What Is 802.11ax (Wi-Fi 6)

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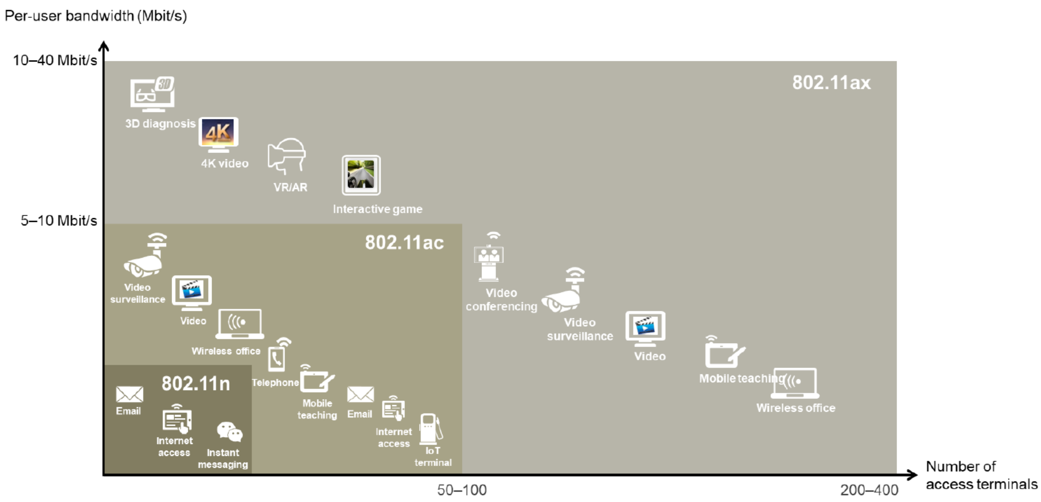
Contents

1 Introduction

Wi-Fi has become a ubiquitous technology in the world. It provides Wi-Fi 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.

As video conferencing, wireless interactive VR, mobile teaching, and various other service applications increasingly diversify, an increasing number of Wi-Fi access terminals are being used. In addition, more and more smart home terminals are available due to the development of the Internet of Things (IoT). Therefore, it is imperative that improvements are achieved in terms of Wi-Fi networks accommodating various types of terminals. This will meet users' bandwidth requirements for different types of applications running on their terminals.

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



The low efficiency of Wi-Fi networks, which is caused by the access of more terminals, needs to be resolved in the next-generation Wi-Fi standard. To address this issue, the High Efficiency WLAN Study Group (HEW SG) was established in as early as 2014, and the 802.11ax standard was ratified in 2019. By introducing technologies such as uplink MU-MIMO, orthogonal frequency division multiple access (OFDMA), and 1024-QAM high-order coding, 802.11ax is designed to resolve network capacity and transmission efficiency problems from aspects such as spectrum resource utilization and multi-user access. Compared with IEEE 802.11ac (Wi-Fi 5), 802.11ax aims to achieve a fourfold increase in average user throughput and increase the number of concurrent users more than threefold in dense user environments.

2 What Is Wi-Fi 6?

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. Table 2-1 lists the new naming conventions for 802.11 standards announced by WFA.

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.

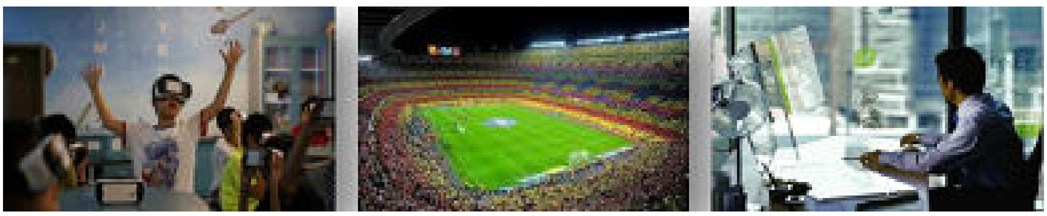
Table 2-1 lists the release dates, supported frequency bands, and new names of 802.11 standards.

Table 2-1 New naming conventions for 802.11 standards

Release Date	802.11 Standard	Frequency Band	New Name
2009	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**

Wi-Fi 6 is designed for high-density wireless access and high-capacity wireless services, such as in outdoor large-scale public venues, high-density stadiums, indoor high-density wireless offices, and electronic classrooms (e-classrooms).

Figure 2-1 High-density and high-bandwidth scenarios



In these scenarios, the number of STAs connected to the Wi-Fi network greatly increases within a short time. The increasing voice and video traffic also leads to adjustment in 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 latency, for example, 4K video streams (bandwidth of 50 Mbit/s), voice streams (latency of less than 30 ms), VR streams (bandwidth of 75 Mbit/s, and latency of less than 15 ms). If the transmission latency is caused by network congestion or retransmission, user experience will be greatly affected. A Wi-Fi 5 network can provide large bandwidth. However, as access density increases, throughput performance encounters a bottleneck. Wi-Fi 6 introduces technologies such as OFDMA, UL MU-MIMO, and 1024-QAM to ensure more reliable services. 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 e-classroom, great challenges will be encountered for video transmission or uplink/downlink interaction. The Wi-Fi 6 network can easily cope with this scenario.

3 Wi-Fi 6 Speed: How Fast Is Wi-Fi 6?

5G represents the high speed of mobile networks. Similarly, Wi-Fi 6 represents the high speed of WLANs. This Wi-Fi 6 speed is determined by the following factors:

Calculation formula:

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

- Number of spatial streams

  A spatial stream is an antenna of an AP. A large number of antennas indicate 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 3-1 Number of spatial streams supported by 802.11 standards

802.11 Standard	Maximum Number of Spatial Streams on a Single Radio
802.11a/g	1
802.11n	4
802.11ac	8
802.11ax	8

- 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 3-2 Symbols and GIs supported by 802.11 standards

Symbol and GI	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

- 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 3-3 QAMs supported by 802.11 standards

802.11 Standard	Highest-Order Modulation	Number of Bits in a Symbol
802.11a/g	64-QAM	6
802.11n	64-QAM	6
802.11ac	256-QAM	8
802.11ax	1024-QAM	10

- Coding 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 coding rate is the ratio of the actually transmitted data code with the error correction code excluded to the theoretical value.

Table 3-4 Coding 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

Negotiation Mode	Modulation Type	802.11a/g	802.11n	802.11ac	802.11ax
MCS5	64-QAM	2/3	2/3	2/3	2/3
MCS6	64-QAM	3/4	3/4	3/4	3/4
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
VMCS11	1024-QAM	-	-	-	5/6

- 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 3-5 Number of subcarriers supported by 802.11 standards

Subcarrier Parameter	Frequency Bandwidth	802.11n	802.11ac	802.11ax
Minimum subcarrier bandwidth	-	312.5 kHz	312.5 kHz	78.125 kHz
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	Coding Rate	Number of Valid Subcarriers	Rate
802.11ac	1/(3.2 us + 0.4 us)	8	5/6	234	**433 Mbit/s**

PHY	1/ (Symbol + GI)	Number of Bits in a Symbol	Coding Rate	Number of Valid Subcarriers	Rate
802.11ax	1/(12.8 us + 0.8 us)	10	5/6	980	**600 Mbit/s**

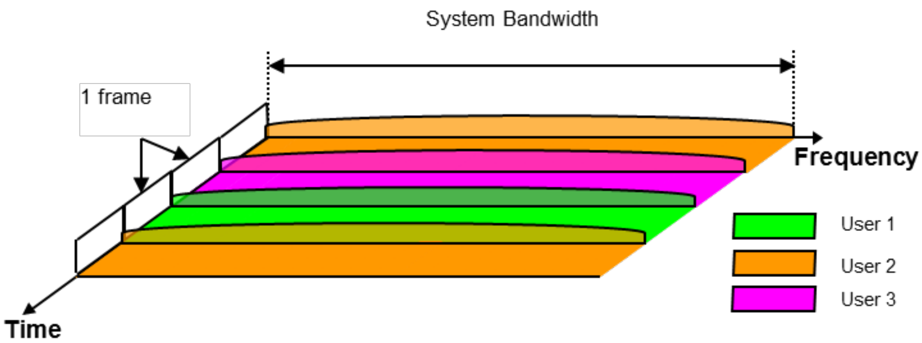
4 Core Technologies of Wi-Fi 6

Wi-Fi 6 (802.11ax) inherits all the advanced MIMO features of Wi-Fi 5 (802.11ac) while also introducing several new features applicable to high-density deployment scenarios. Some of the Wi-Fi 6 highlights are described as follows:

4.1 OFDMA Technology

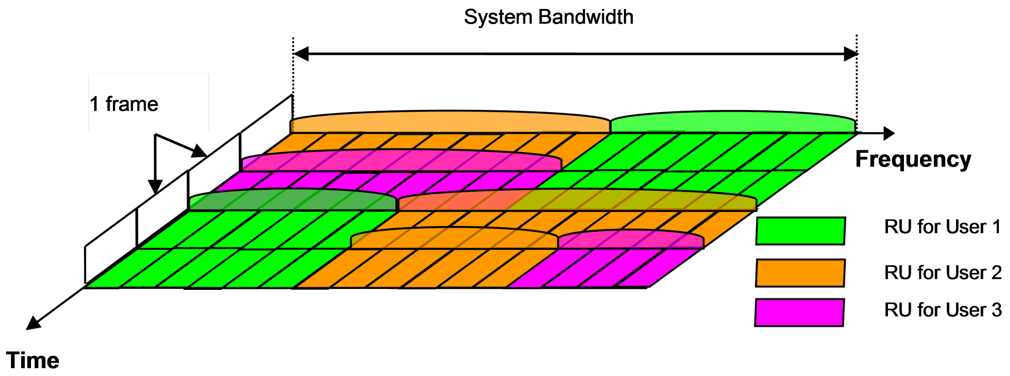
Before 802.11ax, the OFDM mode was used for data transmission, and users were distinguished based on time segments. In each time segment, one user occupied all subcarriers and sent a complete data packet, as shown in the following figure.

Figure 4-1 OFDM working mode



OFDMA is a more efficient data transmission mode introduced by Wi-Fi 6. It is also referred to as MU-OFDMA since Wi-Fi 6 supports uplink and downlink MU modes. This technology enables multiple users to reuse channel resources by allocating subcarriers to various users and adding multiple access in the OFDM system. To date, OFDMA has been utilized in 3GPP Long Term Evolution (LTE) among numerous other technologies. In addition, Wi-Fi 6 defines the smallest subcarrier as a resource unit (RU), which includes at least 26 subcarriers and uniquely identifies a user. The resources of the entire channel are divided into small RUs with fixed sizes. In this mode, user data is carried on each RU; therefore, on the total time-frequency resources, multiple users can send data in a time segment simultaneously.

Figure 4-2 OFDMA working mode

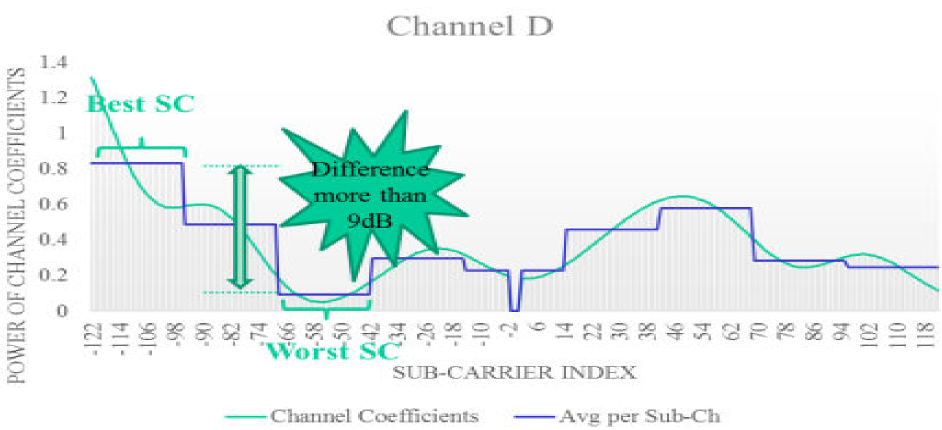


Compared with OFDM, the following improvements have been made in OFDMA:

- **More refined channel resource allocation**

  Transmit power can be allocated based on channel quality, especially when the channel status of certain nodes is below standard. 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 4-3 Channel quality in frequency domains of different subcarriers



- **Enhanced QoS**

  In IEEE 802.11ac and all earlier Wi-Fi standards, to transmit data, users occupy the entire channel. Therefore, a QoS data frame can be sent only after the current transmitter releases the entire channel, which leads to long latency. In OFDMA mode, one transmitter occupies only some of the entire channel's resources. Therefore, data of multiple users can be sent simultaneously, thereby reducing network access latency of QoS nodes.

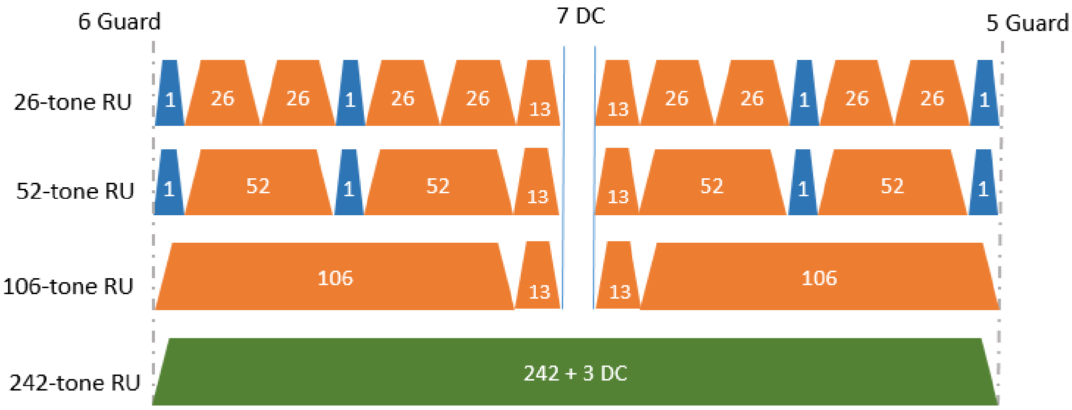
- **More concurrent users and higher user bandwidth**

  OFDMA divides the entire channel's resources into multiple subcarriers, which are then divided into several groups based on RU type. Each user may occupy one or more groups of RUs to meet various bandwidth requirements. In Wi-Fi 6, the minimum RU size and minimum subcarrier bandwidth are 2 MHz and 78.125 kHz, respectively. Therefore, the minimum RU type is 26-subcarrier RU. By analogy, RU types include: 52-subcarrier, 106-subcarrier, 242-subcarrier, 484-subcarrier, and 996-subcarrier RUs. The more the number of RUs, the higher efficiency of multi-user processing and the higher throughput.

Table 4-1 Number of RUs at different frequency bandwidths

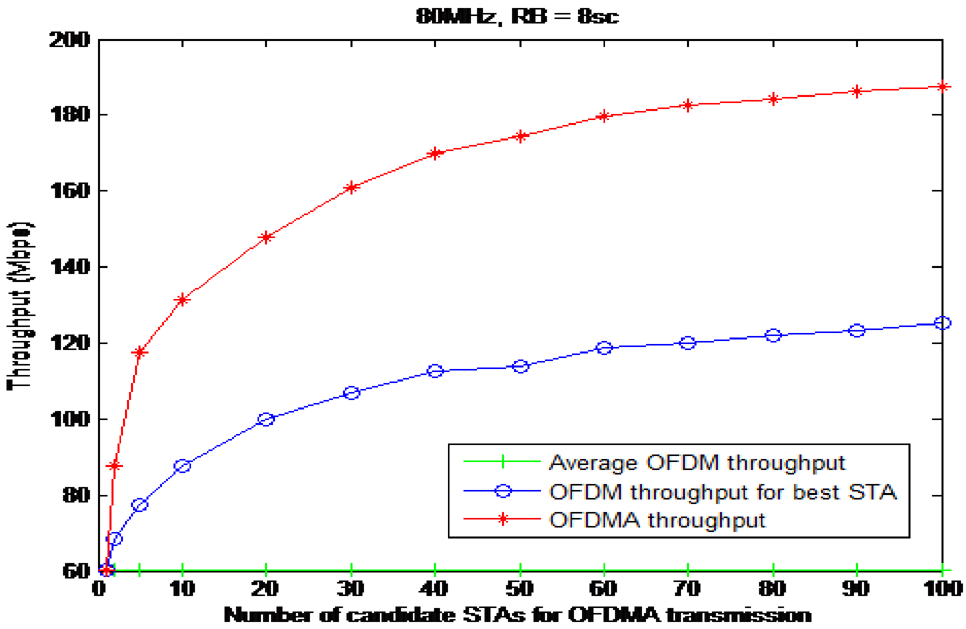
RU Type	CBW20	CBW40	CBW80	CBW160 and CBW80+80
26-subcarrier RU	9	18	37	74
52-subcarrier RU	4	8	16	32
106-subcarrier RU	2	4	8	16
242-subcarrier RU	1-SU/MU-MIMO	2	4	8
484-subcarrier RU	-	1-SU/MU-MIMO	2	4
996-subcarrier RU	-	-	1-SU/MU-MIMO	2
2×996-subcarrier RU	-	-	-	1-SU/MU-MIMO

Figure 4-4 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.

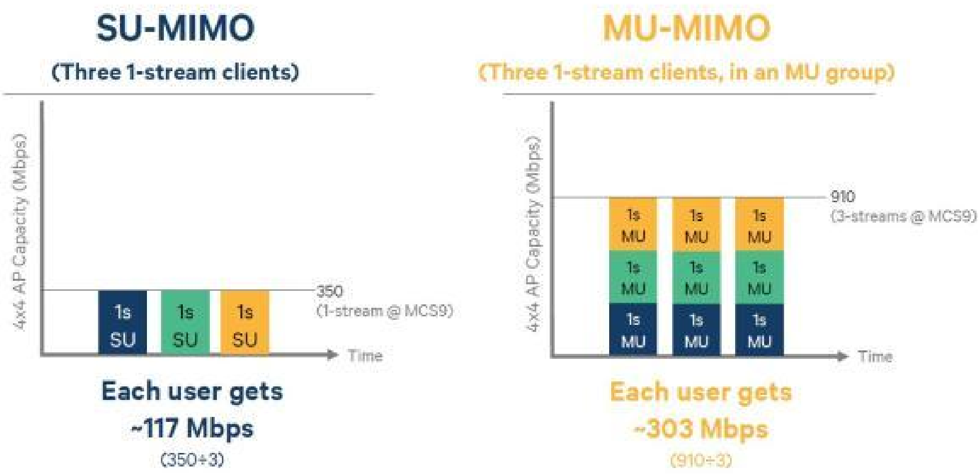
Figure 4-5 Multi-user throughput simulation in OFDMA and OFDM modes



4.2 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.

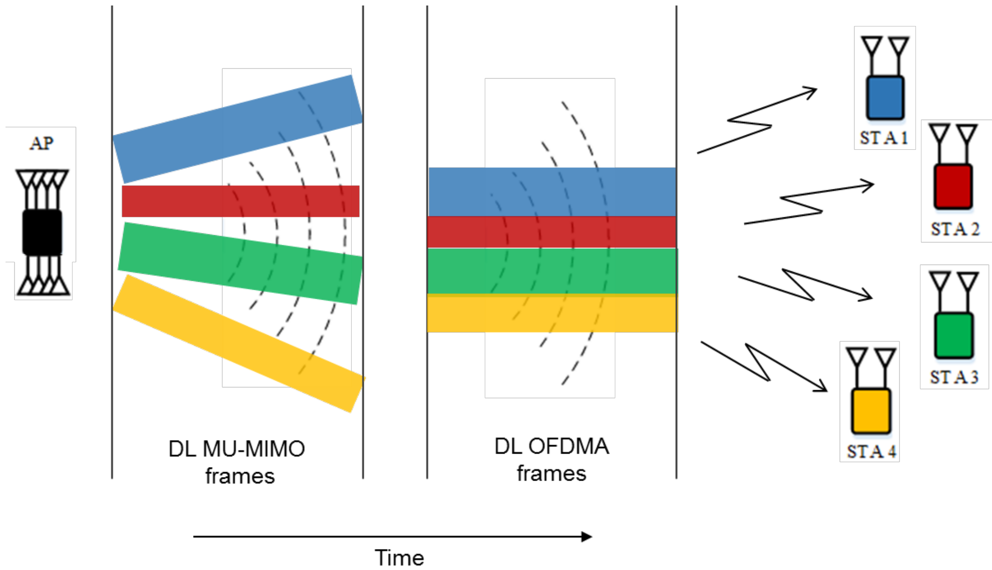
Figure 4-6 Throughput difference between SU-MIMO and MU-MIMO



- **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.

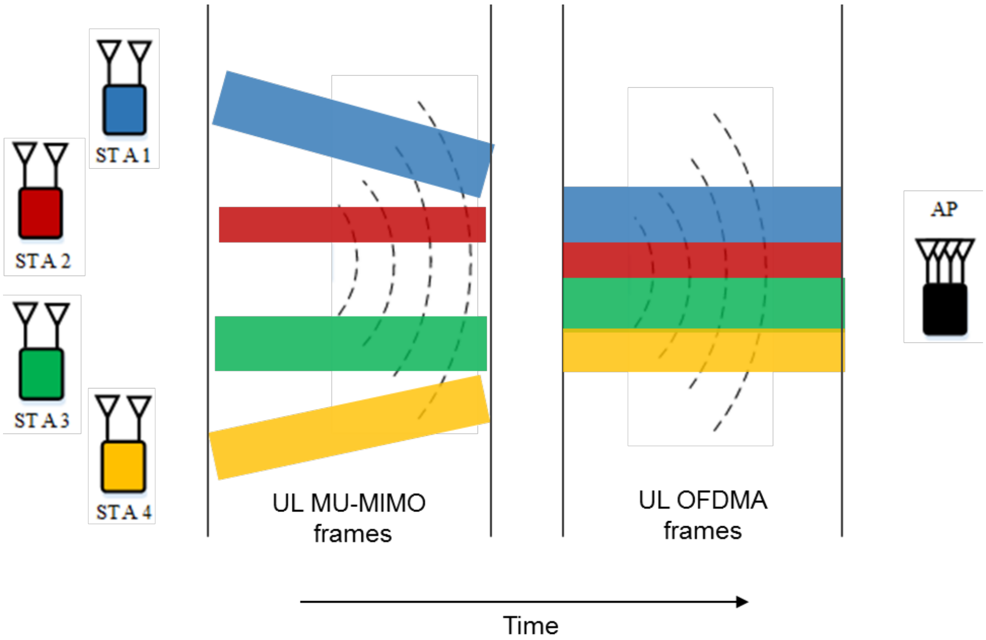
  Figure 4-7 8x8 MU-MIMO AP scheduling sequence in the downlink multi-user mode



- **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 4-8 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.

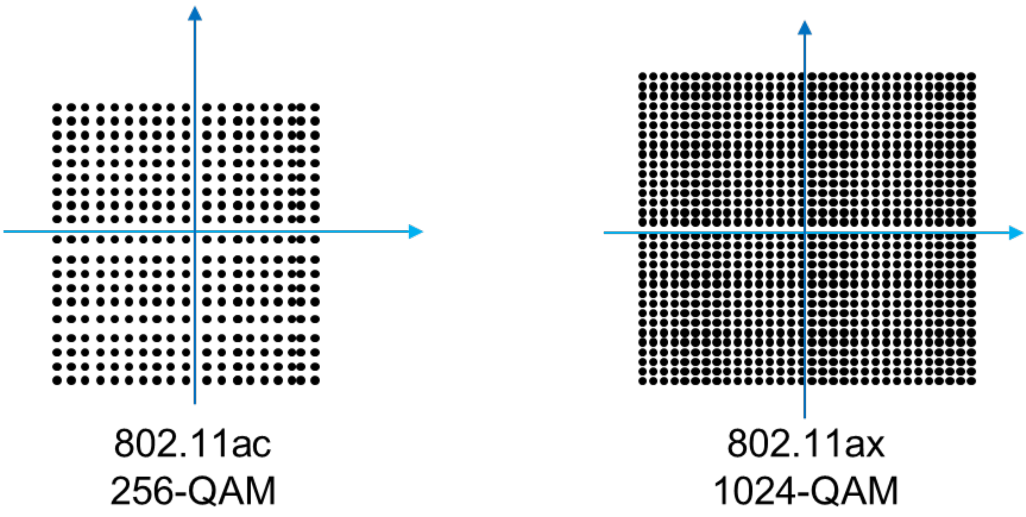
Table 4-2 Comparison between OFDMA and MU-MIMO

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

4.3 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 ($2^8 = 256$). 802.11ax uses 1024-QAM quadrature amplitude modulation, and each symbol bit transmits 10-bit data ($2^{10} = 1024$). Therefore, compared with 802.11ac, 802.11ax increases data throughput of a single spatial stream by 25%.

Figure 4-9 Constellation maps of 256-QAM and 1024-QAM



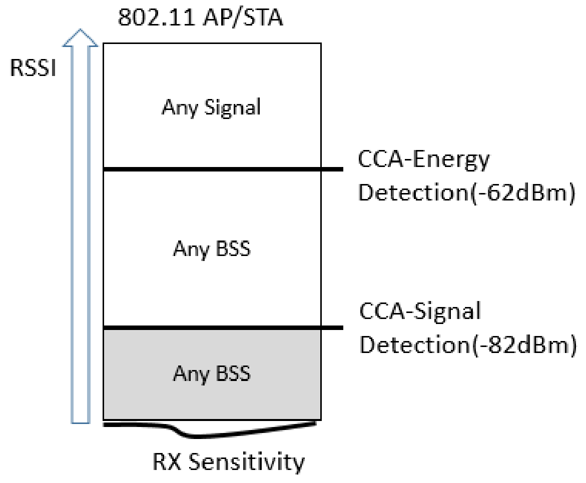
The successful application of 1024-QAM modulation in 802.11ax depends on channel conditions. Dense constellation points require great error vector magnitude (EVM) (used to quantize the performance of the radio receiver or transmitter in modulation precision) and receiver sensitivity. In addition, the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

4.4 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.

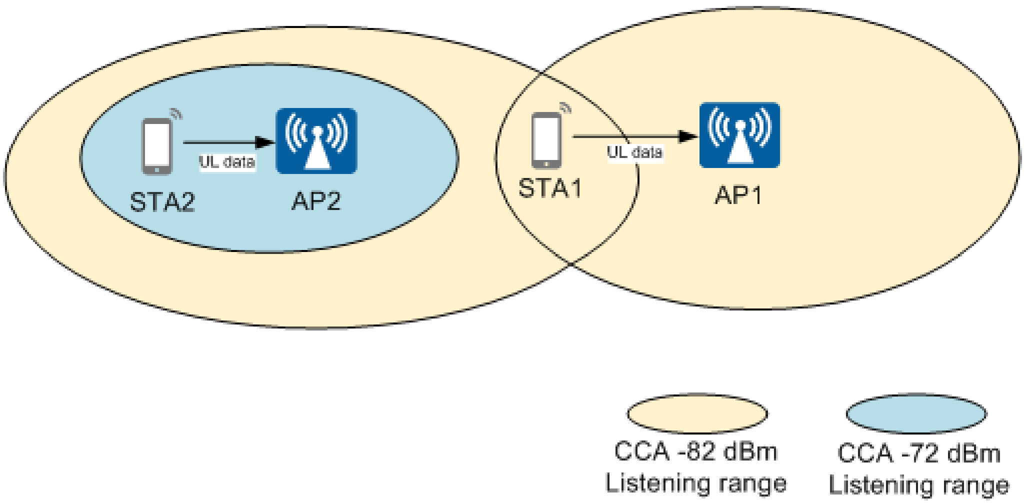
In 802.11ac and earlier standards, the mechanism of dynamically adjusting the clear channel assessment (CCA) threshold is used to reduce co-channel interference. The system identifies the co-channel interference strength, dynamicaly adjusts the CCA threshold, ignores co-channel weak interference signals,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

Figure 4-10 Default CCA threshold of 802.11



For example, as shown in the following figure, 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.

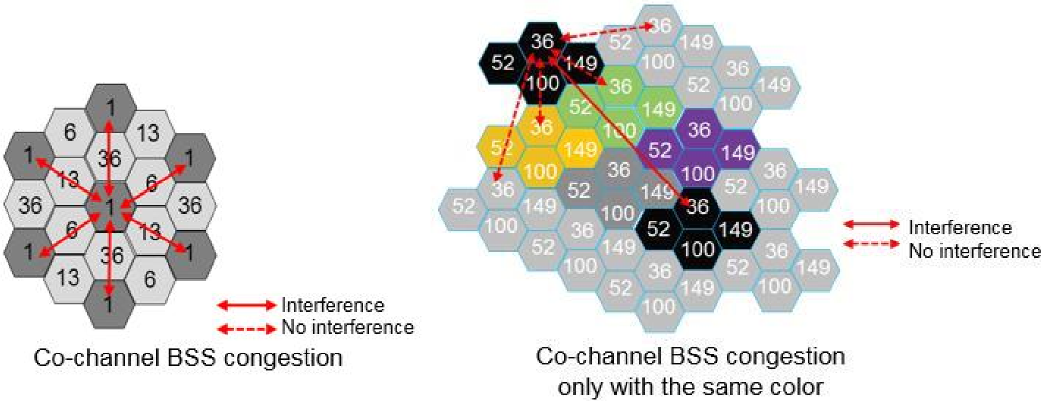
Figure 4-11 Dynamic adjustment of the CCA threshold



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 BSS sand 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.

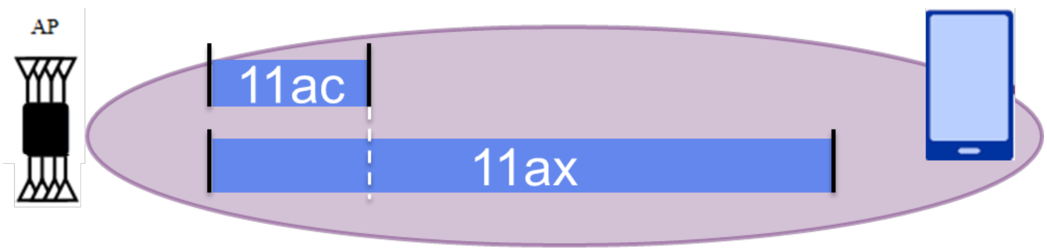
Figure 4-12 How the BSS color mechanism reduces interference



4.5 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 range.

Figure 4-13 Range increase brought by long OFDM symbol and narrowband transmission



5 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. The following introduces the other new features of 802.11ax.

5.1 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

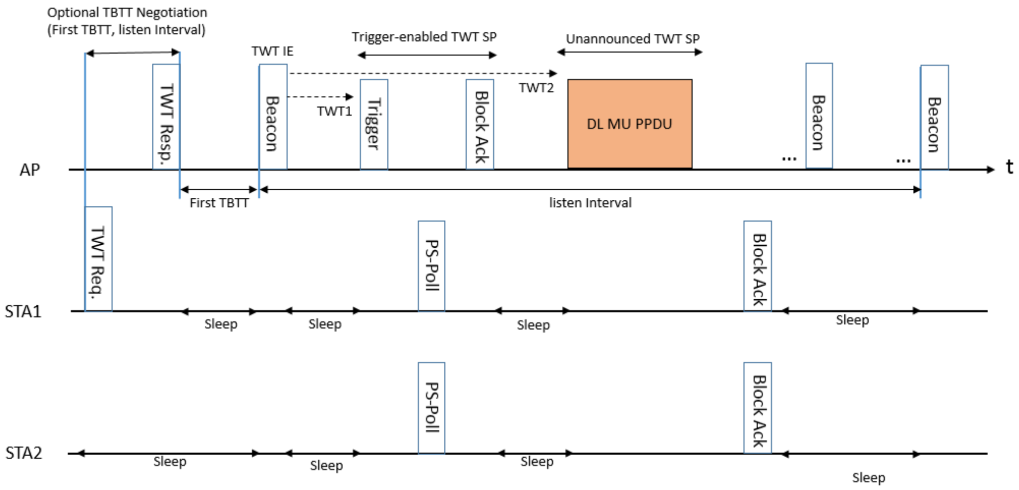
STAs. In this case, STAs in compliance only with the 2.4 GHz frequency band terminal are more cost-effective.

5.2 TWT

Referencing from 802.11ah, the Target Wake Time (TWT) is an important resource scheduling function supported by 802.11ax. It allows STAs to negotiate with APs for the waking schedule and then send or receive data. APs can group STAs into different TWT periods to reduce the number of devices that simultaneously compete for the wireless medium after wakeup. In addition, the TWT increases the device sleep time. For battery-powered STAs, battery life has significantly 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 the broadcast TWT operation.

Figure 5-1 Broadcast TWT operation



6 802.11ax Access Points Provided by Huawei

Huawei WLAN provides Wi-Fi 6 APs: AP7060DN and AirEngine series APs. For details, see **https://e.huawei.com/cn/products/enterprise-networking/wlan/wifi-6/new-products-launch**.

7 More Information

Wi-Fi 5: **What Are 802.11ac and 802.11ac Wave 2**

Wi-Fi 6:

- **(eBook) Wi-Fi 6**
- **(eBook) Wi-Fi 6 Advanced**

Wi-Fi 7:

- **(eBook) Wi-Fi 7**
- **What Is WiFi 7?**