HUAWEI

White Paper

Huawei Wi-Fi 6 (802.11ax) Technology White Paper

Version 1.0

Contents

1 Introduction to Wi-Fi Development

Wi-Fi has become a ubiquitous technology in the world. It provides connections for billions of devices and is the first choice for more and more users to access the Internet. Additionally, Wi-Fi has gradually replaced wired access. To adapt to new service applications and reduce the gap with wired network bandwidth, each generation of 802.11 standards greatly improves the wireless speed.

In 1997, IEEE formulated the first wireless local area network (WLAN) standard 802.11, with the data transmission speed of only 2 Mbit/s. Regardless of the low speed, this standard has changed the access mode of users and freed people from the bondage of cables.

To meet the increasing requirements for the network transmission speed, IEEE released the 802.11b standard in 1999. 802.11b runs on the 2.4 GHz frequency band, and the transmission speed is 11 Mbit/s, which is 5 times the original standard. In the same year, IEEE released the IEEE 802.11a standard, which uses the same core protocol as the original standard and runs on the 5 GHz frequency band. The maximum original data transmission speed reaches 54 Mbit/s, which meets the requirement of medium throughput (20 Mbit/s) on the real network. As the 2.4 GHz frequency band has been widely used, working on the 5 GHz frequency band greatly reduces conflict.

In 2003, orthogonal frequency division multiplexing (OFDM) technology used in the 802.11a standard was adapted to operate on the 2.4 GHz frequency band. 802.11g was generated. The frequency of the carrier is 2.4 GHz (same as that of 802.11b), the original transmission speed is 54 Mbit/s, and the net transmission speed is about 24.7 Mbit/s (same as that of 802.11a).

An important Wi-Fi standard that greatly improves Wi-Fi transmission and access is the 802.11n standard released in 2009. This standard introduces new concepts, such as Multiple-Input Multiple-Output (MIMO), security encryption, and advanced MIMO-based functions (such as beamforming and spatial multiplexing), and the transmission speed reaches 600 Mbit/s. In addition, 802.11n is the first Wi-Fi based that supports operation at both the 2.4 GHz and 5 GHz frequency bands.

Rapid development of mobile services and high-density access impose higher requirements on the Wi-Fi network bandwidth. In 2013, the 802.11ac standard was released. This standard supports wider radio frequency bandwidth (up to 160 MHz), higher order modulation technology (256-QAM), and the transmission speed of up to 1.73 Gbit/s, which further improves the Wi-Fi network throughput. In 2015, the 802.11ac Wave 2 standard was released to push beamforming and MU-MIMO to the mainstream, improving the system access capacity. However, 802.11ac supports only 5 GHz terminals, which degrades user experience on the 2.4 GHz frequency band.

As service applications such as video conferencing, wireless interactive VR, and mobile teaching are developing and spreading, more and more Wi-Fi access terminals are deployed. Additionally, Internet of Things (IoT) development brings more mobile terminals to the wireless network. Even the home Wi-Fi network that has few access terminals has become crowded with the access of more and more smart home devices. Therefore, the Wi-Fi network needs to continuously improve the speed. It is necessary to consider whether to increase the access capacity to adapt to the increasing number of STAs and user experience requirements of different applications.

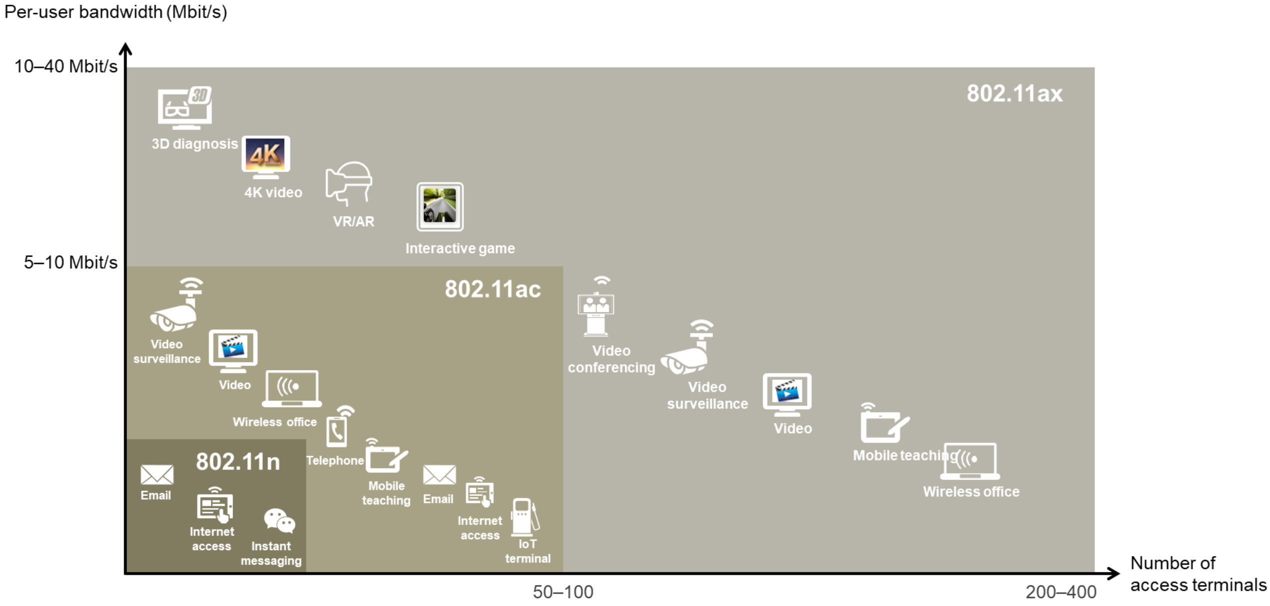


Figure 1-1 Relationship between the access capacity and per capita bandwidth in different Wi-Fi standards

The next-generation Wi-Fi needs to solve the problem of low efficiency of the entire Wi-Fi network caused by access of more terminals. In 2014, the IEEE 802.11 working group begun to tackle this challenge and expected to release 802.11ax (also called Wi-Fi 6) in 2019. This new standard will introduce technologies such as uplink Multi-User MIMO (MU-MIMO), orthogonal frequency division multiple access (OFDMA), and higher-order coding 1024-QAM to solve network capacity and transmission efficiency problems in terms of spectrum resource utilization and multi-user access. One of the goals of Wi-Fi 6 is to increase the average user throughput by at least four times and increase the number of concurrent users by more than three times in the dense-user environment compared with Wi-Fi 5. Therefore, Wi-Fi 6 (802.11ax) is also called High-Efficiency Wireless (HEW).

2 What Is Wi-Fi 6 (802.11ax)?

Wi-Fi 6 is short for the next-generation 802.11ax standard. With the evolution of Wi-Fi standards, Wi-Fi Alliance (WFA) renames Wi-Fi standards using sequence numbers to help Wi-Fi users and device vendors easily learn about their connected and supported Wi-Fi device models. Additionally, the new naming convention is to better highlight the significant progress of Wi-Fi technology. The latest standard supports a large number of new functions to provide higher throughput, faster speed, and more concurrent connections. According to the WFA announcement, the current Wi-Fi names correspond to the 802.11 standards as follows.

Table 2-1 New naming convention for 802.11 standards

Release Year	802.11 Standard	Frequency Band	New Name
	802.11n	2.4 GHz or 5 GHz	Wi-Fi 4
2013	802.11ac Wave 1	5 GHz	Wi-Fi 5
2015	802.11ac Wave 2	5 GHz	
2019	802.11ax	2.4 GHz or 5 GHz	**Wi-Fi 6**

Similar to the previous 802.11 standards, 802.11ax will be compatible with the previous 802.11ac/n/g/a/b standards. Legacy terminals can seamlessly connect to an 802.11ax network.

2.1 How Fast Is Wi-Fi 6?

4G represents the high speed of mobile networks. Similarly, Wi-Fi 6 represents the high speed of WLANs. This high speed is determined by the following factors:

Calculation formula:

Speed = Number of spatial streams x 1/(Symbol + GI) x Encoding scheme x Bit rate x Number of valid subcarriers

1. Number of spatial streams

   The spatial stream is the antenna of an AP. A large number of antennas indicates higher throughput of the entire system. Similar to lanes on a highway, an 8-lane highway carries more traffic than a 4-lane highway.

   Table 2-2 Number of spatial streams supported by 802.11 standards

	802.11a/g	802.11n	802.11ac	802.11ax
Maximum number of spatial streams on a single radio	1	4	8	8

2. Symbol and guard interval (GI)

   Symbol is the transmission signal in the time domain. There must be a GI between two adjacent symbols to avoid interference between each other. Take high-speed trains as an example. Each train is equivalent to a symbol. There must be a time interval between the two trains departing from the same station. Otherwise, the two trains may collide. The GI varies depending on Wi-Fi standards. In most cases, a large GI is required when the transmission speed is high. For example, the time interval between two 350 km/h high-speed trains running on the same lane is larger than that of two 250 km/h high-speed trains.

Table 2-3 Symbols and GIs supported by 802.11 standards

	Before 802.11ac	802.11ax
Symbol	3.2 us	12.8 us
Short GI	0.4 us	/
GI	0.8 us	0.8 us
2*GI	/	1.6 us
4*GI	/	3.2 us

3. Encoding scheme

The encoding scheme is the modulation technology, that is, the number of bits that can be carried in a symbol. From Wi-Fi 1 to Wi-Fi 6, each new modulation technology increases the rate of each spatial stream by at least 20%.

Table 2-4 QAMs supported by 802.11 standards

	802.11a/g	802.11n	802.11ac	802.11ax
Higher-order modulation	64-QAM	64-QAM	256-QAM	1024-QAM
Number of bits in a symbol	6	6	8	10

4. Bit rate

Theoretically, lossless transmission is supported based on the encoding scheme. During actual transmission, some information codes used for error correction need to be added. Redundancy is used for achieving high reliability. The bit rate is the ratio of the actually transmitted data code with the error correction code excluded to the theoretical value.

Table 2-5 Bit rates supported by 802.11 standards

Negotiation Mode	Modulation Type	802.11a/g	802.11n	802.11ac	802.11ax
MCS0	BPSK	1/2	1/2	1/2	1/2
MCS1	QPSK	1/2	1/2	1/2	1/2
MCS2	QPSK	3/4	3/4	3/4	3/4
MCS3	16-QAM	1/2	1/2	1/2	1/2
MCS4	16-QAM	3/4	3/4	3/4	3/4
MCS5	64-QAM	2/3	2/3	2/3	2/3
MCS6	64-QAM	3/4	3/4	3/4	3/4

Negotiation Mode	Modulation Type	802.11a/g	802.11n	802.11ac	802.11ax
MCS7	64-QAM	5/6	5/6	5/6	5/6
VMCS8	256-QAM	-	-	3/4	3/4
VMCS9	256-QAM	-	-	5/6	5/6
VMCS10	1024-QAM	-	-	-	3/4
VMC11	1024-QAM	-	-	-	5/6

5. Number of valid subcarriers

Carriers are similar to symbols in the frequency domain. One subcarrier carries one symbol, and the number of subcarriers varies according to the modulation mode and frequency bandwidth.

Table 2-6 Number of subcarriers supported by 802.11 standards

	Frequency Bandwidth	802.11n	802.11ac	802.11ax
Minimum Subcarrier Bandwidth	-	312.5 kHz	312.5 kHz	78.125KHz
Number of valid subcarriers	HT20	52	52	234
	HT40	108	108	468
	HT80	-	234	980
	HT160	-	2 x 234	2 x 980

The maximum rate of a single spatial stream at HT80 bandwidth can be calculated in 802.11ac and 802.11ax.

PHY	1/(Symbol + GI)	Number of Bits in a Symbol	Bit Rate	Number of Valid Subcarriers	Rate
802.11ac	1/(3.2 us + 0.4 us)	8	5/6	234	**433 Mbit/s**
802.11ax	1/(12.8 us + 0.8 us)	10	5/6	980	**600 Mbit/s**

2.2 Core Technologies of Wi-Fi 6

Wi-Fi 6 (802.11ax) inherits all advanced MIMO features of Wi-Fi 5 (802.11ac) and introduces many new features for high-density deployment scenarios. The following are the new core features of Wi-Fi 6:

- OFDMA technology
- DL/UL MU-MIMO technology

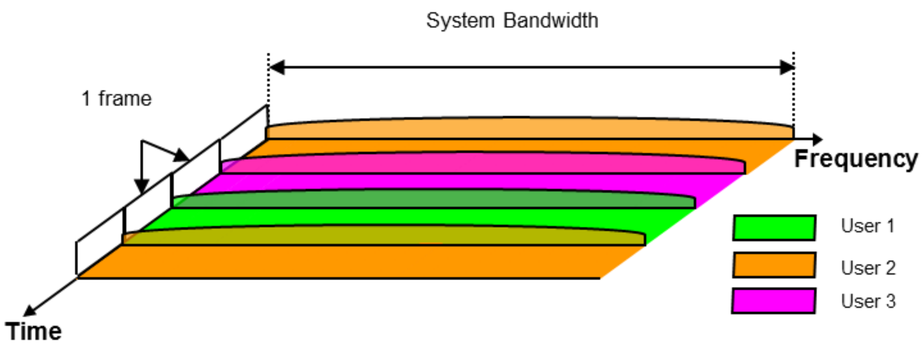
- Higher-order modulation technology (1024-QAM)
- Spatial Reuse (SR) & basic service set (BSS) coloring mechanism
- Extended range (ER)

The following details these new core features.

2.2.1 OFDMA Technology

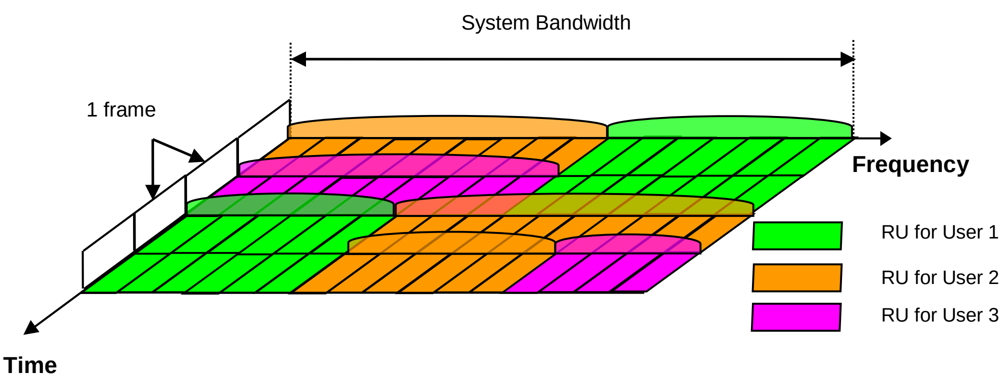
Before 802.11ax, the OFDM mode is used for data transmission, and users are distinguished by time segment. During each time segment, one user occupies all subcarriers and sends a complete data packet, as shown in the following figure.

Figure 2-1 OFDM working mode



802.11ax introduces a more efficient data transmission mode, which is called OFDMA. 802.11ax supports the uplink and downlink MU mode; therefore, this mode can also be called MU-OFDMA. It allows multiple users to reuse channel resources by allocating subcarriers to different users and adding multiple access in the OFDM system. So far, this technology has been used by many wireless technologies, such as 3GPP LTE. In addition, the 802.11ax standard defines the smallest subchannel as a resource unit (RU). Each RU includes at least 26 subcarriers, and users are distinguished by time-frequency RUs. The resources of the entire channel are divided into small fixed time-frequency RUs. In this mode, user data is carried on each RU. Therefore, on the total time-frequency resources, multiple users may simultaneously send data on each time segment, as shown in the following figure.

Figure 2-2 OFDMA working mode

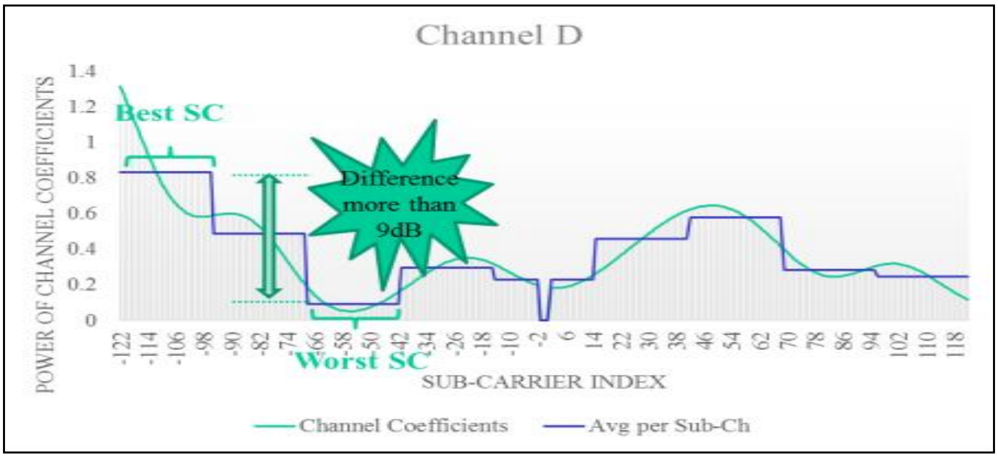


Compared with OFDM, OFDMA has the following advantages:

- Finer channel resource allocation

  The transmit power can be allocated based on the channel quality, especially when the channel status of some nodes is not good. This can help allocate channel time-frequency resources in a more delicate manner. The following figure shows how 802.11ax selects optimal RU resources based on channel quality to transmit data when channel quality greatly differs in frequency domains of different subcarriers.

Figure 2-3 Channel quality in frequency domains of different subcarriers



- **Better QoS**

  802.11ac and earlier standards occupy the entire channel to transmit data. If a QoS data packet needs to be sent, it must wait until the current sender releases the complete channel. Therefore, a long delay exists. In OFDMA mode, one sender occupies only some resources of the entire channel. Therefore, data of multiple users can be sent at a time. This reduces the access delay of QoS nodes.

- **More concurrent users and higher user bandwidth**

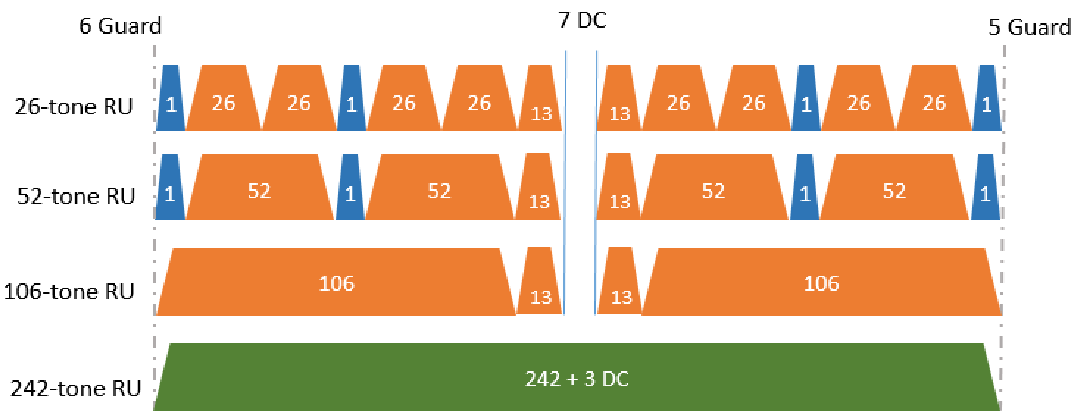
  OFDMA divides resources of the entire channel into multiple subcarriers, which are also called subchannels. The subcarriers are further divided into several groups by RU type. Each user may occupy one or more groups of RUs to meet different bandwidth requirements. In 802.11ax, the minimum RU size is 2 MHz, and the minimum subcarrier bandwidth is 78.125 kHz. Therefore, the minimum RU type is 26-subcarrier RU. By analogy, there are 52-subcarrier RUs, 106-subcarrier RUs, 242-subcarrier RUs, 484-subcarrier RUs, and 996-subcarrier RUs. The following table lists the maximum number of RUs under different frequency bandwidths.

Table 2-7 Number of RUs at different frequency bandwidths

RU Type	CBW20	CBW40	CBW80	CBW160 and CBW80+80
26-subcarrier RU	9	18	37	74
52-subcarrier RU	4	8	16	32
106-subcarrier RU	2	4	8	16

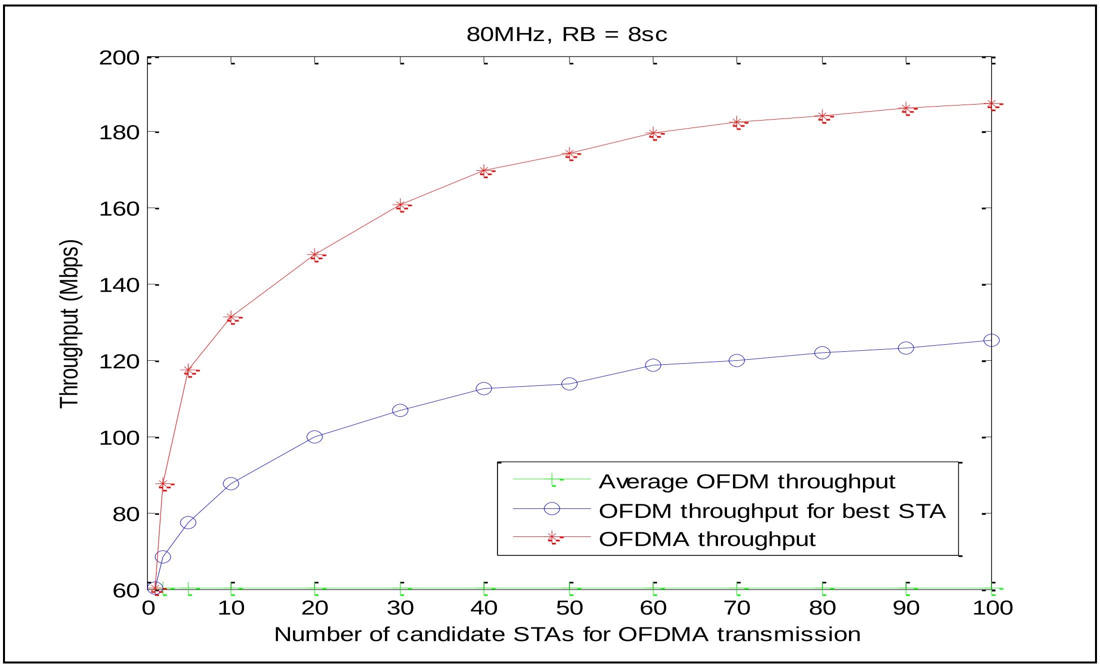
RU Type	CBW20	CBW40	CBW80	CBW160 and CBW80+80
242-subcarrier RU	1-SU/MU-MIMO	2	4	8
484-subcarrier RU	N/A	1-SU/MU-MIMO	2	4
996-subcarrier RU	N/A	N/A	1-SU/MU-MIMO	2
2x996-subcarrier RU	N/A	N/A	N/A	1-SU/MU-MIMO

Figure 2-4 Positions of RUs in the 20 MHz frequency bandwidth



A large number of RUs indicates higher efficiency of multi-user processing and higher throughput. The following figure shows the simulation benefits.

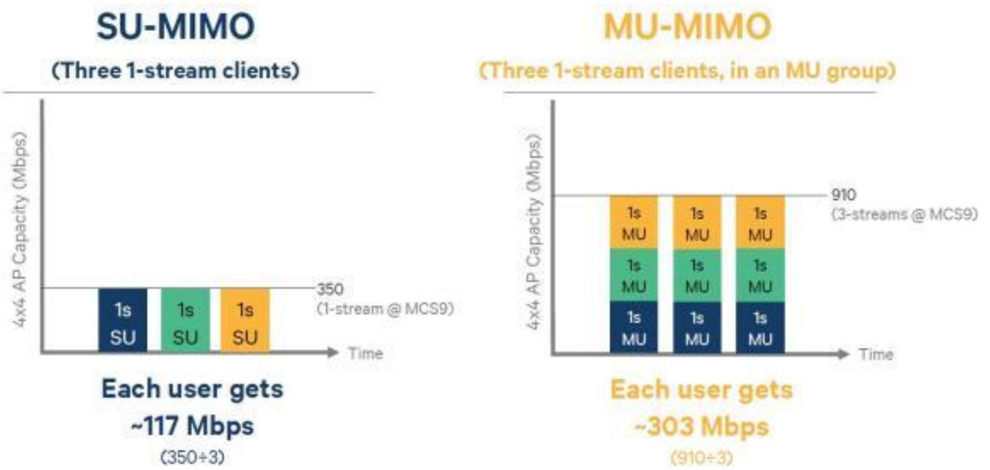
Figure 2-5 Multi-user throughput simulation in OFDMA and OFDM modes



2.2.2 DL/UL MU-MIMO Technology

MU-MIMO uses spatial diversity of channels to transmit independent data streams on the same bandwidth. Unlike OFDMA, all users use all bandwidths, which brings multiplexing gains. Limited by the size of the antenna, a terminal typically supports only one or two spatial streams (antennas), which is less than the number of spatial streams (antennas) on an AP. Therefore, MU-MIMO technology is introduced to enable an AP to transmit data with multiple terminals at the same time, which greatly improves the throughput.

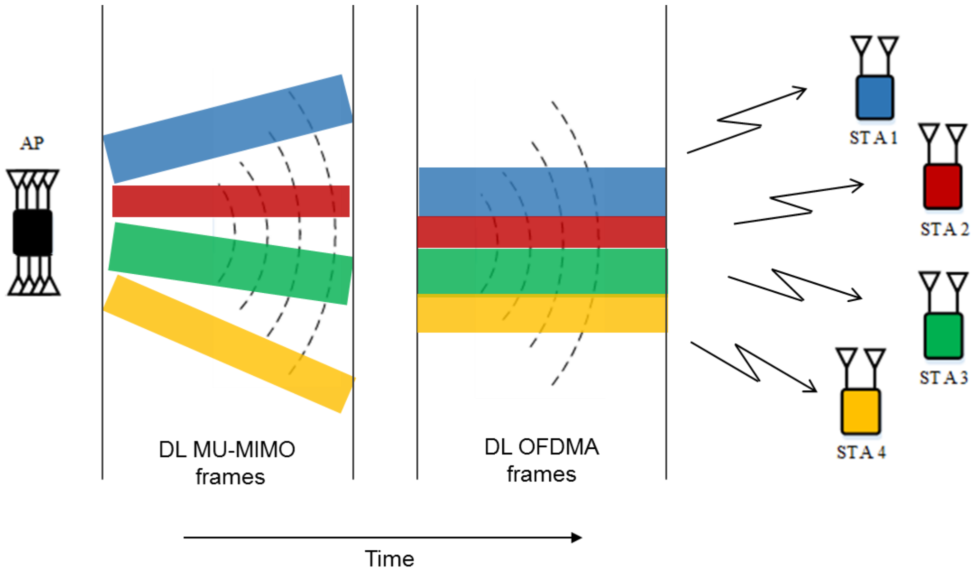
Figure 2-6 Throughput difference between SU-MIMO and MU-MIMO



- **DL MU-MIMO technology**

  MU-MIMO has been introduced since 802.11ac, but only DL 4x4 MU-MIMO is supported. In 802.11ax, the number of MU-MIMO is further increased, and DL 8x8 MU-MIMO is supported. DL OFDMA technology can be used to simultaneously perform MU-MIMO transmission and allocate different RUs for multi-user multiple-access transmission, which increases the concurrent access capacity of the system and balances the throughput.

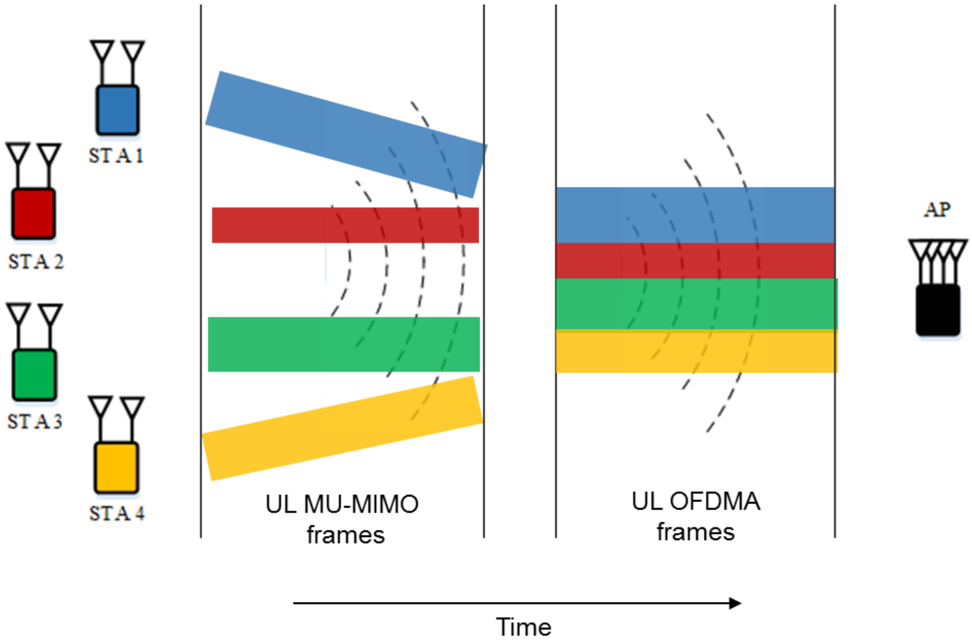
Figure 2-7 8x8 MU-MIMO AP scheduling sequence in the downlink multi-user mode



- **UL MU-MIMO technology**

  UL MU-MIMO is an important feature introduced in 802.11ax. Similar to UL SU-MIMO, UL MU-MIMO uses the same channel resources to transmit data on multiple spatial streams by using multi-antenna technology of the transmitter and receiver. The only difference is that multiple data streams of UL MU-MIMO are from multiple users. 802.11ac and earlier 802.11 standards use UL SU-MIMO, that is, a user can receive data from only one user, which is inefficient in multi-user concurrent scenarios. After 802.11ax supports UL MU-MIMO, UL OFDMA technology is leveraged to allow MU-MIMO transmission and multi-user multiple-access transmission at the same time. This improves the transmission efficiency in multi-user concurrent scenarios and greatly reduces the application delay.

Figure 2-8 Uplink scheduling sequence in multi-user mode



Although 802.11ax allows OFDMA and MU-MIMO to work at the same time, they are different. OFDMA allows multiple users to subdivide channels (subchannels) to improve the concurrency efficiency. MU-MIMO allows multiple users to use different spatial streams to increase the throughput. The following table lists the comparison between OFDMA and MU-MIMO.

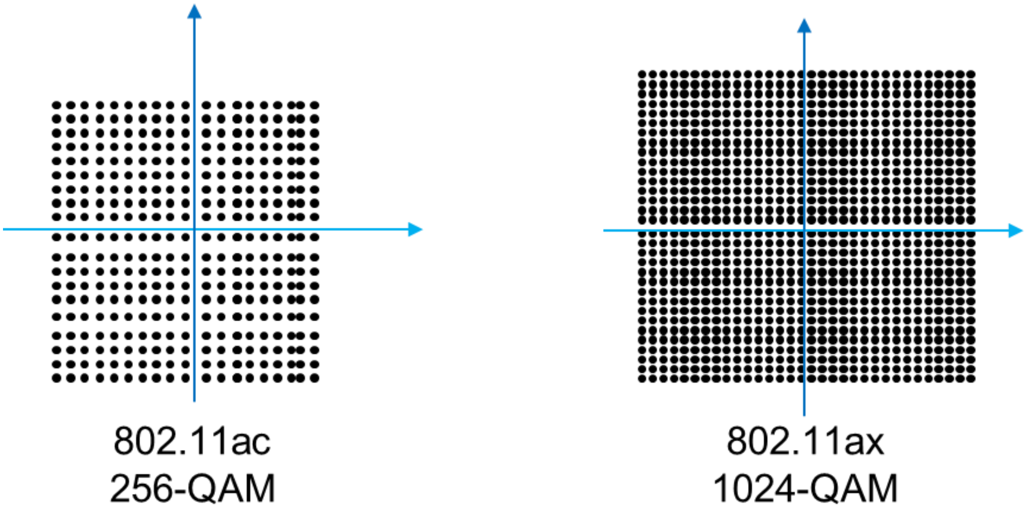
Table 2-8 Comparison between OFDMA and MU-MIMO

OFDMA	MU-MIMO
Improve the efficiency	Improve the capacity
Reduce the latency	Increase the rate of each user
Most suitable for low-bandwidth applications	Most suitable for high-bandwidth applications
Most suitable for small-packet transmission	Most suitable for large-packet transmission

2.2.3 Higher-order modulation technology (1024-QAM)

The 802.11ax standard aims to increase the system capacity, reduce the latency, and improve efficiency in multi-user high-density scenarios. However, high efficiency is not mutually exclusive with the fast speed. 802.11ac uses 256-QAM, and each symbol transmits 8-bit data ($2^{\wedge 8}$ = 256). 802.11ax uses 1024-QAM quadrature amplitude modulation, and each symbol bit transmits 10-bit data ($2^{\wedge 10}$ = 1024). Therefore, compared with 802.11ac, 802.11ax increases data throughput of a single spatial stream by 25%.

Figure 2-9 Constellation maps of 256-QAM and 1024-QAM



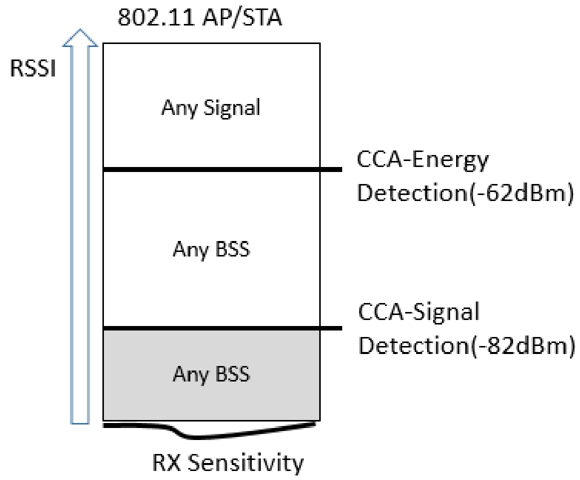
The successful application of 1024-QAM modulation in 802.11ax depends on channel conditions. Dense constellation points require great error vector magnitude (EVM) (used to quantize the performance of the radio receiver or transmitter in modulation precision) and receiver sensitivity. In addition, the channel quality must be higher than that in other modulation types.

2.2.4 Spatial Reuse (SR) & BSS coloring mechanism

A channel allows only one user to transmit data within a specified time. If a Wi-Fi AP and a STA detect transmission of another 802.11 radio on the same channel, they automatically avoid conflicts and wait for the channel to become idle for transmission. Therefore, each user uses channel resources in turn. Therefore, channels are valuable resources on wireless networks. In high-density scenarios, channel allocation and utilization greatly affect the capacity and stability of the entire wireless network. 802.11ax can run on the 2.4 GHz or 5 GHz frequency band (unlike 802.11ac, which can run only on the 5 GHz frequency band). In high-density deployment scenarios, the number of available channels may be too small (especially on the 2.4 GHz frequency band). The system throughput can be increased by improving the channel multiplexing capability.

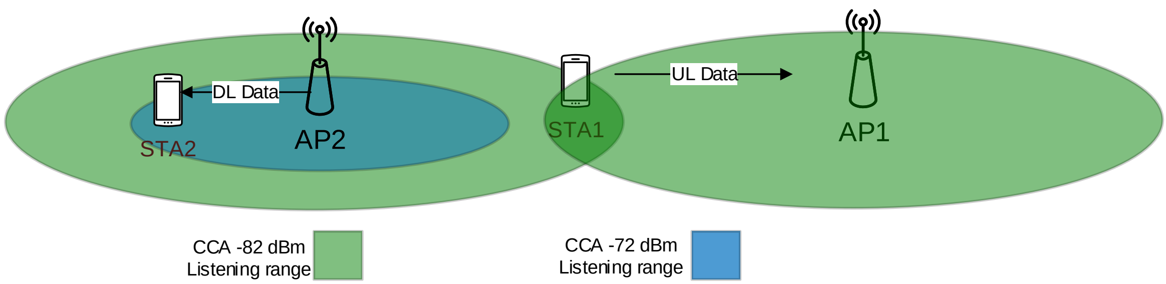
In 802.11ac and earlier standards, the mechanism of dynamically adjusting the clear channel assessment (CCA) threshold is used to reduce co-channel interference. The system identifies the co-channel interference strength, dynamically adjusts the CCA threshold, ignores co-channel weak interference signals, and implements co-channel concurrent transmission. This increases the system throughput.

Figure 2-10 Default CCA threshold of 802.11



For example, as shown in Figure 2-11, STA1 on AP1 is transmitting data. If AP2 wants to send data to STA2, AP2 needs to detect whether the channel is idle. The default CCA threshold is –82 dBm. When finding that the channel is occupied by STA1, AP2 delays the transmission because the parallel transmission cannot be performed. In fact, all the STAs associated with AP2 are delayed to send. The dynamic CCA threshold adjustment mechanism is introduced. When AP2 detects that the co-frequency channel is occupied, it can adjust the CCA threshold listening range (for example, from –82 dBm to –72 dBm) based on the interference strength to avoid interference impact. In this way, co-frequency concurrent transmission can be implemented.

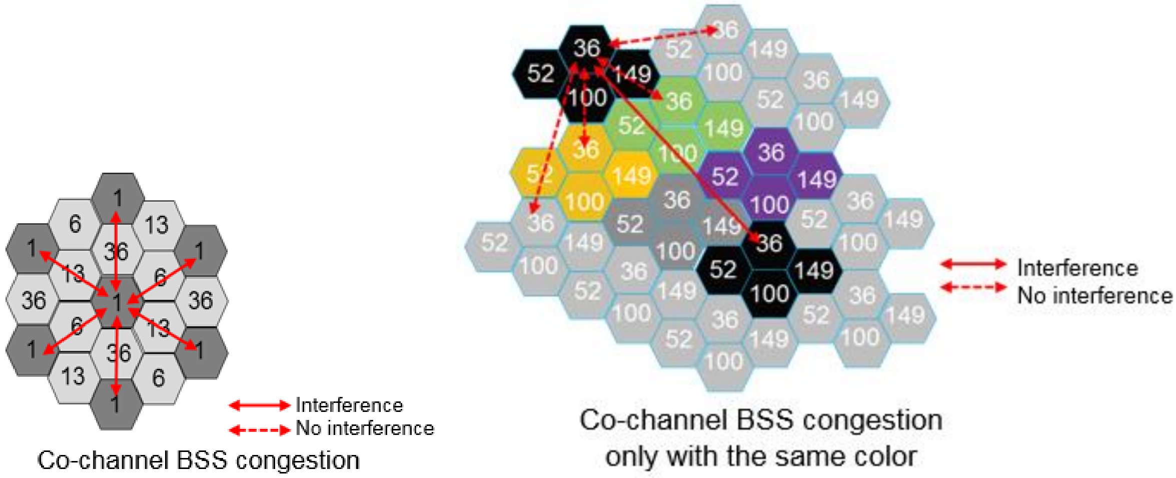
Figure 2-11 Dynamic CCA threshold adjustment



Due to the mobility of Wi-Fi STAs, co-channel interference detected on the Wi-Fi network is not static but changes with the movement of the STAs. Therefore, the dynamic CCA mechanism is effective.

802.11ax introduces a new co-frequency transmission identification mechanism called BSS coloring. The BSS color field is added to the PHY packet header to color data from different BSSs and allocate a color to each channel. The color identifies a BSS that should not be interfered. The receiver can identify co-channel interference signals and stop receiving them at an early stage, thereby avoiding waste of transceiver time. If the colors are the same, the interference signals are considered to be in the same BSS, and signal transmission is delayed. If the colors are different, no interference exists between the two Wi-Fi devices. They can then transmit data on the same channel and at the same frequency. In this mode, the channels with the same color are kept far away from each other. The dynamic CCA mechanism is used to set such signals to be insensitive. In fact, they are unlikely to interfere with each other.

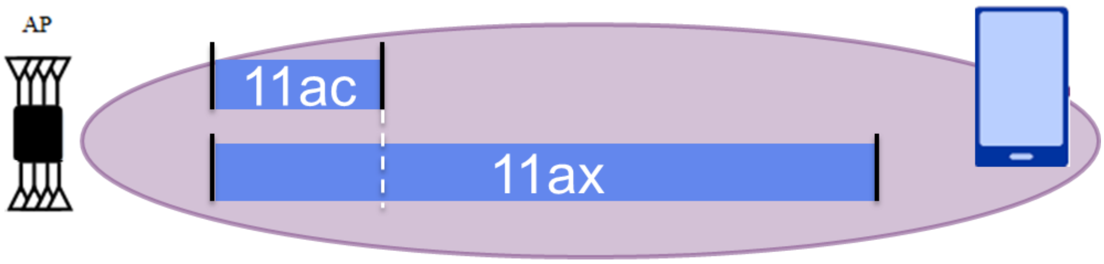
Figure 2-12 How the BSS color mechanism reduces interference



2.2.5 Extended Range

The 802.11ax standard uses the long OFDM symbol transmission mechanism. The data transmission duration increases from 3.2 us to 12.8 us. A longer transmission time can reduce the packet loss rate of STAs. In addition, 802.11ax can use only 2 MHz bandwidth for narrowband transmission, which reduces noise interference on the frequency band, improves the receiver sensitivity of STAs, and increases the coverage distance.

Figure 2-13 Long OFDM symbol and narrowband transmission increase the coverage distance



2.3 Other New Features of Wi-Fi 6 (802.11ax)

The preceding core technologies are sufficient to prove the efficient transmission and high-density capacity brought by 802.11ax. However, 802.11ax is not the final standard of Wi-Fi. This is only the start of the HEW. The new 802.11ax standard still needs to be compatible with legacy devices and considers the development of future-oriented IoT networks and energy conservation. Other new features of 802.11ax include the support for the 2.4 GHz frequency band and target wakeup time (TWT).

2.3.1 Support for the 2.4 GHz Frequency Band

The 2.4 GHz frequency band is narrow, and only three 20 MHz channels (1,6 and 11) do not interfere with each other. The 2.4 GHz frequency band has been abandoned in the 802.11ac standard. However, it is undeniable that 2.4 GHz is still an available Wi-Fi frequency band. It is still widely used in many scenarios. Therefore, in the 802.11ax standard, the 2.4 GHz frequency band is supported to make full use of the advantages of this frequency band.

- **Advantage 1: Coverage**

  In a wireless communications system, signals with a relatively high frequency are more likely to penetrate obstacles than those with a relatively low frequency. A lower frequency indicates a longer wavelength, stronger diffraction capability, poorer penetration capability, smaller signal loss attenuation, and longer transmission distance. Although the 5 GHz frequency band can bring a higher transmission speed, the signal attenuation is larger. Therefore, the transmission distance is shorter than that of the 2.4 GHz frequency band. When deploying a high-density wireless network, the 2.4 GHz frequency band is not only used to be compatible with old devices but also to fill coverage holes in edge areas.

- **Advantage 2: Low cost**

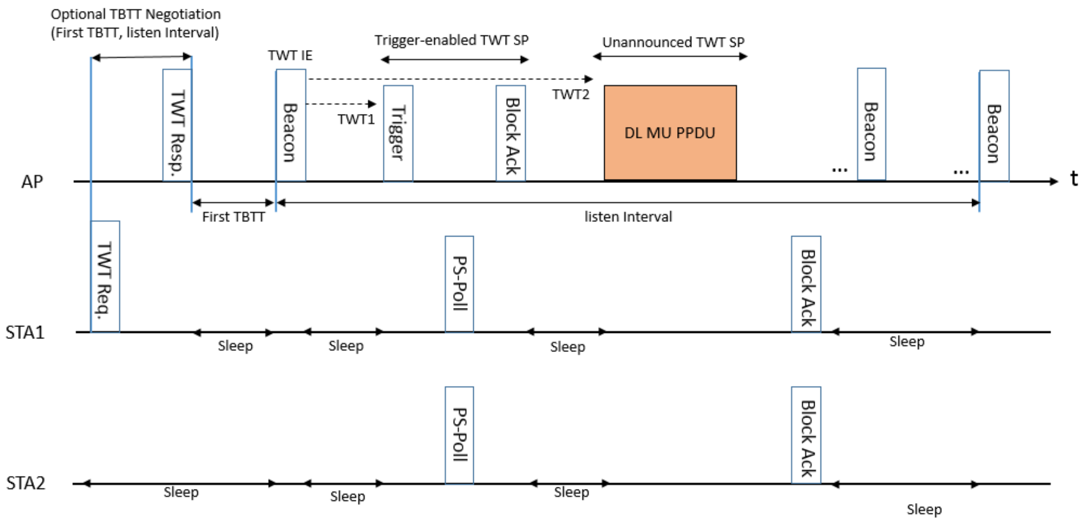
  At present, hundreds of millions of 2.4 GHz devices are used online. Even IoT devices use the 2.4 GHz frequency band. In some scenarios with a low traffic volume (such as geo-fence and asset management), there are a large number of STAs. In this case, STAs in compliance only with the 2.4 GHz frequency band terminal are more cost-effective.

2.3.2 TWT

Referencing from 802.11ah, the Target Wakeup Time (TWT) is another important resource scheduling function supported by 802.11ax. It allows devices to negotiate when and how long they will wake up and then send or receive data. Additionally, APs can group STAs into different TWT periods to reduce the number of devices that simultaneously compete for the wireless medium after wakeup. The TWT also increases the device sleep time. For battery-powered STAs, the battery life is greatly improved.

An 802.11ax AP can negotiate with the participating STAs the use of the TWT function to define a specific time or set of times for individual STAs to access the medium. The STAs and the AP exchange information that includes an expected activity duration. This avoids contention and overlapping between STAs. 802.11ax STAs may use TWT to reduce energy consumption, entering a sleep state until their TWT arrives. In addition, an AP can provide schedules and deliver TWT values to STAs without individual TWT agreements between them. The standard calls this procedure "Broadcast TWT" operation.

Figure 2-14 Broadcast TWT operation



3 Why Wi-Fi 6 (802.11ax)?

802.11ax is designed for high-density wireless access and high-capacity wireless services, such as outdoor large-scale public places, high-density stadiums, indoor high-density wireless office, and electronic classrooms.

Figure 3-1 High-density and high-bandwidth scenarios

In these scenarios, the number of STAs connected to the Wi-Fi network greatly increases in a short time. The increasing voice and video traffic also brings adjustment to the Wi-Fi network. According to the prediction, the global mobile video traffic will account for more than 50% of the mobile data traffic by 2020, and more than 80% mobile traffic will be carried over Wi-Fi. Some services are sensitive to bandwidth and delay, for example, 4K video streams (bandwidth of 30 Mbit/s), voice streams (delay of less than 30 ms), VR streams (bandwidth of 50 Mbit/s, and delay of less than 15 ms). If the transmission delay is caused by network congestion or retransmission, user experience will be greatly affected. The existing Wi-Fi 5 (802.11ac) network can provide large bandwidth. However, as the access density increases, throughput performance encounters a bottleneck. The Wi-Fi 6 (802.11ax) network uses technologies such as OFDMA, UL MU-MIMO, and 1024-QAM to ensure that these services are more reliable than before. In addition to a larger access capacity, the network can balance the bandwidth of each user. For example, if there are more than 100 students in an electronic classroom, great challenges will be encountered for video transmission or uplink/downlink interaction. The 802.11ax network can easily cope with this scenario.

4 Coexistence of 5G and Wi-Fi 6 (802.11ax)

This is not a new topic. From 1999 to 2000, some people proposed that 2G would replace Wi-Fi; from 2008 to 2009, they estimated that 4G would replace Wi-Fi. Now, someone is talking about 5G instead of Wi-Fi. However, the application scenarios of 5G and Wi-Fi are different. Wi-Fi is mainly used in indoor environments, while 5G is a wide area network (WAN) technology that is more applicable to outdoor scenarios. Therefore, it is believed that Wi-Fi and 5G will coexist for a long time.

Further analysis can be made from the following aspects:

- Traffic

  If 5G technology replaces Wi-Fi, a package with unlimited traffic must be launched. Otherwise, the cost will be far greater than that of broadband. Additionally, the price of broadband is becoming lower, and is a cost-effective choice. In the current 4G era, the unlimited traffic package is only a stunt. The operators have launched unlimited traffic packages. However, when the traffic volume exceeds the package volume, the network automatically switches to the 2G mode, with the highest speed of only 128 kbit/s. Therefore, the so-called unlimited traffic is just nonsense.

- Network coverage

5G network technology uses ultra-high frequency spectrum (5G frequency band: 24 GHz–52 GHz; 4G frequency band: 1.8 GHz–2.6 GHz, excluding 2.4 GHz). As mentioned above, a higher frequency indicates the weaker diffraction and weaker capability of traversing obstacles. Therefore, 5G signals are easily weakened. If 5G signal coverage is required, more base stations need to be constructed than 4G networks. If there are several walls inside building, the signal attenuation is even more serious. Another extreme example is the basement. The Wi-Fi network can connect a router to the basement to generate signals through wired connections. However, 5G networks cannot cover the basement of all buildings and therefore cannot replace Wi-Fi networks. In addition, almost all smart devices have Wi-Fi modules, and most IoT devices are equipped with Wi-Fi modules. Only one public IP address is configured for the egress device. A large number of IP addresses are used on the LAN. Users can easily manage these devices on their own Wi-Fi networks. On a 5G network, more public IP addresses will be occupied.

- Network capacity

  Bandwidth x Spectrum efficiency x Number of STAs = Total capacity The advantage of 5G is its carrier aggregation technology, which improves the spectrum utilization and greatly increases the network capacity. In the 3G/4G era, when users use mobile phones to access the Internet in densely populated places such as subways and stations, the Internet access delay becomes longer and the network speed becomes slow. In the 5G era, as the network capacity greatly increases, the impact of the preceding phenomena is greatly reduced. It seems that 5G allows for unlimited access. However, with the advent of the IoT era, the number of network access devices greatly increases. If all Internet access devices are directly connected to base stations in the area, this 5G network will certainly be congested. Wi-Fi is a good choice to reduce the burden on the base stations.

- Transmission rate

  The three most important features of 5G promoted by mobile device vendors are high speed, large capacity, and low latency. In fact, the latest generation of Wi-Fi is faster than 5G. The latest 802.11ax (Wi-Fi 6) single-stream peak rate is 1.2 Gbit/s (the peak rate of the 5G network is 1 Gbit/s). On average, the time required for evolution of each Wi-Fi generation is about half of that of the mobile network. Therefore, from the latest Wi-Fi 6, the rate will continue to be higher than that of the mobile network.

- Terminal type

  All industries, such as office, logistics, business, and smart home, are heading towards all Wi-Fi. The first step is to connect devices, users, and terminals to the Internet. Assuming that 5G replaces Wi-Fi, all connected terminals in the future need to be equipped with a SIM card to access the Internet. This is a reason why 5G cannot replace Wi-Fi in indoor scenarios. Similar devices include VRs, game consoles, e-readers, and STBs.

- Battery power consumption of mobile terminals

  Mobile terminals including mobile phones and tablets use batteries for power supply. In most cases, the service life of batteries is considered to be related to the installed services and usage frequency. However, the access quality of various mobile signals is also related to the power consumption of the battery. When the signal quality deteriorates, a mobile terminal automatically increases the transmit power to improve the signal quality to ensure good user experience. As a result, the power consumption of the battery increases. Sources of Wi-Fi signals are mostly in the indoor range, while those of 5G signals are the outdoor base stations dozens of kilometers away. When a mobile terminal uploads data, the transmission distance of Wi-Fi signals is far less than that of 5G signals. In most cases, the communication distance of 5G is thousands of times that of Wi-Fi. This requires a great increase in the signal strength of mobile terminals, which increases the power consumption. It has been tested that if network data is used for half an hour, Wi-Fi networks can save power by 5% compared with 4G mobile networks. In addition, the latest-generation Wi-Fi 6 (802.11ax) supports the TWT function. This function can automatically wake up devices when services are required and allow the devices to automatically sleep when no service is involved, further saving power.

Therefore, 5G cannot completely replace Wi-Fi and is deeply integrated with Wi-Fi. Nowadays, Wi-Fi is more a necessary infrastructure or central hub for enterprise digital transformation. For example, Wi-Fi networks are the central hubs of most smart retail, smart logistics, and smart office solutions.

5 Huawei's Contribution to Wi-Fi 6 (802.11ax) Industry Development

With its extensive experience in the wireless communications field and strong strength, Huawei actively participates in the work of the IEEE 802 working group. Huawei experts Osama and Edward are chairmen of different 802.11 standard working groups. Dr. Osama has outstanding performance in formulating the 802.11ac standard, and is re-elected as the chairman of the 802.11ax standard working group to take the lead in formulating the 802.11ax technical standard. At the same time, Huawei has an 802.11ax standard formulation team consisting of 15 wireless experts. The team has submitted a total of 299 standard proposals, ranking No. 1 in all vendors.

Figure 5-1 802.11ax task group leadership

Status of Project IEEE 802.11ax

High Efficiency (HE) Wireless LAN Task Group

Task Group Leadership

Chair	Osama Aboul-Magd (Huawei Technologies)
1st Vice Chair	Ron Porat (Broadcom Ltd.)
2nd Vice Chair	Alfred Asterjadhi (Qualcomm)
Secretary	Yasuhiko Inoue (NTT)
Technical Editor	Robert Stacey (Intel)

WFA is another important international organization in the Wi-Fi field. Huawei joined WFA in 2011 and became one of the 15 core members of the board. Huawei is also one of the only two Wi-Fi device vendors in WFA.

Huawei is the leader of the 10G Wi-Fi standard, the practitioner of 10G Wi-Fi productization, and the promoter of the 10G Wi-Fi industry chain. In 2014, Huawei launched the industry's first 10G Wi-Fi prototype based on the next-generation architecture, which was the first to promote Wi-Fi to the 10G era. Huawei then collaborated with Qualcomm, the world's largest mobile terminal chip vendor, to invest in the development of 802.11ax products. In September 2017, Huawei completed the last step in the industry chain, released the industry's first commercial product, and achieved large-scale deployment Shanghai Bund, China, in September 2018, further accelerating the commercial use of 10G Wi-Fi.

Figure 5-2 Large-scale commercial use of 802.11ax APs in Shanghai Bund

6 Huawei Wi-Fi 6 (802.11ax) Products and Features

A high-performance Wi-Fi network requires not only the upgrade of Wi-Fi APs to the latest 802.11ax standard but also features related to signal coverage and software algorithm optimization. In addition, a full range of Wi-Fi AP products and solutions need to be customized based on different application scenarios.

6.1 Industry's First Wi-Fi 6 AP for Commercial Use

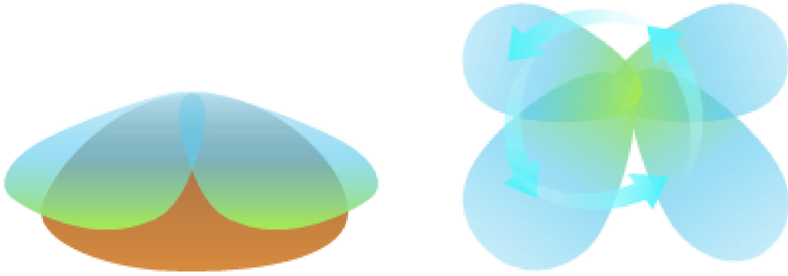
Figure 6-1 Huawei Wi-Fi 6 AP: AP7060DN

- 1024-QAM and 8x8 MU-MIMO, with four-fold increase in the rate
- OFDMA, from conflict to order, with four-fold increase in the concurrent capacity
- Orderly service scheduling, with a delay of less than 15 ms
- High-density access control technology, improving concurrent performance by 30%
- Convergence of the Wi-Fi and IoT networks to expand services such as ESL and asset management, reducing TCO by 50%

6.2 Huawei Third-Generation Smart Antenna

Compared with omnidirectional antennas, smart antennas have many advantages. For example, the signal strength in different directions can be adjusted flexibly, and signals can move with the user. Huawei's third-generation smart antennas are leading in the industry. They have multiple directional radiation patterns and one omnidirectional radiation mode on the horizontal plane. A smart antenna receives signals from transmitters in omnidirectional mode. Based on the received signals, the smart antenna algorithm can determine the location of a transmitter and control the CPU to send control signals to the transmitter in the directional radiation pattern with the direction of the maximum radiation.

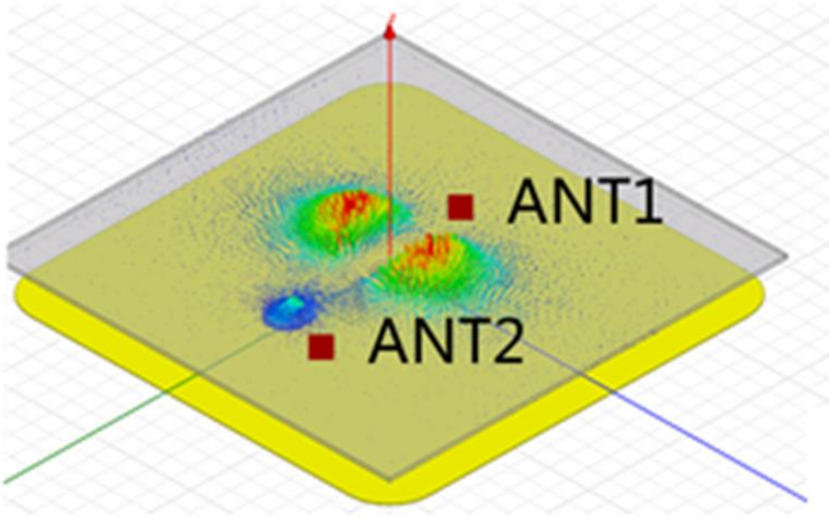
Figure 6-2 Omnidirectional antenna and Huawei's third-generation smart antenna



6.3 Triple-Radio and Dual-5G Design

Currently, a large number of Wi-Fi APs use dual-band design (2.4 GHz & 5 GHz). To provide a larger access capacity and higher bandwidth, each Wi-Fi AP vendor optimizes the radio algorithm and service processing algorithm. However, in certain high-density scenarios, optimized Wi-Fi APs still cannot handle higher-density user access or instantaneous traffic burst services. This is similar to a crowded highway during holidays. Traffic is still congested regardless of traffic control and distribution. The simplest way to solve this problem is to add a highway next to it. Similarly, a third radio (generally, a 5 GHz radio) is added to a Wi-Fi AP. With this third radio, the number of access users and the throughput are both increased. Why do not other vendors in the industry adopt such a good solution? This is because it is difficult to resolve adjacent-channel interference of 5 GHz radios after another 5 GHz radio is added. If adjacent-channel interference cannot be resolved, the added 5 GHz radio does not increase the capacity or throughput. On the contrary, the original 5 GHz radio is interfered, causing performance deterioration. Huawei transfers the technology of controlling co-channel interference in the LTE field to the Wi-Fi field. A high-performance filter module is added between the two 5 GHz radios to prevent interference and allow concurrent access of multiple users, increasing the total throughput.

Figure 6-3 Field strength distribution of two 5 GHz radios after a high-performance filter is added



As mentioned above, the 802.11ax standard is designed for high-efficient and high-capacity Wi-Fi networks. However, to achieve the high efficiency and high capacity, all terminals must comply with the 802.11ax standard. A large number of Wi-Fi terminals in compliance with 802.11ac and earlier standards are operating in the market. Therefore, efficiency improvement of 802.11ax can be hardly achieved. Before 802.11ax terminals are widely used, Huawei uses SmartRadio technology to optimize the software algorithm to allow 802.11ax APs to be compatible with Wi-Fi terminals in compliance with 802.11ac and earlier standards. This improves experience for these legacy terminals.

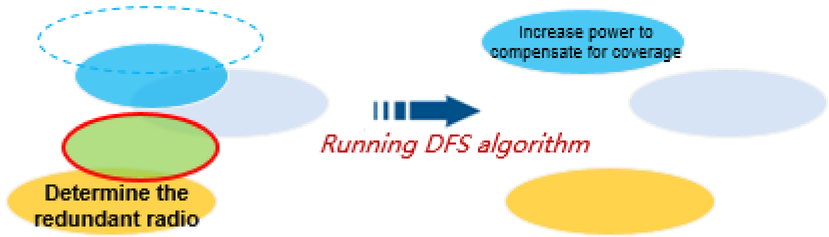
6.4 SmartRadio Technology: Intelligent Radio Calibration

Wireless networks are more difficult to plan than wired networks. The typical reason is that wireless networks are easily interfered by uncertainties in surrounding environments. With the increase of the access volume, Wi-Fi load balancing and channel resource optimization become important. This requires that the network can be intelligently optimized based on the environment and provide good experience at every moment.

1. Dynamic frequency selection (DFS)

   DFS is a technology that intelligently adjusts network coverage based on the regional topology. That is, it can identify redundant radios and increase power to compensate for coverage. When a large number of 5 GHz STAs are connected to the network, the 2.4 GHz radio with less channel resources can be automatically switched to the 5 GHz radio with more channel resources, improving the system capacity and user throughput.

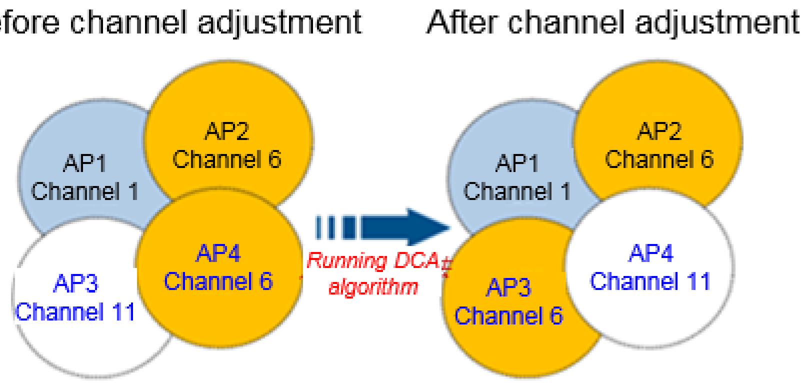
Figure 6-4 DFS



2. Dynamic channel assignment (DCA)

   Channels on a Wi-Fi network are valuable resources. There is always interference between channels. Imagine that a wide road is divided into different lanes. If resources are not properly allocated, competition irrationality will lead to traffic chaos. Similarly, on a Wi-Fi network, if channel resource allocation is improper, co-channel interference occurs, which greatly affects the BSS throughput and user experience. However, dynamic channel allocation is a complex process. For example, there are 1000 APs and 13 channels on a network. Theoretically, there are $13^{\wedge 1000}$ allocation combinations. Obviously Wi-Fi APs cannot bear such a large amount of computation. Huawei uses the patented K-Best algorithm to divide APs into several calibration groups. Each group allocates channels separately. When each radio is filtered, only K channel allocation combinations are reserved. Then, the system traverses the selected combinations for multiple times to find the most appropriate combination, allocates the most reasonable channel to each AP, and balances the operation complexity and performance.

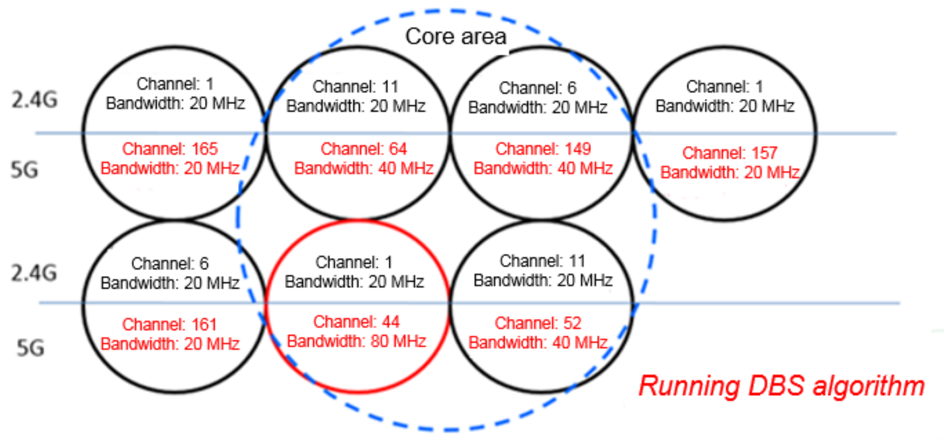
Figure 6-5 DCA



3. Dynamic bandwidth selection (DBS)

   From 802.11ac, four types of frequency bandwidth are added to the Wi-Fi system: 20 MHz, 40 MHz, 80 MHz, and 160 MHz. Higher frequency bandwidth indicates higher throughput. However, the number of available channels is limited. It is impossible to configure each AP to work in 80 MHz or even 160 MHz mode. Based on the second-generation KBS algorithm, Huawei allocates more network resources to hotspots in high-traffic areas and allocates proper bandwidth to each AP based on traffic information and spectrum resources. This feature improves user experience.

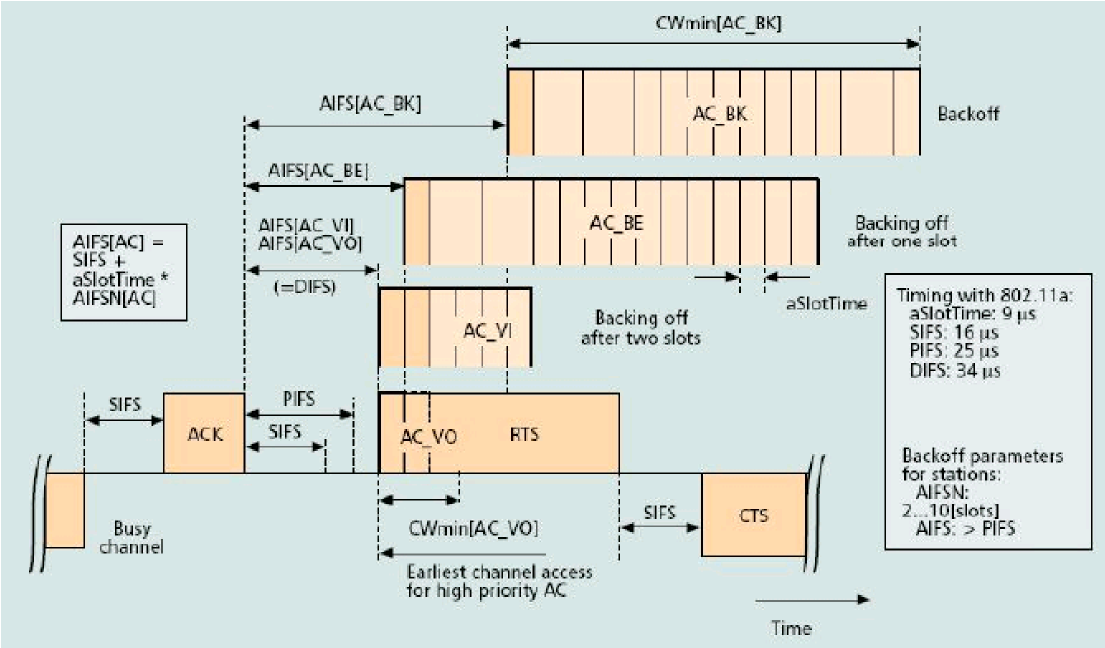
Figure 6-6 DBS



6.5 SmartRadio Technology: Intelligent EDCA Scheduling

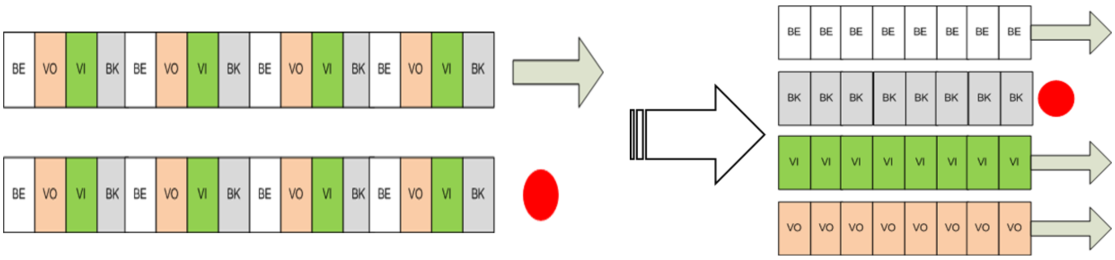
Enhanced distributed channel access (EDCA) is a channel preemption mechanism defined by 802.11e, enabling high-priority packets to be sent first and provided with more bandwidth. EDCA prioritizes queues of four access categories (ACs) in descending order, that is, AC-voice (AC-VO), AC-video (AC-VI), AC-best effort (AC-BE), and AC-background (AC-BK). This ensures that packets in a high-priority queue have greater capabilities in channel preemption. Huawei optimizes the EDCA scheduling mechanism to dynamically calculate the optimal EDCA parameters based on the service load on the air interface to make EDCA priority allocation more intelligent. During peak hours, increase the gap between the VO/VI and BE/BK parameters to ensure the experience of high-priority services.

Figure 6-7 Dynamic EDCA parameter adaptation



In addition, if a single queue is scheduled on a Wi-Fi AP, no differential delay or packet loss occurs upon congestion. As a result, high-priority services may not be scheduled preferentially. Huawei optimizes the forwarding scheduling mechanism to optimize the scheduling of a single queue based on the TID. When different backpressure thresholds are used, some congestion does not affect other queues, improving service processing efficiency and user experience.

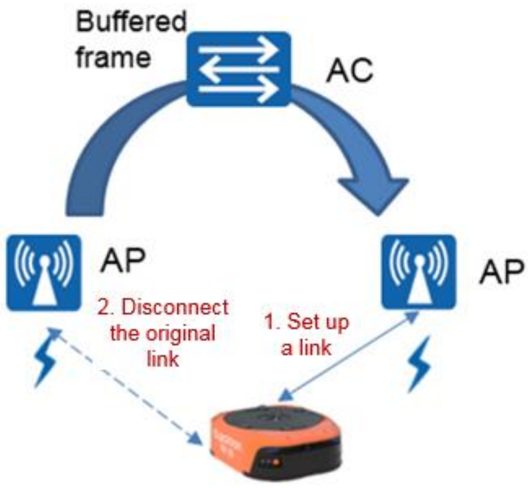
Figure 6-8 Multi-queue scheduling mechanism



6.6 SmartRadio Technology: Intelligent Lossless Roaming

Roaming is a behavior status of a STA. Roaming quality greatly affects user experience. Different from an LTE network, a STA on a Wi-Fi network is a decision-maker and an initiator of a roaming behavior. A STA proactively switches an association relationship with an AP to another AP, so that the STA is always connected to the Wi-Fi network. An AP provides wireless signals required for STA roaming, provides wireless services with the same SSID, and ensures seamless communication of a moving STA. From the perspective of the roaming behavior design, roaming aims to improve the overall Wi-Fi network performance by minimizing unnecessary data interaction traffic. To achieve low delay and no packet loss during roaming, Huawei lossless roaming technology reduces the scanning scope based on the network topology identification algorithm to quickly find the best roaming AP. Soft handover technology is used to ensure that the original link is not interrupted during the establishment of a roaming link. After the roaming link is set up, the original link is cut off, and the packets on the home AP are buffered and replayed. The number of handshake packets decreases to 2, and the roaming delay is decreased by more than 75%.

Figure 6-9 Lossless roaming in soft handover



In the 802.11ax era, the number of spatial streams supported by Wi-Fi 6 APs is doubled, functions are increasing, and IoT devices are also supported. These additional functions and devices will inevitably require the Wi-Fi 6 APs to provide higher power consumption, which cannot be met by the standard 802.11af PoE. In the future, the Wi-Fi 6 APs are expected to be equipped with the 802.11at PoE+ capability. Therefore, the upstream PoE power supply must be considered during product design and network deployment. PoE switches on the access layer also need to be upgraded. In addition, the air interface throughput of a Wi-Fi 6 AP with the lowest performance (2x2 MU-MIMO) reaches 2 Gbit/s. If only one GE port is configured, the throughput of the Wi-Fi 6 AP will become the bottleneck. It is estimated that multi-rate Ethernet ports will become the mainstream on the Wi-Fi 6 AP. Huawei has equipped 2.5GE/5GE upstream multi-rate Ethernet ports on some Wi-Fi 5 (802.11ac Wave 2) products. On the Wi-Fi 6 high-end APs, 10GE upstream multi-rate Ethernet ports will be available.

In 2017, Huawei released the industry's first multi-rate Ethernet switch S6720-SI, which supports twenty-four 2.5GE/5GE/10GE auto-sensing Ethernet ports and 200-meter long-distance PoE++ (60 W) power supply, meeting the advent of the Wi-Fi 6 era in advance.

7 Summary

In general, the three core technologies of 802.11ax, DL/UL MU-MIMO, OFDMA, and 1024-QAM, achieve the target. Based on its own software algorithm, Huawei improves the performance of legacy terminals in compliance with 802.11ac and earlier standards. The following are some frequently asked questions (FAQs) about whether to upgrade to the Wi-Fi 6 network immediately:

Q: The 802.11ax standard has not been released yet. Will it be inconsistent with the officially released standard after the upgrade to Wi-Fi 6?

A: The 802.11ax standard is expected to be officially released in the third quarter of 2019, when WFA will start Wi-Fi 6 product certification. Currently, Huawei Wi-Fi 6 products can meet the certification requirements of WFA and can be put into commercial use. The Wi-Fi 6 terminals to be launched will be fully compatible with the existing Wi-Fi 6 APs.

Q: In what scenarios do we need to upgrade the network to the Wi-Fi 6 network?

A: If 802.11ac or 802.11ac Wave 2 products are running on your network and the current network can support your services, you do not need to upgrade the network in a hurry. If products in compliance with 802.11n or earlier standards are used and the current network cannot meet your service requirements, you are advised to upgrade your network to the Wi-Fi 6 network and leverage the high-efficiency and high-performance capability of the Wi-Fi 6 network to accelerate service digitalization. In addition, if you are planning to construct a new Wi-Fi network, you are advised to deploy Wi-Fi 6 APs directly. In this manner, you can enjoy the efficient value brought by the Wi-Fi 6 network and ensure that your network meets the service development requirements in more than five years.

Q: Is it more secure to upgrade to the Wi-Fi 6 network?

A: Although the 802.11ax standard does not specify any new security enhancement function or requirement, it is understood that the later Wi-Fi 6 APs will soon support the WPA3 encryption function, which is a more secure encryption mode and has the following new functions added:

1. Strong protection for users who use weak passwords. If you enter incorrect passwords for multiple times, the system locks the account and shields the Wi-Fi authentication process to prevent brute force attacks.
2. WPA3 simplifies the security setting process of devices without the display interface. A nearby Wi-Fi device can be used as the configuration panel of other devices to provide better security for IoT devices. Users will be able to use their mobile phones or tablets to configure passwords and credentials for devices without a screen (such as a smart lock, smart bulb, or doorbell), rather than open them to anyone for access and control.
3. When you access an open network, personalized data encryption is used to enhance user privacy security. It is a feature that encrypts the connection between each device and the AP.
4. The password algorithm of WPA3 is improved to 192 bits of Commercial National Security Algorithm (CNSA). Compared with the 128-bit encryption algorithm of WPA2, the CNSA algorithm increases the difficulty of brute force password cracking.

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