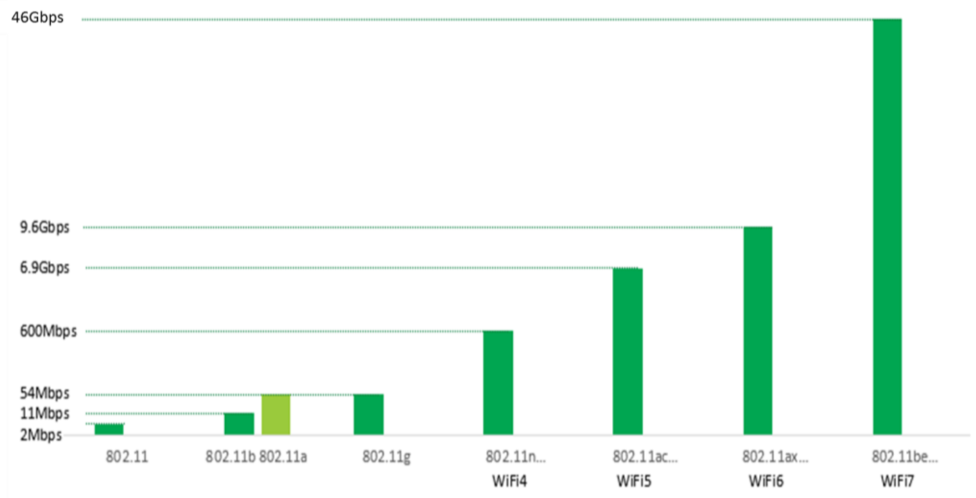

Figure 2-1 Evolution of the IEEE802.11 Standards

2.2 WFA Progress

802.11ax is the name assigned by the IEEE 802.11 standards organization of to the new-generation WLAN standard. To facilitate the popularization of the new technology, the WFA decided in October 2018 to name Wi-Fi generations in “Wi-Fi + number” format. When users use Wi-Fi, they can know the technology standard and rate level according to the number, just as they know the cellular network standard they use according to the 3G/4G sticker on their mobile phones. In the new format, Wi-Fi 5 corresponds to 802.11ac and Wi-Fi 6 to 802.11ax.

On September 16, 2019, the WFA announced the launch of the Wi-Fi CERTIFIED 6 program. Soon after that, ZTE's CPE product, the ZXHN F2886S, passed Wi-Fi 6 certification, becoming the industry’s first XGS-PON ONT that completed Wi-Fi 6 certification and supports 10GE and IoT interfaces as well as the first ONT from China that passed WPA3 security testing. The ZXHN F2886S has won full recognition from authoritative institutions for its network capacity, bandwidth use efficiency, and Wi-Fi security protection. It has become a frontrunner and benchmark in the industry.

2.3 802.11ax Rates

The 802.11ax standard supports up to eight spatial streams and 160MHz bandwidth. Table 2-1 shows the modulation and coding schemes of a single spatial stream.

Table 2-1 Modulation and Coding Schemes of a Single Spatial Stream

MCS Index	DCM	Modulation Type	Coding Rate	Data Rate (in Mb/s)											
				20 MHz Channels			40 MHz Channels			80 MHz Channels			160 MHz Channels		
				0.8us GI	1.6us GI	3.2us GI	0.8us GI	1.6us GI	3.2us GI	0.8us GI	1.6us GI	3.2us GI	0.8us GI	1.6us GI	3.2us GI
0	1	BPSK	1/2	4.3	4	3.6	8.6	8.1	7.3	18	17	15.3	36	34	30.6
	0		1/2	8.6	8.1	7.3	17.2	16.3	14.6	36	34	30.6	72.1	68.1	61.3
1	1	QPSK	1/2	8.6	8.1	7.3	17.2	16.3	14.6	36	34	30.6	72.1	68.1	61.3
	0		1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
2	N/A	QPSK	3/4	25.8	24.2	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
3	1	16-QAM	1/2	17.2	16.3	14.6	34.4	32.5	29.3	72.1	68.1	61.3	144.1	136.1	122.5
	0		1/2	34.4	32.5	29.3	68.8	65	58.5	144.1	136.1	122.5	288.2	272.2	245
4	1	16-QAM	3/4	25.8	24.4	21.9	51.6	48.8	43.9	108.1	102.1	91.9	216.2	204.2	183.8
	0		3/4	51.6	48.8	43.9	103.2	97.5	87.8	216.2	204.2	183.8	432.4	408.3	367.5
5	N/A	64-QAM	2/3	68.8	65	58.5	137.6	130	117	288.2	272.2	245	576.5	544.4	490
6	N/A	64-QAM	3/4	77.4	73.1	65.8	154.9	146.3	131.6	324.3	306.3	275.6	648.5	612.5	551.3
7	N/A	64-QAM	5/6	86	81.3	73.1	172.1	162.5	146.3	360.3	340.3	306.3	720.6	680.6	612.5
8	N/A	256-QAM	3/4	103.2	97.5	87.8	206.5	195	175.5	432.4	408.3	367.5	864.7	816.7	735
9	N/A	256-QAM	5/6	114.7	108.3	97.5	229.4	216.7	195	480.4	453.7	408.3	960.7	907.4	816.6
10	N/A	1024-QAM	3/4	129	121.9	109.7	258.1	243.8	219.4	540.4	510.4	459.4	1080.9	1020.8	918.8
11	N/A	1024-QAM	5/6	143.4	135.4	121.9	286.8	270.8	243.8	600.4	567.1	510.4	1201	1134.2	1020.8

Wi-Fi 6 technology supports up to eight spatial streams. Because the number of spatial streams is proportional to the maximum theoretical rate, we can calculate that, based on the theoretical rate of a single spatial stream, Wi-Fi 6 can achieve a 9.6Gbps theoretical rate when operating at 160MHz@5GHz.

3 Key Technologies of 802.11ax

To improve spectral efficiency, boost throughput, and improve performance in dense scenarios, 802.11ax has improvements in the following key technologies compared with 802.11ac.

Table 3-1 Comparison of Features between 802.11ax and 802.11ac

Feature	**802.11ac**	**802.11ax**
OFDMA	Not supported	Supported. OFDMA is a multi-user version of the OFDM digital modulation scheme. It groups subcarriers to form Resource Units (RUs) and then allocates the RUs to implement concurrent transmission for multiple users at multiple addresses.
MU-MIMO	Only Downlink is supported.	Both Downlink and Uplink are supported.
1024QAM	Not supported	Supported. 1024-QAM is a more-efficient, higher-order modulation scheme.
Spatial Reuse (SR)	Not supported	Supported. BSS coloring allows a device to distinguish the transmissions of its own Wi-Fi network from those of the adjacent networks. The transmit power and Power Detect (PD) threshold can be dynamically adjusted to increase SR.
Target Wake Time (TWT)	Not supported	Supported. TWT reduces power consumption and media access competition.
Long OFDM symbol	GI: 0.4µs/0.8µs Symbol duration: 3.2µs	GI: 0.8 µs, 1.6 µs or 3.2 µs Symbol duration: 12.8 µs
Dual Carrier Modulation (DCM)	Single carrier modulation	Supported. One signal is concurrently transmitted over two subcarriers to achieve diversity.
Extended Range (ER)	Not supported	Supported. When the distance between AP and STA reaches a certain value, the AP and STA negotiate to transmit signals over smaller spectrum to expand coverage.

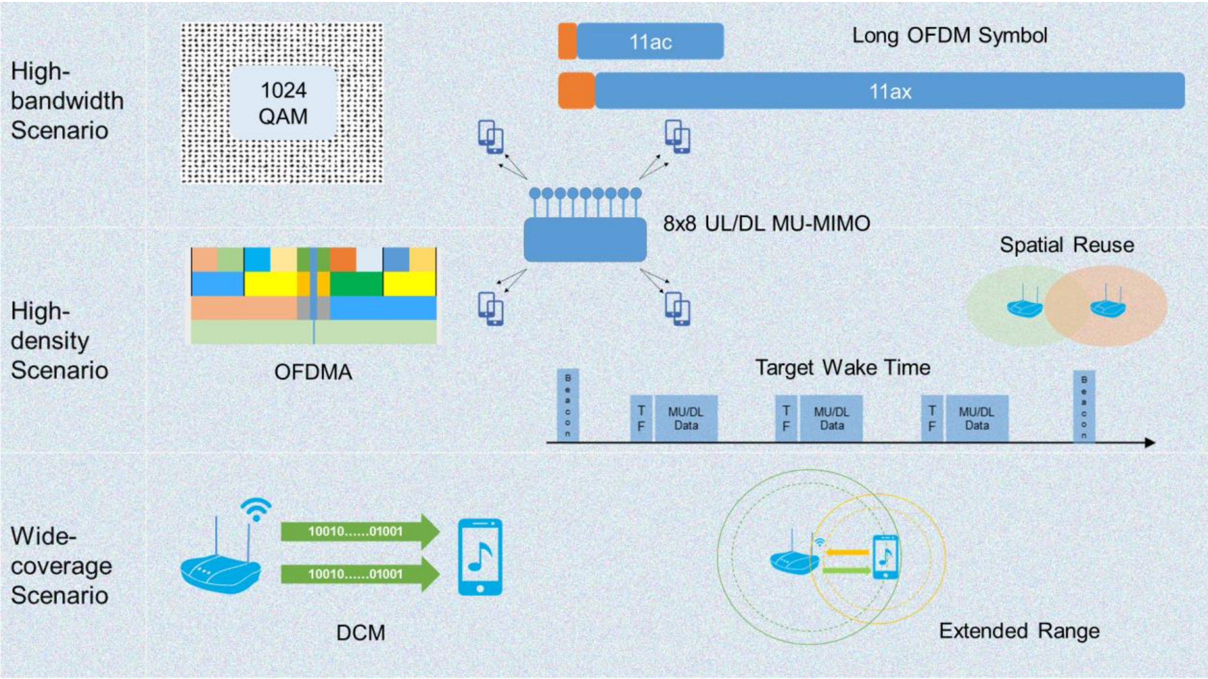

Figure 3-1 Key 802.11ax Technologies and Corresponding Scenarios

3.1 OFDMA

OFDMA divides a channel into dozens or hundreds of subcarriers, which are then grouped into several RUs. One or more RUs can be assigned to each user to meet different bandwidth requirements.

OFDMA assigns RUs to different users to implement concurrent transmission for multiple users. This mechanism effectively reduces the overheads used to contend for transmission opportunities and the overheads of frame preambles and frame intervals, which in turn improves spectrum utilization and air-interface efficiency. The improvements are especially obvious in high-density scenarios such as railway stations and stadiums. In addition, concurrent transmission slashes the average waiting time of multiple STAs, and avoids the long wait caused by the exclusive occupation of the entire channel by low-rate frames. As a result, latency and jitter are reduced by concurrent transmission.

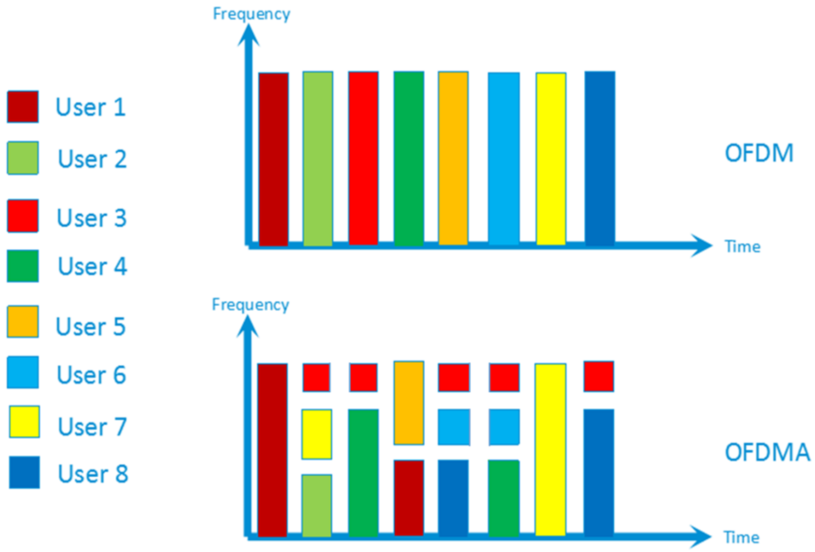

Figure 3-1 OFDM vs OFDMA

3.1.1 Resource Unit (RU)

In a dense multi-user environment, a Wi-Fi channel can be divided into dedicated subchannels to enable multiple OFDMA users to share one 802.11ax Wi-Fi channel.802.11ax divides the bandwidth of a Wi-Fi channel into multiple RUs. The concept of RU in 802.11ax is similar to the concept of resource block in LTE. The smallest RU consists of 26 subcarriers.802.11ax specifies the number of subcarriers contained in RUs of different sizes. An RU may contain 26/52/106/242/484/996/2*996 subcarriers.

20MHz bandwidth can house a maximum of nine RU-26s and connect up to nine concurrent users. A 20MHz channel contains 256 subcarriers, with each subcarrier providing 78.125kHz bandwidth. Not all the subcarriers in the channel are used to carry data. Some subcarriers are used as Guard Intervals (GIs) to prevent interference between adjacent channels or subcarriers, while some are used as DC subcarriers or pilot subcarriers to implement synchronization between AP and STA. The following figure shows the RU specifications in a 20MHz channel.

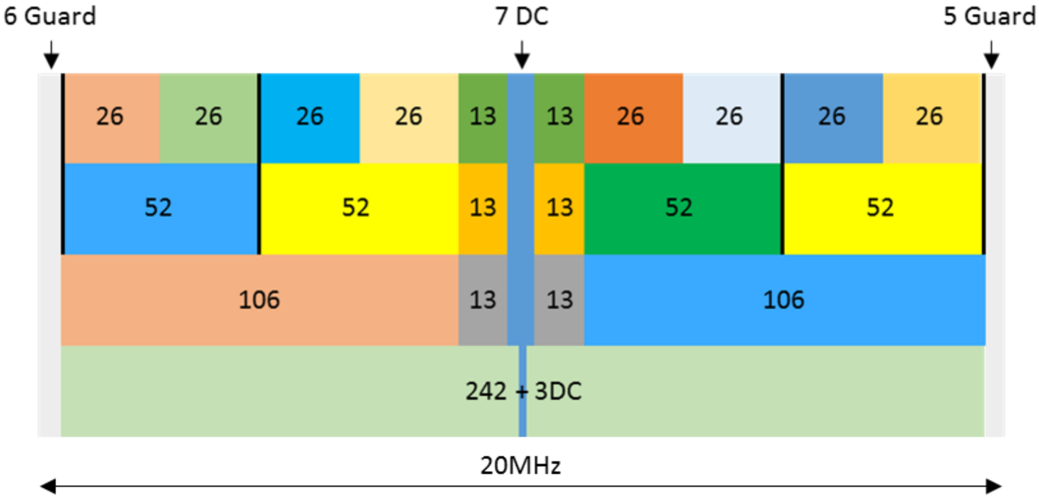

Figure 3-2 Numbers of RUs in a 20MHz Channel

802.11ax also specifies the types and maximum numbers of RUs supported by different channel bandwidths, as shown in the table below:

Table 3-2 Numbers of RUs Supported by Different Channel Bandwidths

RU Size	20MHz	40MHz	80MHz	160MHz
26 subcarriers	9	18	37	74
52 subcarriers	4	8	16	32
106 subcarriers	2	4	8	16
242 subcarriers	1	2	4	8
484 subcarriers	N/A	1	2	4
996 subcarriers	N/A	N/A	1	2
2*996 subcarriers	N/A	N/A	N/A	1

3.1.2 Downlink OFDMA Technology

The downlink does not need advance signaling to trigger or initiate transmissions. The AP itself knows the characteristics of the data to be transmitted. It only needs to send the data in an appropriate way that is defined by information such as STA ID, RU, MCS, and coding mode. All the information is written into the HE-SIG-B field in the multi-user downlink OFDMA frame. After receiving the field, the STA can know whether it is the intended recipient of the packet, and discover the corresponding RU and decoding mode. After that, it can demodulate the contents of the received packet.

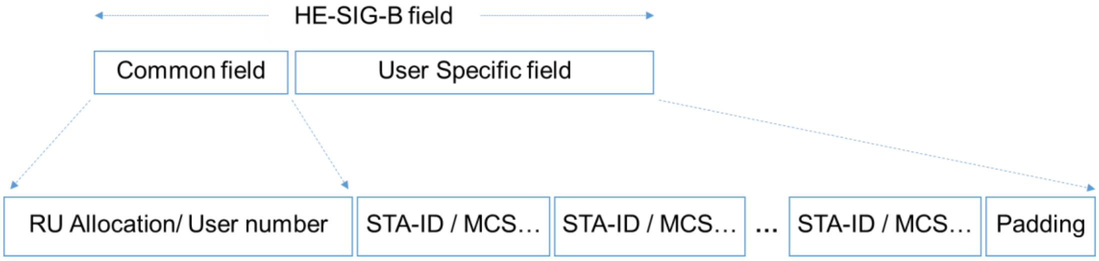

Figure 3-4 Structure of the HE-SIG-B Field

HE-SIG-B is a field with a variable length that is determined by the number of addressing STAs. The field consists of the Common field and the User Specific field.

Common field: The RU Allocation sub-field specifies the RU allocation scheme and the number of users.

User Specific field: It describes each STA's key information including STA-ID, MCS, and coding mode.

3.1.3 Uplink OFDMA Technology

To let STAs send uplink OFDMA packets in a unified manner, the multi-user OFDMA uplink needs a special trigger frame. The main function of the trigger frame is to inform the STAs of the requirements of the uplink data expected to be received. The uplink data requirements, which include the number of spatial streams, the allocation of RU resources, the duration of the PPDU, and control information such as the STAs' transmit power, are intended to ensure that the receive power of multiple STAs is basically the same at the AP.

Each client occupies their own RUs through polling so that multiple STAs can use different RUs to send uplink OFDMA packets over different sub-frequency bands.

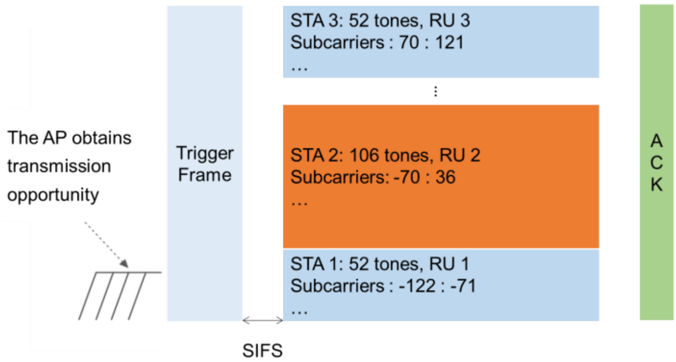

Figure 3-5 Trigger Process of Uplink OFDMA Transmission

The trigger-frame-based uplink transmission mechanism has requirements for the transmission time, frequency, sampling clock, and power of the transmitting STA. On one hand, this reduces the synchronization difficulty at the receiving AP and enhances the AP's control over the STA. On the other hand, frequency synchronization and sampling clock synchronization can avoid Inter-Carrier Interference (ICI), and power pre-offset can decrease mutual interference between user signals at the receiving end.

3.2 MU-MIMO

Multi-user Multiple-Input Multiple-Output (MU-MIMO) is a multi-antenna technology based on the beamforming technique. In a high-bandwidth scenario, the MIMO technology is used to implement spatial multiplexing, which enables several independent data streams to be sent on the same bandwidth to multiply system capacity. In a high-density scenario, the space division technology is used to concurrently transmit data between the AP and multiple STAs to greatly improve throughput and transmission efficiency.

In addition to inheriting the DL MU-MIMO technology of 802.11ac, 802.11ax also adds UL MU-MIMO. Consequently, 802.11ax supports up to eight antennas; that is, it can concurrently transmit the data of a maximum of eight users.

MU-MIMO increases the whole-system capacity. It is more efficient in transmitting large data packets at a high SNR, so it is suitable for heavy traffic scenarios such as video, voice and office.

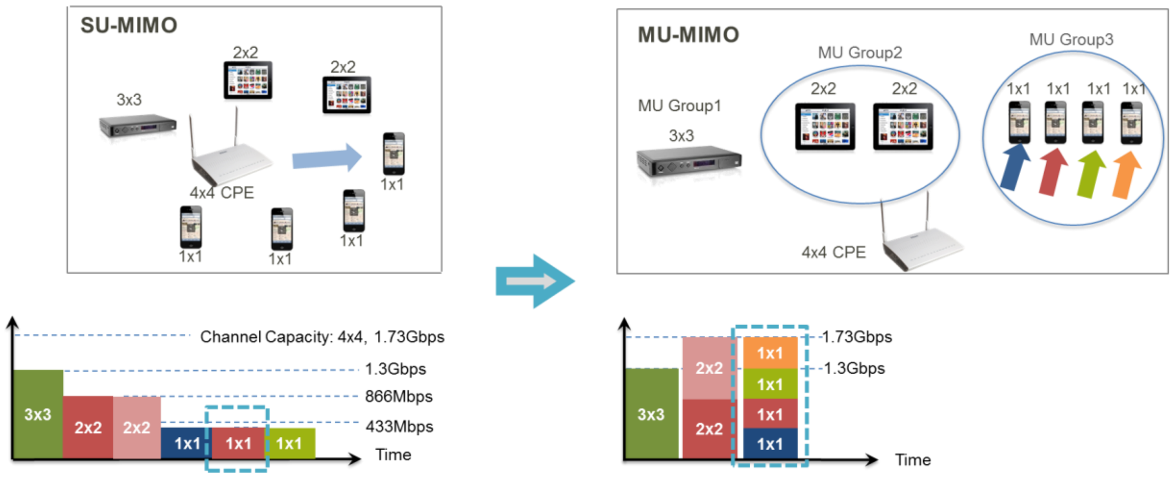

Figure 3-3 SU-MIMO vs MU-MIMO

3.2.1 DL MU-MIMO

In terms of the basic principle of DL MU-MIMO, 802.11ax and 802.11ac are basically the same. First, the AP performs a detection by using all the antennas to send an empty probe frame to the STAs. The STAs acknowledges the information received from each antenna. Through this exchange, channel information is fed back to form a channel matrix. This matrix pre-encodes data before transmission to implement beamforming, which directs different user data to different STAs at different locations. The entire process can be simply described as follows: The AP calculates a channel matrix for each STA, and then directs the beams carrying information to different STAs. Each beam carries the packets of the target STA.

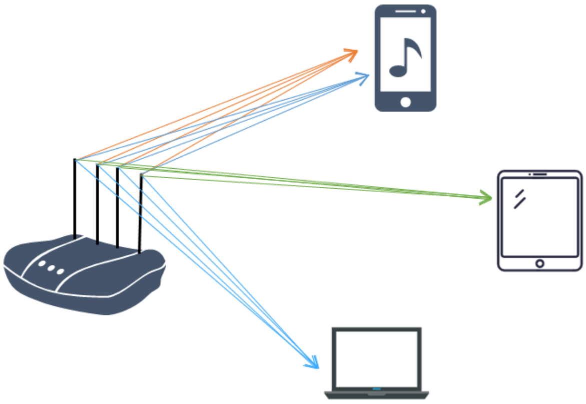

Figure 3-4 Diagram of the DL MU-MIMO Technology

3.2.2 UL MU-MIMO

UL MU-MIMO is a new technology introduced to 802.11ax.Its exchange mode is similar to the UL OFDMA process. First, the AP initiates a polling to learn about the caching status and traffic characteristics of the STAs. Then it performs an equivalent calculation on the uplink to determine how to allocate spatial streams and conduct transmission synchronization. After that, it uses a trigger frame to trigger transmission, notifies and arranges for multiple STAs to carry out uplink transmission, and finally replies with an ACK message to complete the entire information exchange process.

3.3 1024-QAM

802.11ax adds MCS10 and MCS11, which support the 1024-QAM scheme, resulting in a 25% boost in theoretical rate over 802.11ac.

It should be noted that when high-order modulation is used, a higher SNR is required to keep the BER/FER at an acceptable level. Therefore, the benefits of the 1024-QAM technology can only be maximized in short-range scenarios with good reception. In reality, a higher SNR is obtained to improve environmental adaptability usually by increasing signal output power, reducing noise, or doing both.

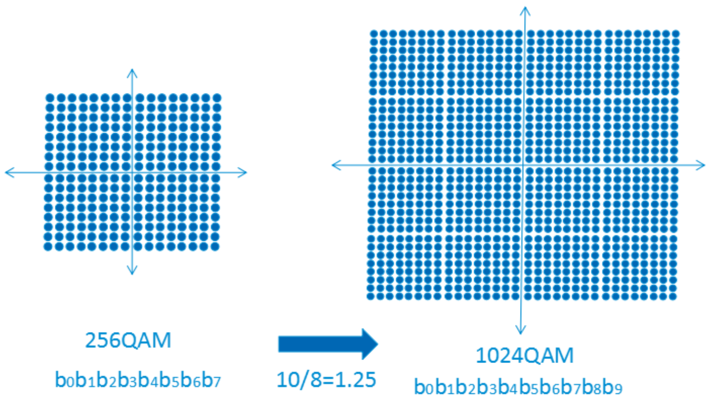

Figure 3-5 256QAM vs 1024QAM

3.4 Spatial Reuse (SR) Technology

To improve the system-level performance and the utilization of spectrum resources in dense environments, 802.11ax introduces the SR technology. The STA can identify signals from Overlapping Basic Service Sets (OBSSs) and make media competition and interference management decisions accordingly.802.11ax mainly uses a combination of technologies, including BSS color code, dynamic adjustment of the CCA threshold, and transmit power control, to implement the SR, thus improving the system-level performance.

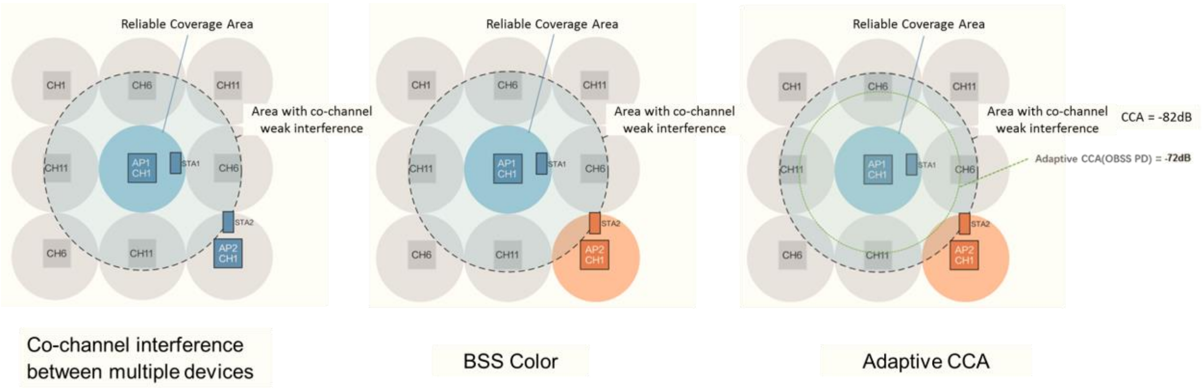

Figure 3-9 SR Technology - Issues and Solutions

Because there are s only three completely independent channels in the 2.4GHz band and a limited number of channels at 80MHz in the 5GHz band, co-channel interference between adjacent devices can hardly be avoided in a scenario where APs are densely deployed. In a traditional Wi-Fi network, interference from co-channel signals will cause a lot of competition and backoff, which greatly reduces the transmission efficiency of the system. As shown in the left diagram in Figure 3-9, both AP 1 and AP 2 operate at channel 1. When AP 1 communicates with STA 1, due to the existence of co-channel interference, AP 2/STA 2 will determine that the current channel is busy and they cannot transmit data. As a result, the two BSSs, which should have been able to operate concurrently, now have to work serially to contend for transmission opportunities.

802.11ax adds a 6-bit BSS field to the PHY header. BSS coloring is used to distinguish intra-BSS and inter-BSS frames. If the BSS color of the detected PLCP Protocol Data Unit (PPDU) is the same as the color of the associated AP, the STA regards this frame as an intra-BSS frame and deems the frame as related to it. If the BSS color of the detected frame is different, the STA will regard it as an inter-BSS frame from the overlapping BSS. That is, it will deem the frame as a packet that it does not need to pay attention to. Therefore, the current channel will be judged to be busy only when an AP /STA verifies that the detected frame is an inter-BSS frame and that co-channel signals are being transmitted. As shown in Figure 3-9, AP 1 and STA 1 are colored blue, while AP 2 and STA 2 are orange. When AP 1/STA 1 transmit data, their signals will still be received by AP2/STA2. However, because of the different BSS colors, AP2/STA2 will determine that the current transmission is not related to themselves. Transmission between AP2 and STA2 can still proceed and will not be interrupted by backoff.

802.11ax needs to be compatible with all the previous Wi-Fi technologies, which use the CCA threshold to determine whether the channel is busy. (The CCA threshold usually ranges from -82dBm to -62dBm).As shown in Figure 3-9, while AP 1 and STA 1 are transmitting data, STA 2 also intends to send a message to AP 2. However, because the default CCA threshold is already reached, the channel is judged as busy and data cannot be transmitted.

To solve this problem, 802.11ax introduces a mechanism to dynamically adjust the CCA threshold. STA 2 can dynamically adjust the range of the CCA threshold (such as raising it from -82dBm to -72dBm in Figure 3-9) according to the degree of co-channel interference it detects. In this way, the co-channel APs can concurrently transmit data, thereby achieving spatial reuse and improving the transmission efficiency of the system.

3.5 Target Wake Time (TWT)

TWT is a new node mechanism introduced by 802.11ax. It allows for a longer and more flexible node period as well as sleep scheduling for multiple STAs, which greatly improves the battery life of IoT sensors and other devices.

TWT enables the AP to independently negotiate with each STA about the wakeup times of the STAs. When not at wakeup times, a STA can enter sleep mode to reduce power consumption. Moreover, TWT breaks the constraints placed by the beacon transmission period on energy saving mechanisms. It allows the STA to wake up during a period other than the beacon transmission period, thus greatly increasing the flexibility of the sleep time. In addition, the AP can set a scheduling process and provide the TWT value to the STA. As a result, no individual TWT protocol is required between AP and STA. This operation is called the "Beacon TWT operation" and it can reduce the number of devices that compete for wireless media at the same time.

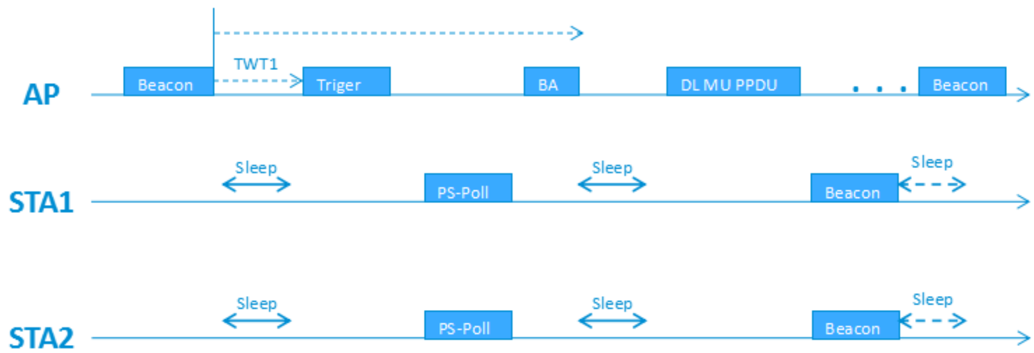

Figure 3-6 Example of Broadcasting TWT

3.6 Long OFDM Symbol

Compared with 802.11ac, 802.11ax has long OFDM symbols to improve the theoretical rate in the time and frequency domains:

Table 3-3 Comparison of the OFDM Symbols of 802.11ac and 802.11ax

Wi-Fi Standard	**802.11ac**	**802.11ax**
GI	0.4us/0.8us	0.8us/ 1.6us/3.2us
Time per OFDM symbol (Ts)	3.2us	12.8us
Time domain transmission efficiency <Ts / (GI + Ts)>	3.2 / (0.4 + 3.2) x 100% ≈ 89%	12.8 / (0.8 + 12.8) x 100% ≈ 94%
Subcarrier width	312.5kHz	78.125kHz
Number of subcarriers in 80MHz	234	980
Transmission efficiency improvement caused by subcarriers (80MHz)	(980/13.6) / (234/3.6) x 100%= 110%	

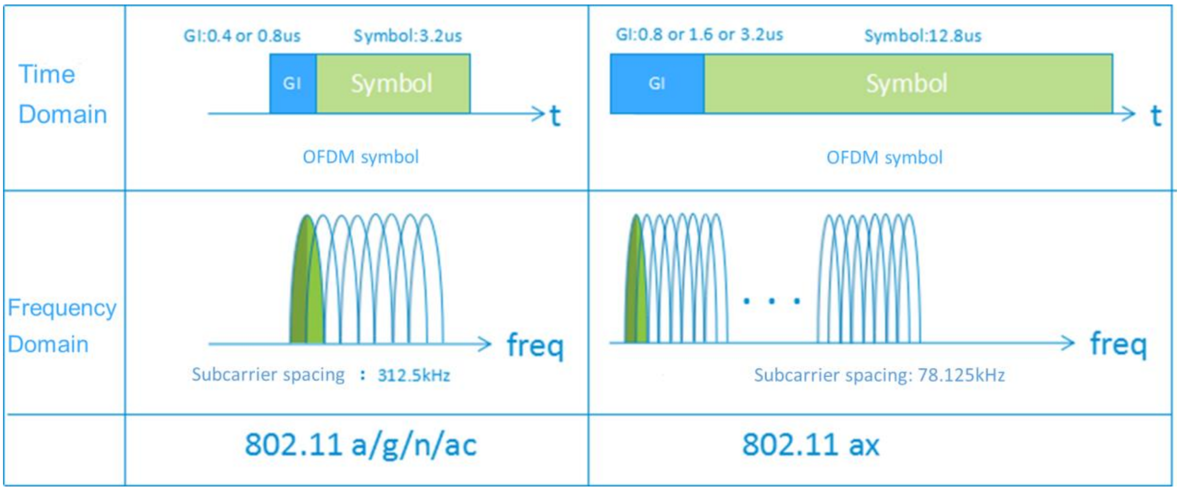

Figure 3-11 GI and Symbol Duration

3.6.1 Guard Interval (GI)

In 802.11ax, the GIs of 0.8us, 1.6us and 3.2us are defined, which improve over the 0.4us and 0.8us GIs of 802.11a/g/n/ac. When signals are transmitted outdoors or in an environment with significant multipath effects, the lengthened GIs can better prevent signal conflicts caused by delays in transmission over space.

3.6.2 Symbol Duration

At the same bandwidth, 802.11ax can use FFTs with more sample points to restore signals. Because the number of sampling points corresponds to the number of subcarriers, the larger the number of FFT points, the more subcarriers, and the smaller the spacing between subcarriers. Both a narrower subcarrier spacing and a longer symbol duration can improve signal robustness and expand signal coverage.

In 802.11ax, the subcarrier spacing can be reduced from 312.5kHz to 78.125kHz, but the corresponding symbol duration will be increased four times. This effectively reduces packet loss and retransmission, which helps ensure the robustness and stability of signals. Especially in medium- and long-distance transmission or transmission through multiple obstacles, the multi-path effect is obvious. The narrower subcarrier spacing and longer symbol duration of 802.11ax can reduce the inter-carrier interference and extend the signal coverage.

3.7 Dual Carrier Modulation (DCM)

802.11ax defines DCM to reuse the same signal on two subcarriers to provide an effect similar to frequency diversity. This mechanism increases equivalent gain by 3dB, reduces interference, and improves long-distance coverage.

In 802.11ax, the use of DCM is limited. Only three modulation mechanisms - BPSK, QPSK and 16-QAM - support DCM. In addition, DCM only supports single/dual space streams. In a word, DCM can work only under MCS0, MCS1, MCS3 and MCS4, and it is enabled only for long-distance transmission.

3.8 Extended Range (ER)

For coverage enhancement, 802 11ax defines the ER PPDU format.

In ER mode, it is forbidden to use RUs with more than 242 subcarriers. Transmission of up to 106 RUs is applied in ER mode to improve coverage. Like DCM, ER is enabled only for long-distance transmission.

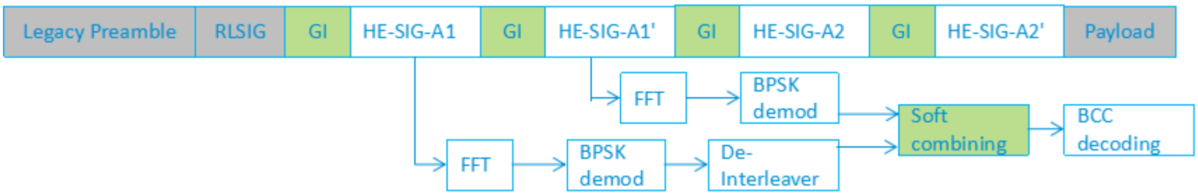

Figure 3-7 Extended Range

4 Wi-Fi 6 Application Scenarios

4.1 Smart Home Applications

Compared with Wi-Fi 5, Wi-Fi 6 is more applicable to high-rate, high-density and low-latency scenarios. High-rate home applications are mainly those involving smart wearable video devices, such as HD video and AR/VR. High-density scenarios are mainly for smart homes and smart security. Low-latency scenarios are mainly for emerging services including online gaming and cloud gaming. The following table summarizes the core capability indicators of Wi-Fi 6 in these scenarios:

Table 4-1 Core Capability Indicators of Wi-Fi 6

High bandwidth	Wi-Fi 6 can stably reach 500Mbps+ bandwidth in the 5GHz band, which is more than twice the rate required by VR.
Low latency	Based on VR service identification, Wi-Fi 6 ensures that the traffic of the VR dedicated channel is less than 50% of the peak traffic, and that the average latency is lower than 5ms.
High density	Wi-Fi 6 allows 128 STAs to be concurrently connected, thus enabling the development of IoT services in the home.

4.1.1 High-Bandwidth Videos Such as 4K/8K/VR

The bit rate of video services increases continuously from SD to HD, then to 4K and 8K, and now to VR. Video services drive the development of ultra broadband, the upgrading of user demand, and the shifting of operators' focus from connectivity to experience.

In network transmission, the key factors that affect video quality include bandwidth, latency, and packet loss. Bandwidth directly affects video metrics including bit rate, resolution, and color depth. That is, it affects how real images look, which is the key element in user experience. Packet loss causes video issues, such as stalling and stuttering, that greatly diminish the pleasure users derive from videos.

To get a better experience, users prefer to watch videos on mobile terminals. Wireless access is the best choice for watching VR videos. It frees users from the wired constraints of VR headsets, bringing them a superior, enjoyable experience.

The Wi-Fi 6 technology supports the coexistence of 2.4G and 5G frequency bands. The 5G band supports 160MHz bandwidth, with the maximum access rate reaching 9.6Gbps. It has relatively less interference and is more suitable for transmitting video services. In addition, Wi-Fi 6 can also use technologies including BSS coloring, MIMO, and dynamic CCA to reduce interference and packet loss. It can employ technologies such as OFDMA and MU-MIMO to decrease latency and thus better adapt to real-time video services. Thanks to all these features, Wi-Fi 6 can bring a better video service experience to users.

4.1.2 Low-Latency Services Such as Online Gaming

Online gaming is a highly interactive service that requires prompt responses to user operations and actions. VR games emerging in recent years, including even cloud VR gaming, have higher requirements in terms of bandwidth and latency. For example, cloud VR gaming requires 80Mbps to 1Gbps bandwidth, less than 20ms to 8ms latency, and lower than 1E-5 to 1E-6 packet loss rates.

The currently mainstream Wi-Fi technologies do not provide good support for VR gaming. Usually a large number of mobile terminals exist and numerous types of services are run in a home. This causes many sources of interference for Wi-Fi and affects the gaming service experience.

Against this background, building a high-rate, low-latency and reliable home wireless network with the Wi-Fi 6 technology is the best choice for improving users' gaming experience. Wi-Fi 6 not only increases the rate. It also adopts technologies such as OFDMA and MU-MIMO to greatly improve channel utilization, thereby meeting the service applications in multi-user scenarios and balancing the resource coordination among multiple mobile terminals in the home network. Technologies including BSS coloring, MU-MIMO and dynamic CCA are employed to reduce interference. The channel slicing technology of Wi-Fi 6 can be used to provide dedicated channels for games. All these technologies work together to reduce latency to meet the low-delay transmission requirements of gaming services, especially cloud VR games.

4.1.3 Smart Networking for Smart Homes

Smart networking offers important support for service scenarios including smart home and smart security. Home networking technology mainly needs to fulfil three requirements. First, it should be able to connect a sufficient number of devices. At present, a smart home can contain dozens of or even more than one hundred sensors. Second, its power consumption should be low. Many smart devices, such as smart doors, are micro-power gadgets that are not connected to power outlets and instead rely on batteries for long-time power supply. Third, it should provide good interoperability and allow users to control smart home devices through a widely used terminal such as a smartphone.

Several home networking technologies, including Zigbee, Z-Wave, Bluetooth and Wi-Fi, are currently available, but they all have their own limitations. For example, Zigbee and Z-Wave are low-power technologies, but their industry chains are scattered, fragmented, or not diversified enough. Moreover, some common mobile terminals do not support these technologies, which hinders interoperability. For Bluetooth and Wi-Fi, the corresponding standards organizations have also launched the specifications for their low-power versions, such as LBT and 802.11ah. However, due to the lack of compatibility, large-scale industry chains have not been established for these technologies. As a result, currently smart home networking technologies still do not have unified standards.

The emergence of the Wi-Fi 6 technology will bring the opportunity of unifying the smart home networking technologies. First, Wi-Fi 6 will become the mainstream next-generation Wi-Fi technology. Gateways, routers, mobile phones and smart devices that support Wi-Fi 6 will experience explosive growth after 2020.Second, the Wi-Fi 6 technology can adapt to dense scenarios. It can be used to implement the Internet of Everything inside the home, and integrate the home IoT with the home wireless LAN. Users can use any device to control home devices from anywhere, which improves service experience.

Wi-Fi6 is suitable for home networking due to another important factor. It borrows from the 802.11ah standard and introduces the Target Wake Time (TWT) function. This function allows devices to negotiate when they are awakened before they can send and receive data. Different

TWT periods are allocated to reduce the chances of competing for wireless media after wake-up. TWT also sets sleep times, which greatly prolongs the battery life of a large number of battery-powered smart devices.

Wi-Fi 6 integrates high density, massive connections, and low power consumption. It is compatible with different widely used mobile terminals to provide good interoperability. With these advantages, Wi-Fi 6 is a very promising technology for use in smart home networking.

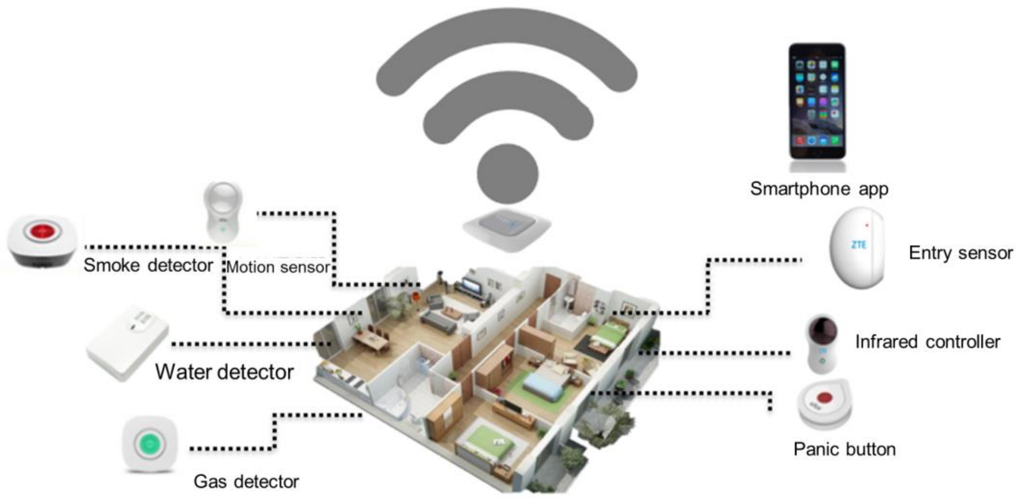

Figure 4-1 Wi-Fi 6 Used in a Smart Home

4.2 Industrial Applications

A wireless access network built with the Wi-Fi 6 technology can easily provide high-density wireless access and enable high-capacity wireless services. Wi-Fi 6 does not simply represent a rate increase, which is up to 9.6Gbps. By introducing the DL/UL MU-MIMO and OFDMA technologies, Wi-Fi 6 meets the access requirements in multi-user dense scenarios and improves the overall efficiency of the wireless network. It uses technologies including subcarrier spacing narrowing, symbol length extension, BSS coloring, and dynamic CCA to improve anti-interference capability to meet the low-latency transmission requirements of video and gaming services.

For example, Wi-Fi 6 can be utilized to provide wireless access in campus networks. Based on the low-cost, wide-coverage and high-quality access that results, video-based office collaboration services can be rolled out to improve employees' network experience and increase work efficiency.

In addition, the Wi-Fi 6 technology can be used to deliver wireless access in large public venues both indoors and outdoors. For example, the airport is a typical high-density public venue. For an airport to provide passengers with Wi-Fi access service, three issues should also be considered in addition to network operation and management.

First, a large number of terminal users have to be connected without lowering the efficiency of the entire wireless network. Wi-Fi 6 introduces such technologies as uplink MU-MIMO, OFDMA, and 1024-QAM high-order coding to increase spectrum resource utilization and enable multi-user access, which in turn boosts network capacity and transmission efficiency. In a dense environment, Wi-Fi 6 raises the per-user throughput at least four times and the number of concurrent users at least three times compared with Wi-Fi 5. For that reason, Wi-Fi 6 is also called High-Efficiency WLAN (HEW).

Second, passengers have to be provided with stable and high-quality wireless transmission. As more video applications such as movies, TV, VR/AR and mobile office emerge, they impose higher requirements for network transmission quality. Specifically, they require high bandwidth, low latency and low bit error rates. Wi-Fi 6 uses technologies including subcarrier spacing narrowing, symbol length extension, BSS coloring, and dynamic CCA to improve anti-interference capability, ensuring stable and high-quality wireless transmission and enhancing service experience.

Figure 4-2 Wi-Fi 6 Applied in a Campus

Third, passengers have to be offered secure data access and transmission, especially in an open environment. Although the Wi-Fi 6 standard itself does not specify any new security functions or enhancements, the Wi-Fi Alliance (WFA) has launched a new-generation encryption standard - WPA3. It is a more secure encryption mode and has become part of the standard configuration of Wi-Fi 6.WPA3 encrypts personalized data to enhance user privacy protections in open access networks. It is a feature used to encrypt the connections between every device and the AP. Therefore, WPA3 can be used in conjunction with Wi-Fi 6 to ensure secure access for airport passengers.

Figure 4-3 Wi-Fi 6 Applied in an Airport

As the new-generation Wi-Fi technology featuring high rates, multiple users and high efficiency, Wi-Fi 6 will be extensively used in various industries.

5 Wi-Fi 6 and 5G

Wi-Fi and cellular networks have been competing against each other for a long time. Wi-Fi is mainly used indoors and cellular chiefly outdoors. Because of its low data charges, Wi-Fi is always an important supplement to cellular in indoor coverage. The two technologies are already mature, with cellular evolved into the fifth generation and Wi-Fi into the sixth. In the future, they will complement each other in specific scenarios and coexist in the long term.

5.1 Application Scenarios

2G cellular mainly carried voice services, while the early 802.11a/b/g Wi-Fi standards mainly transmitted data services. In the application scenarios of the 2G era, the two technologies were basically complementary. Starting from the 3G era, networks began to carry a large amount of data services. In the 4G era, the booming development of mobile Internet applications led to explosive growth in mobile data traffic. In dense scenarios such as high-speed railway stations, stadiums, shopping malls and cafes, some competition emerged between 4G and 802.11n/ac Wi-Fi. As VoIP technology matures, Wi-Fi began to provide some voice services in many scenarios. An application pattern where 4G and Wi-Fi 5 both compete against and complement each other gradually took shape. Generally speaking, 4G focuses on mobile and WAN scenarios, while Wi-Fi 5 focuses on high bandwidth and LAN scenarios.

As 5G and Wi-Fi 6 learns from and compete with each other, their main battlefields are not expected to change in the future, but there may be more nuanced differences in their application. In addition to the traditional scenarios that have high mobility requirements, 5G will be favored where low interference, high QoS, high security, low latency, and massive connections are required. In scenarios that call for high bandwidth, low mobility, low network cost and low service tariffs, however, Wi-Fi 6 is preferred.

Table 5-1 Main Scenario Differences between 5G and Wi-Fi 6

Scenario Focus	5G	Wi-Fi 6
Frequency band interference	Authorized frequency bands, whose interference is controllable.★	Unauthorized frequency bands, whose interference is uncontrollable.
QoS	Reliable physical layer retransmission★	MAC retransmission, which is best-effort transmission
Security	At all levels from the bottom layers★	MAC and above layers
High bandwidth	Also featured	Advantageous★
Low latency	Low latency with no air interface competition★	High latency with air interface competition
Mobility	Advantageous★	Poor
Wide coverage	Advantageous★	Poor
Network cost	High	Advantageous★

5.2 Technical Specifications

Both 5G and Wi-Fi 6 use OFDMA as their main technology, and they even both employ LDPC in user-plane coding. It can be said that the two technologies increasingly converge, and their spectrum utilizations are very close. However, some minor technical differences still exist between them because they focus on different application scenarios.

Competitive access has always been a problem with Wi-Fi, causing high air-interface latency and difficulties in improving multi-user performance. By adopting technologies like uplink OFDMA and MU-MIMO, Wi-Fi 6 significantly improves the capability of simultaneous transmission for multiple users. However, to be benchmarked against 5G, the Wi-Fi technology needs to be further optimized in terms of clock and time accuracy.

Because 5G and Wi-Fi 6 focus on different application applications, Wi-Fi 6 has its own advantages. First, since Wi-Fi 6 is not used in high-speed movement scenarios, it does not produce obvious Doppler effects. Its channel estimation algorithm is relatively simple and it can obtain a better SNR than 5G. A higher-order 1024QAM scheme can be used to boost the transmission efficiency. Second, because Wi-Fi works in asynchronous uplink/downlink duplex mode, it can obtain a higher download rate by only operating in the downlink in a unit time. In addition, Wi-Fi 6 has a smaller coverage range than 5G and can use a shorter GI to further increase transmission rates, giving a slight advantage over 5G in theoretical downlink speeds.

Table 5-2 Main Technical Specification Differences between 5G and Wi-Fi 6

Technical Specifications	5G	Wi-Fi 6
Operating band	700MHz/2.6GHz/3.5GHz	2.4GHz/5.8GHz
Maximum system download rate	20Gbps@64T64R/100MHz	9.6Gbps@8T8R/160MHz
Typical download rate	850Mbps@2T2R/100MHz	950Mbps@2T2R/80MHz
Time division multiplexing mode	TDD synchronization	TDD quasi-synchronization
Frequency division multiplexing mode	OFDMA	OFDMA
Coding mode	LDPC/Polar	LDPC
Maximum modulation	256QAM	1024QAM
Subcarrier spacing	30kHz/60kHz	312.5KHz/78.125KHz
Typical symbol length	35.68us/17.84us	12.8us
Typical CP/GI	2.34us/1.17us	0.8us
MU-MIMO	Yes	Yes
Access network latency	0.5 - 5ms	10 - 50ms
Maximum coverage range	100km@50dBm/2.6G	100m@20dBm/2.4G
Maximum number of users	300 - 1000	32 - 256
Typical remote cost	1000RMB@2T2R/24dBm	300RMB@2T2R/20dBm

6 Evolution Directions of Wi-Fi 6

6.1 Wi-Fi 6E

As the Federal Communications Commission (FCC) resolved in 2018 to open up the 5.925GHz to 7.125GHz band and later the Wi-Fi Alliance (WFA) incorporated this band into the Wi-Fi 6 standard, Wi-Fi 6E has already gained official recognition. Moreover, Wi-Fi 6E has been officially introduced into the Wi-Fi 6 standard. Wi-Fi 6 will open up the 6GHz band for unauthorized use, allowing it to operate at the three bands of 2.4GHz/5GHz/6GHz.For the 6GHz band, however, its test specifications are still being customized by the WFA and its chips have not hit the mass market.

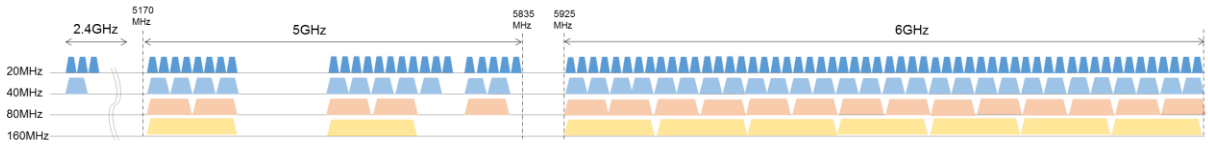

Figure 6-1 2.4GHz/5GHz/6GHz Channels of Wi-Fi 6

The introduction of the 6GHz band adds seven 160MHz channels. This on the one hand doubles the throughput and on the other hand greatly reduces the possibility of multiple devices sharing spectrum, which in turn greatly enhances the support of Wi-Fi 6E for high-bandwidth applications.

Although the mainstream Wi-Fi 6 devices currently do not support Wi-Fi 6E, chipmakers are still actively launching Wi-Fi 6E products. It is forecasted that in the first half year of 2021, mainstream chipmakers will release their flagship three-band Wi-Fi 6 chips. In the future, it is highly likely that high-end STAs will support Wi-Fi 6E.The planning of 6GHz spectrum in various countries is also an important factor affecting how fast Wi-Fi 6E is adopted.

6.2 Next-Generation Wi-Fi Technology after Wi-Fi 6

Wi-Fi 6 is designed partly to improve network performance in dense scenarios. With the release of the EasyMesh™ specification and the rapid increase in multi-AP requirements and applications, the focus has shifted to having the next-generation Wi-Fi technology after Wi-Fi 6 coordinate multiple APs to optimize network performance. Meanwhile, with the introduction of 6GHz, tri-band CPEs will start large-scale commercial use in the near future. This makes the topic of taking full advantage of multi-link benefits of Wi-Fi technology more attractive.

The next-generation Wi-Fi standard is still being formulated, and its functions and technology are still being discussed and improved. Based on information disclosed by the IEEE 802.11 Working Group, the possible directions for future technical improvement by the new standard are as follows:

1. Single-channel operation optimization: The new standard will continue the support of Wi-Fi 6E for the 6GHz band and offer support for 320MHz channels, 16 spatial streams, and 4096-QAM.

2. Multi-link operation mechanism: The new standard will allow an STA to use two or more links, such as both 5GHz and 6GHz channels, concurrently. This improves throughput, delivers low latency, and enables load balancing.

3. Multi-AP coordination mechanism: The new standard will implement distributed MIMO between multiple APs and reuse idle spatial streams. This will boost network performance in multi-AP environments, especially in mesh network scenarios which are increasingly in demand.

4. Low-latency operation mechanism: The new standard will employ latency measurement and multi-link technologies to provide low-latency operation modes and enhance the QoS mechanism for low-latency services.

This will enable the new standard to support high-throughput and low-latency services such as 4K/8K video, VR/AR video, gaming, remote office, and cloud computing.

5. Link adaptation mechanism: For example, the new standard will use Hybrid Automatic Repeat Request (HARQ) technology to combine and decode a transmitted erroneous message and the retransmitted erroneous message to improve the decoding success rate.

Amid fierce competition between Wi-Fi 6 and 5G, the development timeline of the next-generation Wi-Fi technology - IEEE 802.11be – has already emerged. With the introduction of new features such as multi-AP coordination, low-latency optimization, and expected theoretical rates up to 46Gbps, the next-generation Wi-Fi technology opens up endless possibilities for wireless applications of the future.