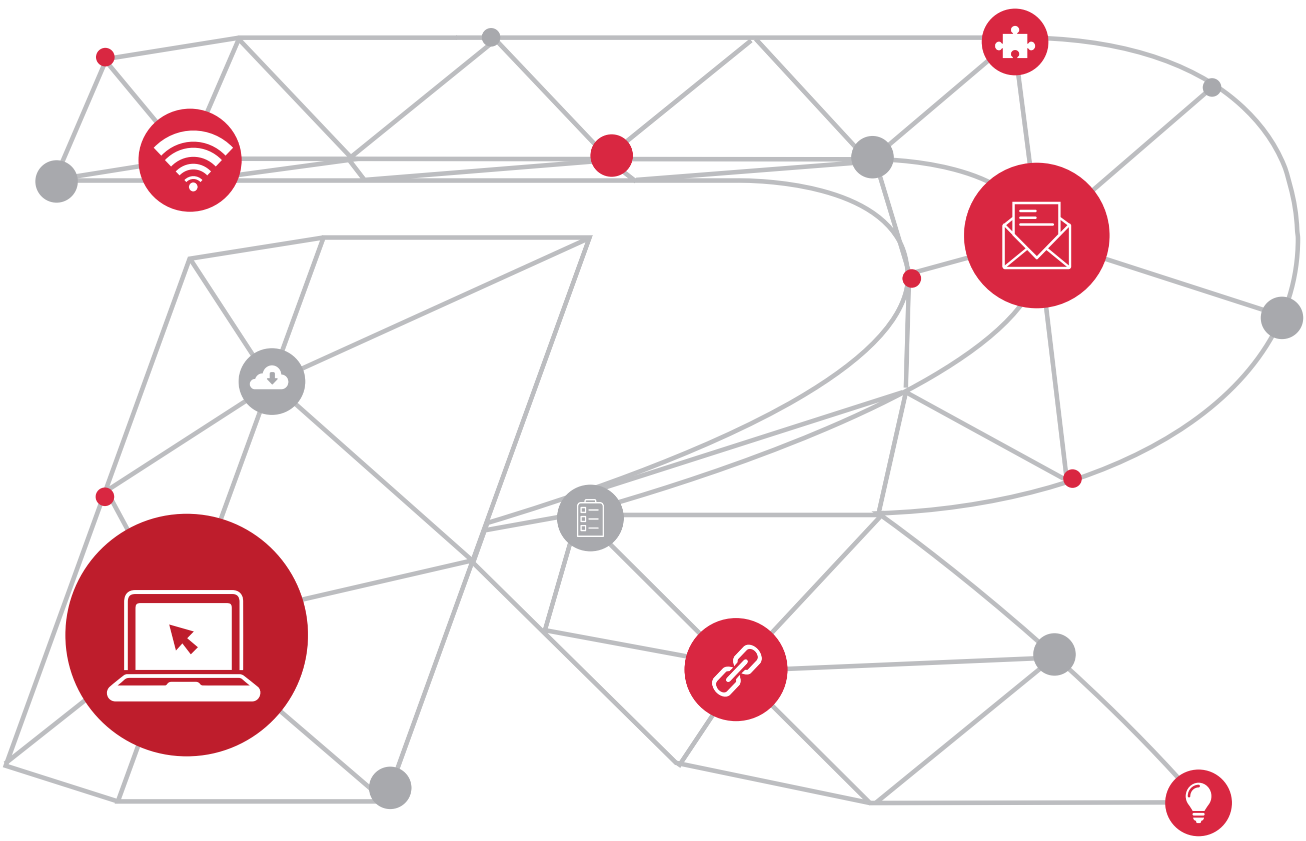
WiFi6 (802.11ax) Technology

White Paper



Contents

Overview

• Origin of 802.11ax Technology

IEEE 802.11 is a working group in the IEEE responsible for the protocol standards for wireless local area networks. The organization has developed several successful WLAN protocols, such as 11g, 11n and 11ac.

802.11 Wireless Standards					
IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac
Year Adopted	1999	1999	2003	2009	2014
Frequency	5 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz	5 GHz
Max Data Rate	54 Mbps	1 Mbps	54 Mbps	600 Mbps	1 Gbps

802.11ac has provided a breakthrough of 1Gbps for WLAN link. However, with the wide application of WLAN applications, the number of APs and terminals is increasing, and the conflicts and interferences between devices may cause unsatisfactory efficiency result for the entire network. New application scenarios, such as video, production network, and automation technology, also put forward higher requirements for WLAN in terms of throughput, stability, and transmission latency.

In response to the new challenges, the 802.11 working group established the HEW (High Efficiency Wireless) research group in 2013 and it became the official 11ax task group in 2014, developing the 11ax protocol based on the 802.11-2012 standard.

Current Progress of the ax Working Group[1]	
May 2014	Official establishment of the working group
November 2016	Draft 1.0
September 2017	Draft 2.0
May 2018	Draft 3.0
January 2019	Draft 4.0
July 2019	Initiate the final vote (plan)
January 2020	Final 802.11 Approval (plan)

• 802.11ax Technical Objective

According to the 11ax Technical Group's plan[2], the main improvement goals of the 11ax technology are:

1. System performance: Improve the average throughput performance per user by at least 4 times in the high-density deployment scenario, improve the power consumption of the terminal devices and reduce the communication latency to meet the QoS application requirements in high-density scenarios.
2. Spectrum Efficiency: Improve the efficiency of wireless spectrum resources utilization and provide the ability to manage interference from nearby devices to improve performance in high-density deployments.
3. Bands of Operation: 802.11ax addresses frequency bands between 1 GHz and 6 GHz, which includes the traditional 2 GHz and 5 GHz bands, as well as the new 6 GHz band.

There is no requirement for maximum link rate in the 11ax objectives. Alternatively, it focuses on high density, multi-user, and efficiency. This generation of protocol will move in the direction which is more practical and closer to user

1. Progress of the 11ax Working Group as of May 2019: http://www.ieee802.org/11/Reports/tgax_update.htm
2. https://mentor.ieee.org/802.11/dcn/14/11-14-1009-02-00ax-proposed-802-11ax-functional-requirements.doc

scenarios.

• 802.11ax and Wi-Fi 6

802.11ax is the name given by the IEEE 802.11 standard organization for the next-generation WLAN standard. The technology is referred to as HE (High Efficiency) in the standard document.
Wi-Fi 6 is a new name for Wi-Fi proposed by WFA (Wi-Fi Alliance, a non-profit organization that promotes Wi-Fi technology and standardized certification of Wi-Fi products) to facilitate the promotion of the new Wi-Fi technology wherein Wi-Fi 5 refers to 802.11ac and Wi-Fi 6 refers to 802.11ax.

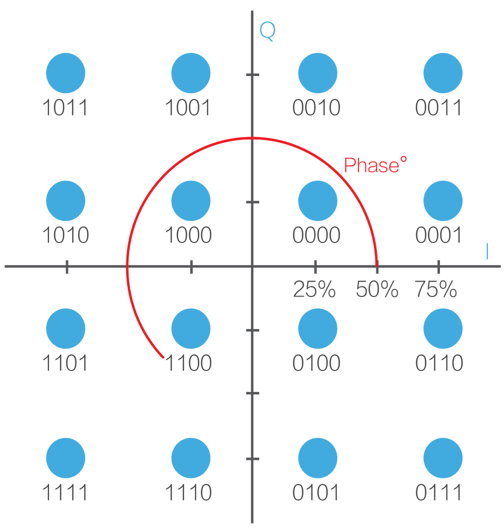
• New 802.11ax Technology

Users' pursuit of faster speed has been running through the entire development of 802.11. As wireless and chip technologies continue to develop, technologies that were previously difficult to implement or too costly are now possible. In 11ax, there are also some new features that increase the physical layer link rate.

• 1024QAM

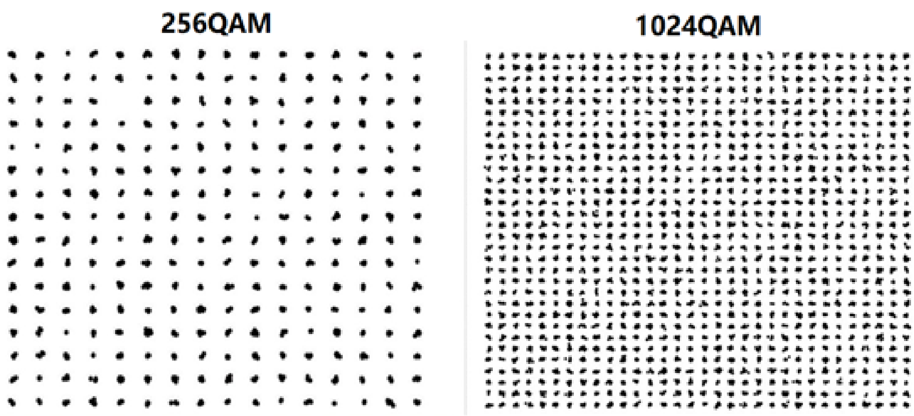
QAM (Quadrature Amplitude Modulation) conveys 2 orthogonal carrier waves of the same frequency with double data to improve spectrum utilization. QAM has a wide range of applications in communication technologies such as Wi-Fi and cellular networks.

In the field of digital communications, the constellation diagram is usually used to visually represent signals and the relationship between signals. QAM is a modulation method that combines amplitude and phase variations, which means that different information is represented by different phase and amplitude combinations of the signals. As shown in the below 16QAM constellation diagram, the data "1100" is represented by a combination of phase 225° and amplitude 25%. 1 signal unit of 16QAM represents 4 bits (16 types) of data.



Amp	Phase	Date
25%	225°	1100

A maximum of 256QAM is supported in the 11ac era. 11ax introduces a higher-order coding, 1024QAM. A signal unit of 1024QAM represents 10 bits (1024 types) of data, which offers 25% higher performance than 256QAM.

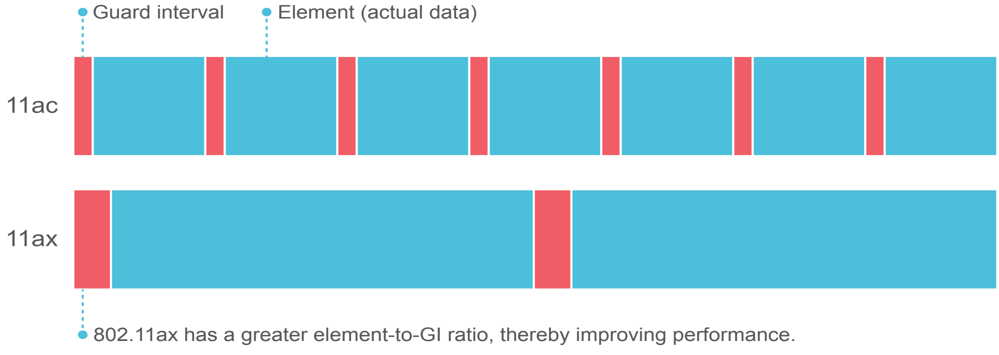


Due to the increase in the information density of 1024QAM, the difference between signals carrying different codes is also smaller, and the requirements for signal quality are also higher. Therefore, the technology can only fully exert its advantages in a scenario with excellent wireless environment and relatively close distance, such as small office and conference room with good signal.

• Long OFDM Symbol

Longer OFDM symbols are used in 11ax, which has three functions[3]:
1. Improve the stability of outdoor communication
2. Enhance the tolerance of delay jitter in UL MU-MIMO and OFDMA communications
3. Improve the efficiency of indoor communication (lower GI time ratio), which is the effect of speed increase discussed in this section

In the OFDM coding of Wi-Fi, the information is divided into a number of small OFDM symbols (the blue section of the figure below). GI (guard interval, the red section in the figure) is inserted between the symbols to reduce the mutual influence between the symbols. Longer symbol length is used in 11ax, which reduces the proportion of GI and improves performance.



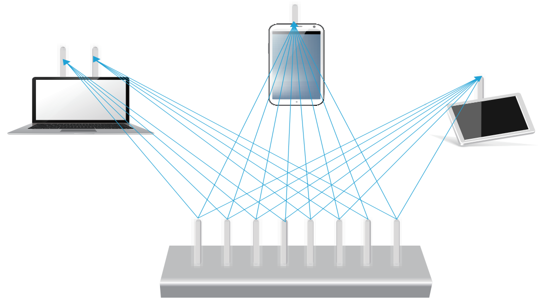
Take a typical indoor deployment as an example. In the 11ac network, the GI is 0.4us or 0.8us, and the symbol length is 3.2us. I.e. the payload accounts for 80%. In the 11ax network, the GI is 0.8us and the symbol length is 12.8us. I.e. the payload accounts for 94%. Therefore, in the same QAM debugging mode, the HE (11ax) speed increases by 14%. This performance gain exists in all types of HE speeds from MCS1 to MCS11, so the users can enjoy the performance gain brought by long symbols regardless of the speeds they use and their environments.

• 8*8 MIMO

3. Reference: IEEE 802.11-15/0099

Although support for 8x8 MIMO spatial streams has been mentioned in the 11ac protocol, there are no mature commercial applications in the 11ac era.

With the advancement of technology, mature 8x8 commercial products have emerged in the 11ax era. This not only improves the maximum throughput performance per user, but also supports MU-MIMO for more users, improving the throughput performance of multi-user concurrency.



• Higer Efficiency

Historical Wi-Fi protocols focus on increases of physical link rates. In addition to the preceding increases of link rates, 802.11ax is more innovative in its support for multi-user high-density scenarios.

Wi-Fi communication is based on the enhanced distributed channel access (EDCA) contention model. Therefore, all STAs need to contend on same channels, which wastes much time due to backoff and waiting. Contention overheads significantly increase as the number of STAs grows. To reduce such wastes, orthogonal frequency division multiple access (OFDMA), multi-user multiple-input multiple-output (MU-MIMO), spatial reuse (SR), and other technologies are introduced.

• DL/UL OFDMA

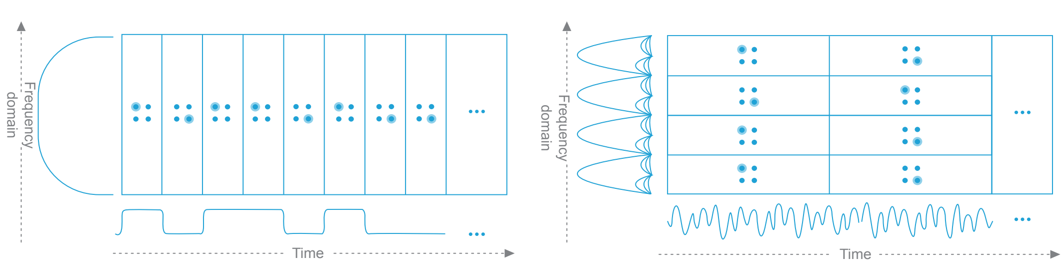
Instead of increasing physical rates, OFDMA boosts multi-user communication efficiency through user concurrency in frequency domain. OFDMA has been successfully applied to LTE, and can theoretically enable better stability in actual scenarios than MU-MIMO, and therefore receives high expectations in 802.11ax.

• Basic OFDM Knowledge

This section first describes orthogonal frequency division multiplexing (OFDM) for better understanding of basic OFDMA theories below. OFDM is applied to 802.11a, 802.11g, 802.11n, and 802.11ac.

Different from single-carrier modulation schemes, OFDM divides the entire carrier band into a large number of adjacent sub-bands (subcarriers). Each subcarrier adopts a conventional modulation scheme for modulation at a low symbol rate.

Single-carrier modulation OFDM modulation

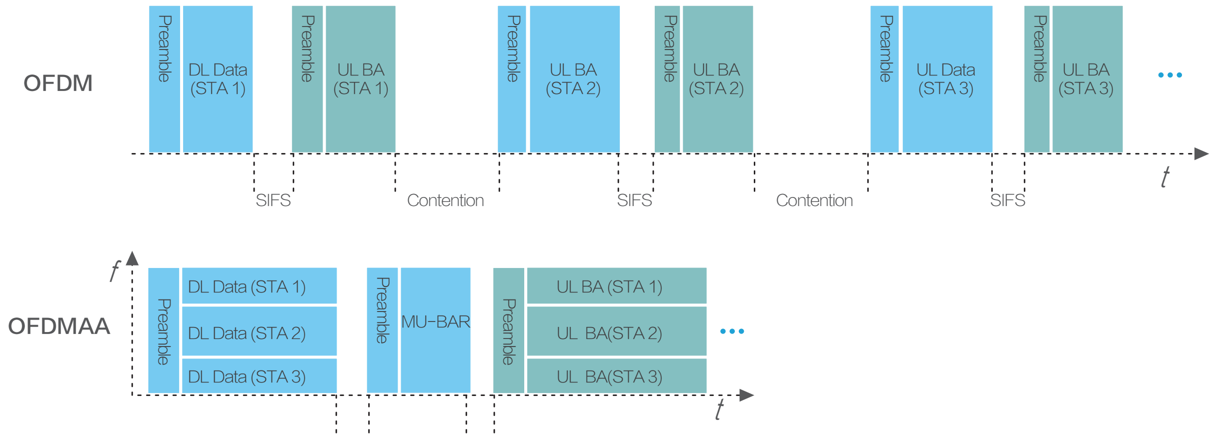


For example, a 20 MHz band of 802.11ac is divided into 64 subcarriers, with each subcarrier having a frequency channel width of 312.5 kHz. Each subcarrier is subdivided into 3.2 μs elements and 0.8 μs guard intervals (GIs). A transmit end generates time-domain signals through inverse Fourier transform by using the 64 subcarriers for signal sending. A receive end decomposes the signals into the 64 subcarriers through Fourier transform, demodulates data on each subcarrier, and obtains the sent data via reassembly.

OFDM features high spectrum efficiency, high channel width scalability, and resistance to multipath fading, and therefore is widely applied to the wireless communications.

• OFDMA

OFDMA evolves from OFDM. In OFDM, all subcarriers in one packet are used for communication with a single user. In OFDMA, different subcarriers in one packet can be allocated to different users for concurrent communication.



As shown in the preceding figure, OFDMA reduces preambles, interframe spaces such as short interframe spaces (SIFSs), and contention backoff time of STAs, thereby increasing communication efficiency in concurrency scenarios.

• Subcarriers and RUs

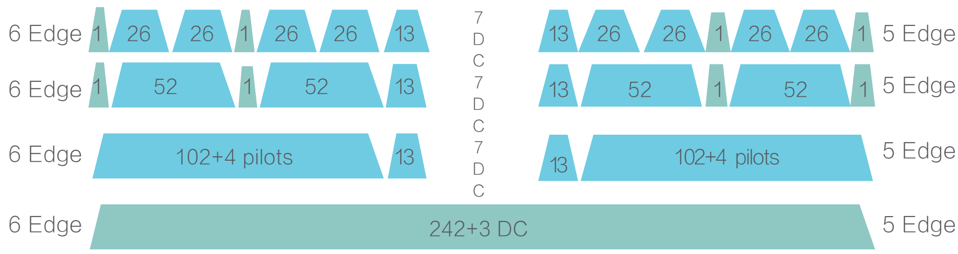
802.11ax specifies the following types of subcarriers:

* **Data subcarriers: used to transmit data.**
* **Pilot subcarriers: distributed among data subcarriers, helping the data subcarriers in phase synchronization.**
* **Unused subcarriers: further classified into direct current (DC) subcarriers, guard band subcarriers, and null subcarriers. These subcarriers provide assistance and protection.**

A data subcarrier set is referred to as a resource unit (RU), and can be allocated to a single user. 802.11ax specifies the following data subcarrier sets of different sizes.

* **26-tone with 2 pilots**
* **52-tone with 4 pilots**
* **106-tone with 4 pilots**
* **242-tone with 8 pilots**
* **484-tone with 16 pilots**
* **996-tone with 16 pilots**

Note Taking 26-tone with 2 pilots as an example, “tone” means subcarrier; “26-tone” indicates an RU composed of 26 subcarriers, and “2 pilots” means two pilot subcarriers. Therefore, “26-tone with 2 pilots” means that the RU consists of 24 data subcarriers and 2 pilot subcarriers. In 802.11ax, each subcarrier has a channel width of 78.125 kHz, and “26-tone” is about 2 MHz, which is the minimum unit of channel width allocatable to a single user.



The preceding figure lists the following four basic RUs:

* 9 x 26-tone: Subcarriers in a single packet are evenly allocated to 9 STAs. (The RU in the middle is split by DC.)

* 4 x 52-tone + 1 x 26-tone: Subcarriers in a single packet are allocated to 5 STAs.

* 2 x 102-tone + 1 x 26-tone: Subcarriers in a single packet are allocated to 3 STAs.

* 1x 242-tone: Subcarriers in a single packet are allocated to 1 STA.

The following table lists maximum numbers of RUs of different sizes under various channel widths.

RU type	CBW20	CBW40	CBW80	CBW80+80 and CBW160
26-tone RU	9	18	37	74
52-tone RU	4	8	16	32
106-tone RU	2	4	8	16
242-tone RU	1	2	4	8
484-tone RU	N/A	1	2	4
996-tone RU	N/A	N/A	1	2
2×996-tone RU	N/A	N/A	N/A	1

As listed above, under the 80 MHz channel width, 37 or 16 concurrent STAs can be supported, bringing significant gains to typical high-density concurrency scenarios.

• HE PPDU

OFDMA needs a special frame structure to allocate RUs in a single packet to different STAs. An STA needs to know a specific band of the subcarriers to be allocated to the STA.

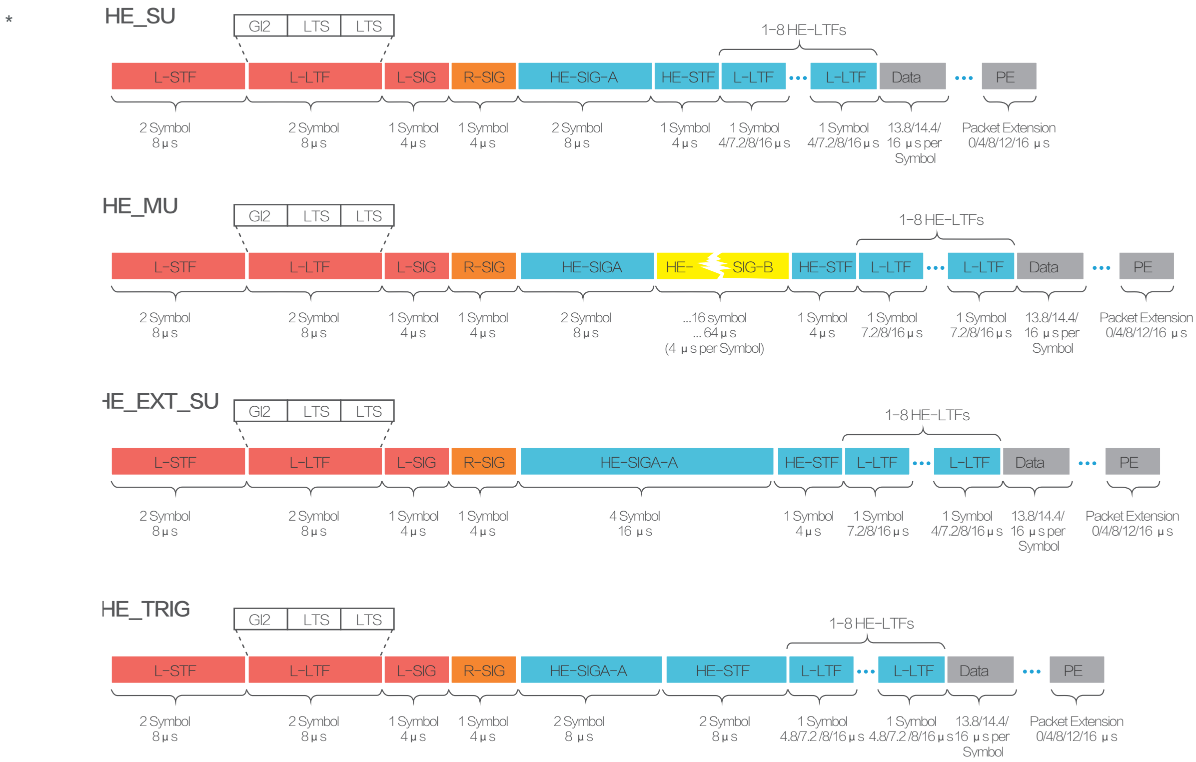
To address the two issues, first learn of the following HE PPDU formats added to 802.11ax:

* HE SU PPDU: used to send packets to a single STA.

* HE Extended Range PPDU: designed for sending packets to a single long-range STA. Packets can be sent only in the primary 20 MHz band by using only one spatial flow and any of MSC 0 to MCS 2. In addition, this format enhances the preamble part in a targeted way.

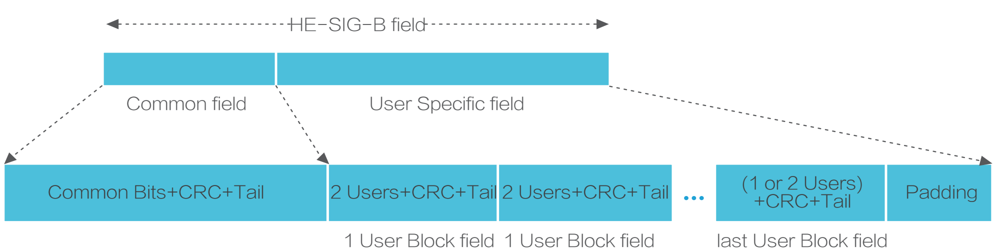
* HE MU PPDU: used to send OFDMA and HE MU-MIMO packets to one or more STAs.

* HE Trigger-based PPDU: used to send uplink OFDMA or MU-MIMO packets. Such sending is triggered by the trigger packet sent by the AP.



Field	Description
L-STF	Legacy short training field, compatible with fields of non-HT devices
L-LTF	Legacy long training field, compatible with fields of non-HT devices
L-SIG	Legacy signal field, compatible with fields of non-HT devices
RL-SIG	Repeated legacy signal field, compatible with fields of non-HT devices
HE-SIG-A	HE signal A field, new information field A
HE-SIG-B	HE signal B field, new information field B
HE-STF	HE short training field, newly added
HE-LTF	HE long training field, newly added
Data	Data field
PE	Packet extension field, alignment or information field at the end of a packet

The HE-SIG-B field can address the two issues above.



The HE-SIG-B field has a variable length, and consists of the Common field and User Specific field.

* The RU Allocation subfield in the Common field determines the RU allocation scheme and the number of users.

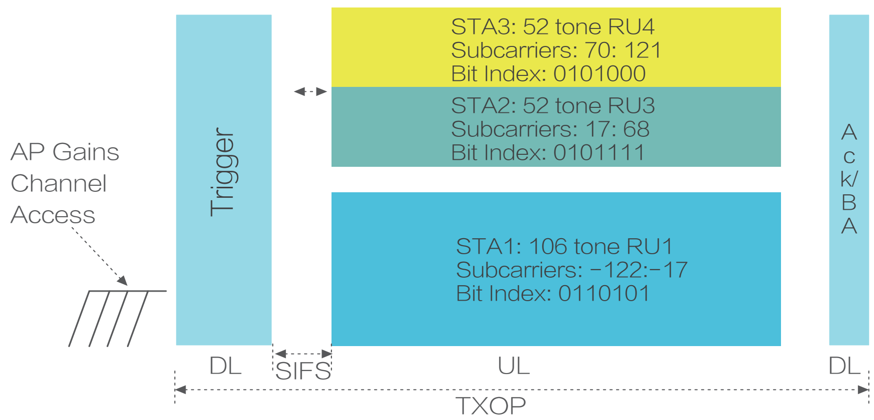
* The User Specific field describes key information of each STA, such as the STA ID, MCS, and coding information. In addition, a user's place in a sorting sequence determines a position and size of an RU to be occupied by the user.

Through the HE-SIG-B field, a STA can know whether a received packet is destined for the STA itself as well as a position and size of a corresponding RU, that is, the STA can properly demodulates content in the RU destined for the STA.

• Trigger Packet and Uplink OFDMA

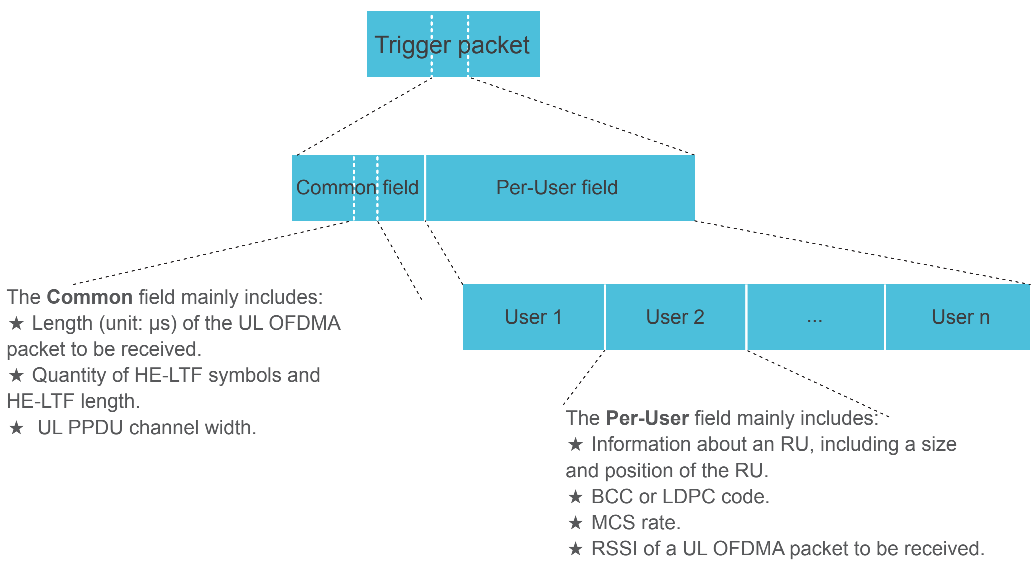
Multiple STAs send uplink OFDMA packets on different sub-bands by using various RUs, similar to the downlink OFDMA packet sending by the AP.

For STAs to send uplink OFDMA packets collaboratively, the AP needs to send control packets, namely, trigger packets. After receiving the trigger packets, the STAs jointly send HE TB (trigger based) PPDUs, that is, uplink OFDMA packets after one SIFS.



As shown in the preceding figure, the AP sends a trigger packet to allocate RUs to three STAs. The STAs jointly send HE TB packets after one SIFS. The AP returns an ACK or a BA after receiving the HE TB packet.

The trigger packet is a non-HE packet, namely, sent at a conventional rate and compatible with existing devices. The trigger packet is composed of a Common field and a Per-User field.



The Common field mainly includes:

* **Length (unit: μs) of the UL OFDMA packet to be received**
* **Quantity of HE-LTF symbols and HE-LTF length**
* **UL OFDMA packet channel width**

The Per-User field mainly includes:

* **Information about an RU, including a size and position of the RU**
* **BCC or LDPC code**
* **MCS rate**
* **RSSI of a UL OFDMA packet to be received**

Trigger Type subfield value	Trigger frame variant
0	Basic
1	Beamforming Report Poll (BFRP)
2	MU-BAR
3	MU-RTS
4	Buffer Status Report Poll (BSRP)
5	GCR MU-BAR
6	Bandwidth Query Report Poll (BQRP)
7	NDP Feedback Report Poll (NFRP)
8-15	Reserved

The trigger packet specifies in detail the UL OFDMA packet of each STA, which greatly improves the AP's STA control capability.

In addition to scheduling basic UL data packets, the trigger packet can be used for other purposes, for example, beamforming requests, multi-user block ACK requests (MU-BARs), and acquisition of the STA's buffer status.

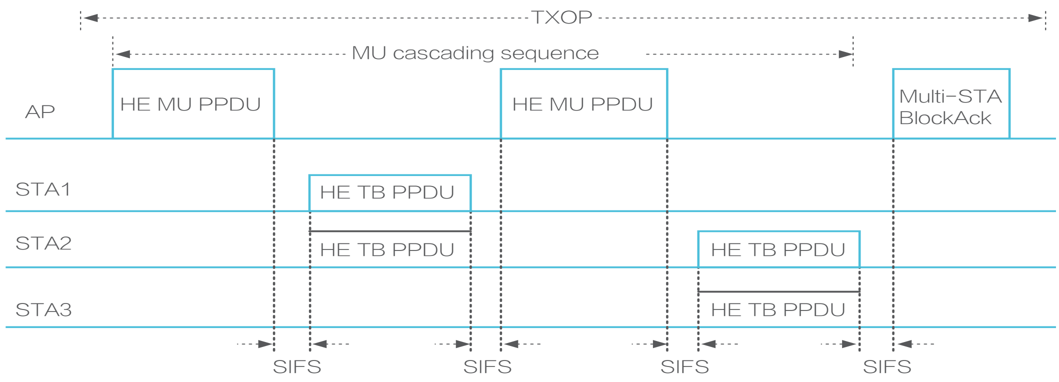
• Cascading Mode

802.11ax further specifies the cascading mode, which features excessively high communication efficiency. As shown in the following figure:

1. The HE MU PPDU sent by the AP includes downlink data, a trigger packet, and an ACK responsive to an uplink packet. The trigger packet triggers the HE TB PPDU of the STA.

2. The HE TB PPDU sent by the STA also includes an ACK responsive to a packet delivered by the AP, together with uplink data to be sent.

The AP controls and schedules communication on the entire network. Therefore, a communication mode similar to cellular network communication is formed. Compared with the conventional EDCA mode, the cascading mode greatly reduces time wasted by contention backoff and increases network-wide communication efficiency.



• DL/UL MU-MIMO

802.11ax extends MU-MIMO by supporting UL MU-MIMO and use of MU-MIMO together with OFDMA (optional), and sending packets via HE MU PPDUs.

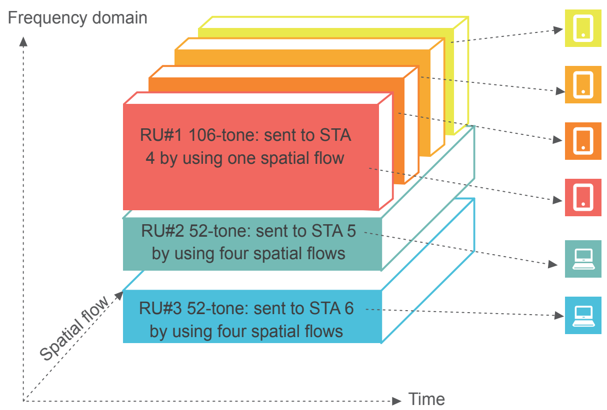
• HE DL MU-MIMO

802.11ax enables MU-MIMO to be used jointly with OFDMA, and sends packets via HE MU PPDUs.

As shown in the following figure, under a 20 MHz channel width, OFDMA subcarriers are divided into three RUs.

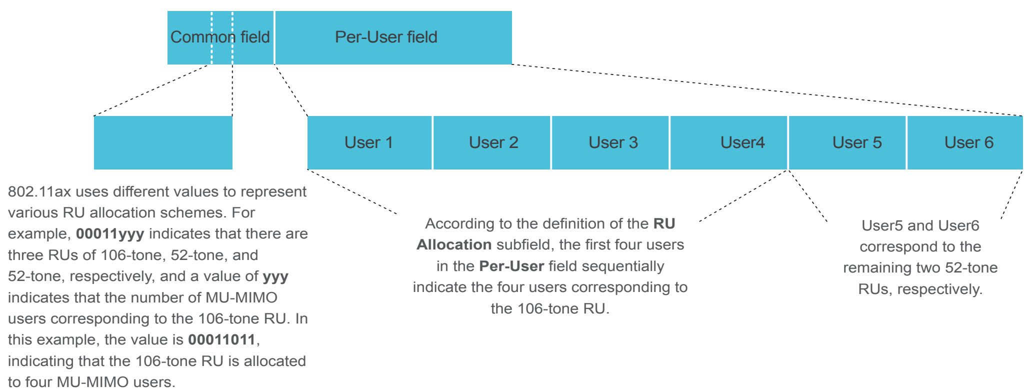
* **RU#2 and RU#3 are 52-tone and are respectively sent to two 3x3 STAs.**

* **RU#1 is 106-tone, and is subdivided into MU-MIMO spatial flows that will be sent to four 1x1 mobile STAs.**



Such a delicate design further increases spectrum resource utilization, and provides more options for various complex high-density scenarios.

The HE-SIG-B field can also implement this complex combined packet.



802.11ax gives free rein to form various combinations of OFDMA and MU-MIMO, and can alternatively enable OFDMA transmission and MU-MIMO transmission separately. Combinations of OFDMA and MU-MIMO are not supported until 802.11ax Wave 2 due to its complexity.

• HE UL MU-MIMO

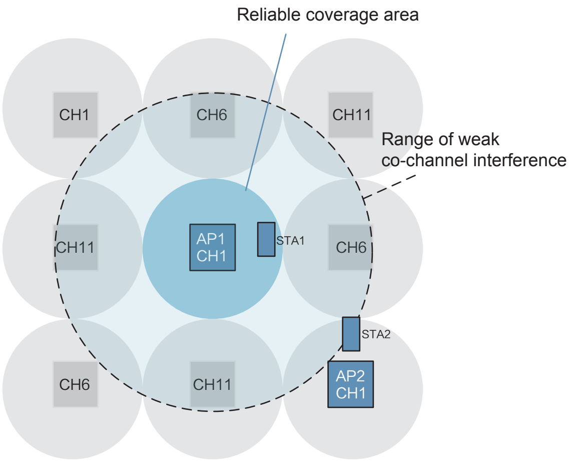
802.11ac supports only downlink MU-MIMO, and uplink ACK packets are sequentially sent, wasting resources. 802.11ax can implement UL MU-MIMO by using a trigger mechanism the same as that of UL OFDMA. For the principle of UL MU-MIMO, see the section "DL/UL OFDMA".

Notably, UL MU-MIMO can also be used in the cascading mode, to build an unprecedented communication mode jointly with the combination of OFDMA and MU-MIMO, enabling flexible control and scheduling capabilities for Wi-Fi networks.

• Spatial Reuse

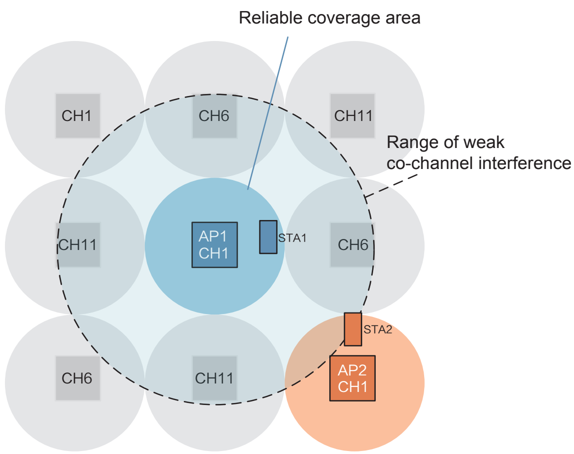
The SR technology reduces co-channel interference between multiple devices, and increases high-density deployment efficiency in the entire network.

In a conventional 802.11ac network, multiple co-channel devices cause much contention and backoff. As shown in the figure on the right, AP1 and AP2 share channel 1. AP1 may still cause co-channel interference to AP2 even if network optimization is performed to adjust the coverage. Consequently, AP2 and STA2 need to wait during communication between AP1 and STA1.



In 802.11ax, the BSS Color field is added to the PHY header of a packet, so that all other STAs identify the “color” of the current packet in an early packet sending stage. If the packet and the STA have the same color, the packet is related to the STA; otherwise, the packet is unrelated to the STA.

As shown in the following figure, AP1 and STA1 are marked as blue, and AP2 and STA2 are marked as orange. When AP1 communicates with STA1, a packet with weak signal strength is received by STA2 and AP2. When STA2 and AP2 determine that the color of the packet is different from their own colors and the signal strength of the packet is lower than the threshold, STA2 and AP2 continue with communication and do not need to wait for the AP1's packet transmission to end. In this case, the interference caused by AP1 is weak, and the signal between AP2 and STA2 has an acceptable signal-to-noise ratio. Therefore, AP2 and STA2 can properly demodulate packets.



Wi-Fi protocols before 802.11ax all use the clear channel assessment (CCA) threshold to determine whether a channel is busy, thereby determining whether packets can be sent. 802.11 protocols define the following thresholds:

* **Carrier sense CCA threshold: The preamble of a packet is detected during carrier sense, to determine the packet start boundary and calculate the signal strength. When the signal strength is greater than this threshold, it is determined that the channel is busy. This threshold is set to –82 dBm.**

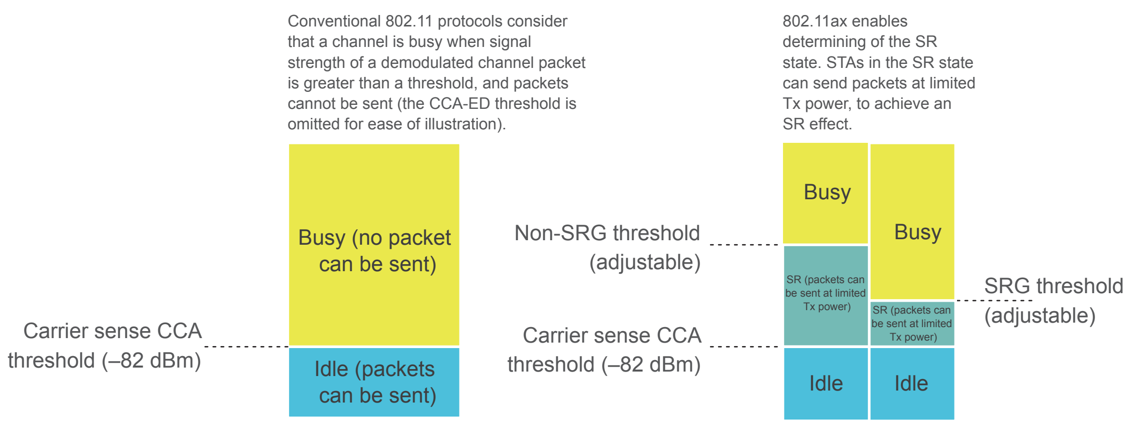
* **Clear channel assessment-energy detection (CCA-ED) threshold: A packet boundary cannot be identified by performing integral energy calculation on a received signal. However, signal strength of a data segment and that of a heterogeneous network (for example, microwave and Bluetooth) can be identified. This threshold is set to –62 dBm.**

In addition to adding the BSS Color field to the PHY header to indicate the packet "color", 802.11ax adds signal strength determining thresholds for packets of the same color and those of different colors, to implement the SR.

* **Non-spatial reuse group (non-SRG) overlapping basic service set (OBSS) packet detect (PD) level: Indicates the SR signal threshold for non-SRG (different-color) packets. A value ranges from –82 dBm to –62 dBm. A STA calculates the signal strength of the packet preamble. If the signal strength is lower than the threshold, an SR operation can be performed, and other STAs can send packets at limited transmit power.**

* **SRG OBSS PD level: Indicates the SR signal threshold for SRG packets. A value ranges from –82 dBm to –62 dBm. An AP can send packets to instruct an STA to perform further adjustment within this range. In this way, when the STA sends SRG packets with signal strength lower than this threshold, other STAs can send packets at limited transmit power. network (for example, microwave and Bluetooth) can be identified. This threshold is set to –62 dBm.**

As shown in the following figure, 802.11ax adds two thresholds. The yellow part indicates the added threshold range in which packets can be sent in the SR state. SR resources and communication efficiency on the entire network are increased.



However, the SR mechanism has its own disadvantage. If the SR threshold is improper, excessive interference occurs between packets, affecting signal demodulation. Therefore, in different scenarios and deployment conditions, a proper algorithm is required to support SR parameter adjustment. A device vendor is given more flexibility but is technically challenged.

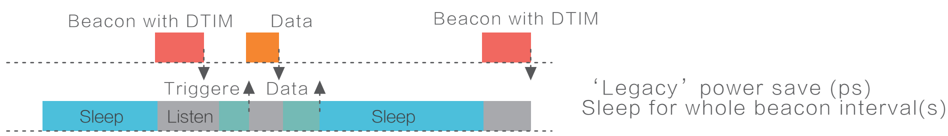
• IoT Promotion

Internet of Things (IoT) has been widely applied to various aspects in the society. Some new 802.11ax features provide help and promotion in IoT scenarios.

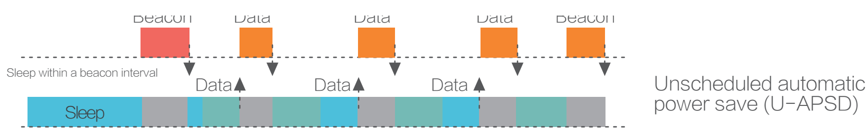
Power Saving by TWT

A main objective of 802.11ax is to improve performance while maintaining or reducing power consumption. With IoT development, power consumption is as important as network performance. 802.11ax inherits some power saving mechanisms formulated in previous 802.11 protocols.

The legacy PS power saving mechanism was first supported in 802.11b, and is applied to all Wi-Fi devices. An STA can enter sleep state at an interval of one or more beacons. An awake STA can send uplink packets, and also can listen to the delivery traffic indication map (DTIM) field of beacons to learn whether there are downlink packets to receive. If yes, the STA can send a trigger packet to obtain the downlink packets. This mechanism is verified to be effective but with limited power saving effect, and an STA usually needs to be wakened up multiple times in one second to read the DTIM field.

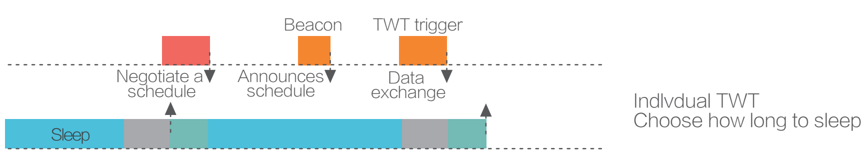


Afterwards, the unscheduled automatic power-save delivery (U-APSD) technology was introduced in 802.11e, to meet power saving requirements of voice-over-Wi-Fi devices. Voice devices usually need to transmit packets at a fixed short interval (for example, 20 ms). U-APSD allows devices to enter sleep state and transmit packets multiple times in one beacon period. Moreover, considering the peering feature of voice communication, U-APSD designs the mechanism of triggering downlink sending via uplink packets.



802.11ax introduces the target wakeup time (TWT) power saving mechanism, to enable more flexibility, longer power saving periods, and sleep scheduling of multiple devices.

TWT allows an AP and a STA to separately negotiate sleep and communication periods, which are usually intervals exceeding several beacon periods and may reach minutes or even hours or days. When the negotiated wakeup moment arrives, the STA awakes and waits for the trigger packet from the AP, and then exchanges data and finally enters sleep state. Because the AP separately negotiates with each STA, the AP can combine or split sleep periods of the STA based on the STA's status, to achieve the optimal communication efficiency.



In addition to the TWT mechanism, 802.11ax enables other improvements, which also contribute to power saving performance of an STA.

* **A bit indicating uplink/downlink is added to the initial preamble of a packet. Generally, a STA only needs to receive downlink packets from an AP in a Wi-Fi network (infrastructure BSS). With this uplink/downlink identifier in the preamble, the STA can avoid receiving a large number of uplink packets from other STAs, thereby saving power. Assuming that a ratio of downlink packets to uplink packets is 2:1, the STA enables power saving in 1/3 of the packet communication time.**

* **A flag bit is also reserved for the BSS Color field in the preamble, and based on this bit, the STA can determine whether a downlink packet is destined for the communication group of the STA and ignore packets from other WLANs. In high-density multi-BSS networks, receiving processing can be significantly decreased, thereby reducing power consumption.**

* **The 20 MHz only feature makes Wi-Fi chips of IoT devices more compact and consume less power.**

20MHz Only Clients

In the IoT era, 802.11ax needs to provide more support for IoT devices. Chip costs decrease due to large shipments of Wi-Fi chips. However, a Wi-Fi chip is much more complex than a Bluetooth or Zigbee chip, and is less cost-competitive for IoT applications. Besides, the complex chip causes high power consumption.

In 802.11ax, TWT is expected to decrease the power consumption to a level the same as those of other IoT communication technologies. However, the complex Wi-Fi chip is still disadvantageous to low-cost IoT applications. Therefore, 802.11ax supports 20 MHz only non-AP HE STAs. Such STAs can operate only in the primary 20 MHz band in the 2.4 GHz or 5 GHz band, and support other mandatory features of 802.11ax, such as OFDMA. These STAs can perform communication in narrower RUs via OFDMA to ensure stability.

As guaranteed by 802.11ax, the AP can detect 20 MHz only devices, and ensure guaranteed communication and proper resource scheduling for these IoT devices.

Outdoor Communication Enhancement

Some new technical features in 802.11ax can enhance outdoor communication and IoT reliability.

* **The new packet format HE Extended Range PPDU is specifically designed for long-range transmission. Packets can be sent only in the primary 20 MHz band by using only one spatial flow and any of MSC 0 to MCS 2. The signal strength of the preamble is increased by 3 dB, to ensure normal signal demodulation in long-range communication.**

* **When a long GI and a 4 x LTF are used, a GI between elements can be increased from 0.8 μs to 3.2 μs to reduce interference, and a length of the LTF field in the preamble can be increased to enhance reliability.The 20 MHz only feature makes Wi-Fi chips of IoT devices more compact and consume less power.**

* **Dual sub-carrier modulation (DCM) doubles subcarriers to carry the same information, thereby enhancing reliability via information redundancy.**

* **In addition, in low-channel width IoT scenarios, small-size RUs of OFDMA are used to transmit data, and can be used jointly with proper algorithm-based scheduling to effectively avoid narrow-band spatial interference and enhance transmission reliability.**

Anylysis of Typical Scenarios

• Multi-user File Transfer

Multi-user file download plays an important role in high-density office and classroom scenarios that focus on the maximum throughput indicator.

The following simulates and analyzes the 802.11ax performance in these scenarios.

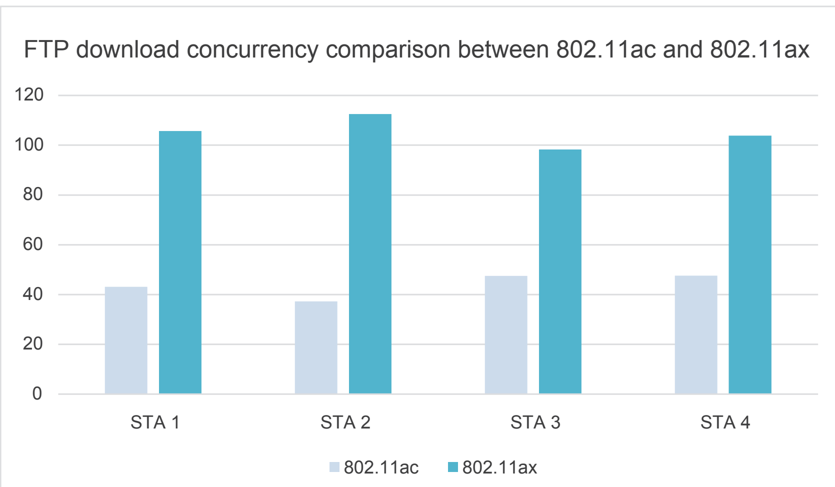
Sending Mode	Number of Concurrent Users	MCS	Single-user Maximum Throughput (Mbps)	Total Throughput (Mbps)	Total Throughput Increased By (%)
11ac/SU	n	9	345.32	345.32	0
11ax/SU	1	11	451.50	451.50	30.75%
11ax/RU484	2	11	238.25	495.11	43.38%
11ax/RU242	4	11	125.26	510.99	47.97%
11ax/RU106	13	9	43.46	397.05	14.98%
11ax/RU52	21	9	20.22	374.12	8.34%
11ax/RU26	37	9	9.87	365.09	5.73%

Analysis of maximum throughputs under different subcarrier channel width allocation schemes of 802.11ax OFDMA

In multi-user file download scenarios, when OFDMA supports less than or equal to four concurrent users, each user can be assigned with relatively large channel width. 802.11ax specifies that MCS 11 can be used for transmission at this channel width, so that 802.11ax increases the system throughput by 30% compared with 802.11ac.

When there are more than four concurrent users, OFDMA subcarrier channel width allocated to each user can be any one or a combination of a 106-tone RU, a 52-tone RU, and a 26-tone RU. 802.11ax specifies that a maximum of the rate of MCS 9 is supported for transmission at this channel width. However, as overheads of pilot and empty subcarriers increase, channel width utilization in this scenario decreases.

Recent experiments show that 802.11ax enables transmission performance twice that of 802.11ac in the scenarios with four concurrent users. Therefore, 802.11ax greatly improves user experience in application scenarios of office file transfer, 4K videos, and cloud desktop.



• Multi-user Web Page Browsing

Web page browsing is another important application among common network applications. This type of service is characterized by small packets. Similar applications include WeChat and voice communication applications.

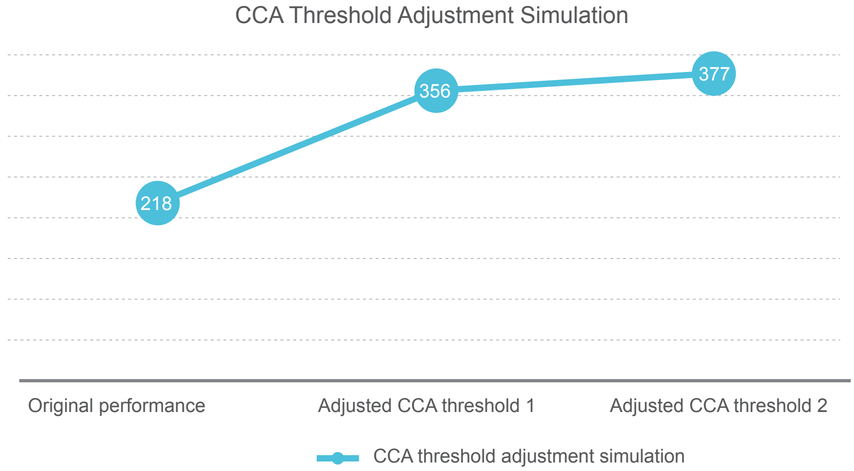
It is assumed that multiple users synchronously send 512-byte packets, and a polling algorithm is used for user scheduling without the consideration of user conflicts.

Sending Mode	Number of Concurrent Users	MCS	Single-user Throughput (Mbps)	Total Throughput (Mbps)	Total Throughput Increased By (%)
802.11ac/SU	n	9	12.45	12.45	0
802.11ax/SU	1	11	12.34	12.34	–0.88%
802.11ax/RU 484	2	11	11.03	22.06	77.19%
802.11ax/RU 242	4	11	10.18	40.71	227.05%
802.11ax/RU 106	8	9	8.45	67.61	443.14%
802.11ax/RU 52	16	9	6.37	101.89	718.52%
802.11ax/RU 26	37	9	4.20	155.38	1148.18%

According to the preceding table, the OFDMA concurrency function can effectively reduce multi-user air-interface overheads in scenarios of transmitting 512-byte packets. In particular, OFDMA can increase the total throughput by 1148% when there are 37 concurrent users. In consideration of actual air-interface environments, channel quality of certain OFDMA users deteriorates, and the total throughput increase may not reach 1148%. However, the total throughput can be increased by at least 34.93% provided that the number of users without channel quality deterioration is greater than or equal to 4, and by 4.4 times provided that the number is greater than or equal to 16.

• Networking Performance

Simulating the OBSS_PD threshold via the CCA threshold can preliminarily estimate a possible gain generated by the OBSS_PD threshold. In the simulation experiment, two BSSs are respectively associated with two STAs. The network-wide performance under different thresholds is compared. The experiment shows that a 70% gain on average is brought by adjusting the CCA threshold. The performance gain in actual scenarios ranges from 20% to 70% due to STA differences and networking scale differences.



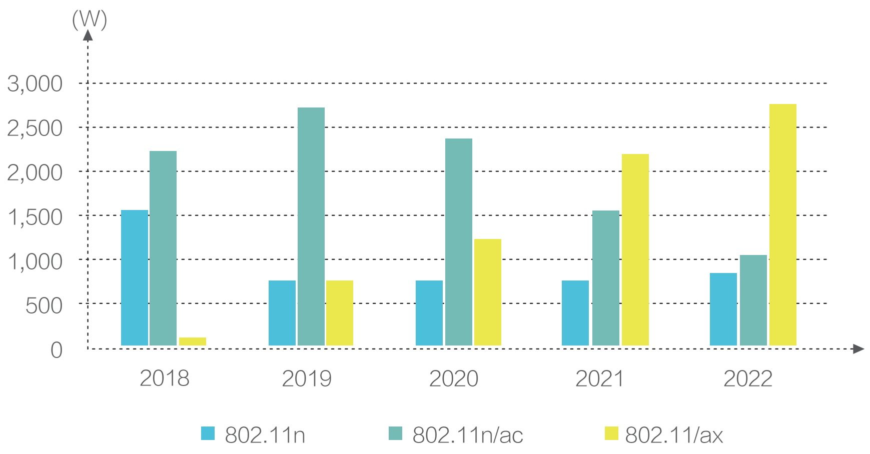
According to the experiment, it is found that the threshold adjustment is like a double-edged sword, and improper adjustment may decrease the performance gain. How to effectively adjust network-wide parameters becomes an important subject for vendors in complex actual network deployment.

Conclusion

As the sixth generation of the Wi-Fi protocol, 802.11ax will be an exciting wireless technology innovation. It not only brings faster and more efficient wireless networks, but also provides stronger support for more business models and application scenarios, such as:

* **High-reliability office/production network scenarios**
* **IoT application scenarios**
* **Real-time high-throughput applications, for example, enterprise-class 4K/8K videos and AR/VR applications**
* **High-density concurrency application scenarios, for example, campuses, stations, and shopping malls**

Same as its precedents, 802.11ax is built on the prior art and is backward compatible. The continuous growth of 802.11ax devices is accompanied with more significant performance gains in 802.11ax network deployment. It can be forecast from the shipment of IDC chips that, the total shipment of 802.11ax STAs will exceed that of 802.11ac STAs in 2021. Therefore, 802.11ax will definitely be the mainstream Wi-Fi technology in the next five years.



Different from its precedents, 802.11ax does not merely consider the optimal performance in ideal conditions, but focuses on improvements to issues in actual scenarios, for example, technologies such as OFDMA, SR, and TWT. 802.11ax enables the AP to have a stronger control capability, but also imposes higher technical requirements for vendors. In combination with big data and AI intelligent algorithm optimization, Wi-Fi 6 will bring brand-new ultimate user experience.

Appendix

1. Comparison among rate-related parameters of three Wi-Fi generations.

	802.11n	802.11ac	802.11ax
Frequency channel width (MHz)	20, 40	20, 40, 80, 80+80, 160	20, 40, 80, 80+80, 160
OFDM subcarrier channel width (kHz)	312.5	312.5	78.125
Element duration (μs)	3.2	3.2	12.8
GI (μs)	0.8	0.4, 0.8	0.8, 1.6, 3.2
Maximum number of flows	3x3	4x4	8x8
MU-MIMO	N/A	Downlink	Downlink, uplink
Modulation mode	OFDM	OFDM	OFDM, OFDMA
Subcarrier modulation scheme	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM
Coding scheme	BCC (mandatory) LDPC (optional)	BCC (mandatory) LDPC (optional)	BCC (mandatory) LDPC (mandatory)

2. Rates in 802.11ax and 802.11ac under 1x1 spatial flow

Mddulation and coding schemes for single spatial stream

MCS index[a]	Modulation type	Coding rate	Data rate (in Mb/s) [b]							
			20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
			1600 ns GI[c]	800 ns GI	1600 ns GI	800 ns GI	1600 ns GI	800 ns GI	1600 ns GI	800 ns GI
0	BPSK	1/2	8	8.6	16	17.2	34	36.0	68	72
1	QPSK	1/2	16	17.2	33	34.4	68	72.1	136	144
2	QPSK	3/4	24	25.8	49	51.6	102	108.1	204	216
3	16-QAM	1/2	33	34.4	65	68.8	136	144.1	272	282
4	16-QAM	3/4	49	51.6	98	103.2	204	216.2	408	432
5	64-QAM	2/3	65	68.8	130	137.6	272	288.2	544	576
6	64-QAM	3/4	73	77.4	146	154.9	306	324.4	613	649
7	64-QAM	5/6	81	86.0	163	172.1	340	360.3	681	721
8	256-QAM	3/4	98	103.2	195	206.5	408	432.4	817	865
9	256-QAM	5/6	108	114.7	217	229.4	453	480.4	907	961
10	1024-QAM	3/4	122	129.0	244	258.1	510	540.4	1021	1081
11	1024-QAM	5/6	135	143.4	271	286.8	567	600.5	1134	1201

Mddulation and coding schemes

MCS index[a]	Spatial Streams	Modulation type	Coding rate	Data rate (in Mbit/s)[15][b]							
				20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
				800 ns.GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	1	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	68
1	1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	1	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	1	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	1	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	1	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	1	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	1	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	1	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	1	256-QAM	5/6	N/A	N/A	180	200	390	433.3	780	866.7

3. Maximum link rates of 802.11ax APs at various channel widths under different numbers of spatial flows (calculated based on 0.8 μs GIs)

Spatial Flow	Maximum Link Rate (Mbps, under 0.8 μs GIs)			
	20 MHz	40 MHz	80 MHz	160 MHz
1x1	143.4	286.8	600.5	1201.0
2x2	286.8	573.5	1201.0	2401.9
4x4	573.5	1147.1	2401.9	4803.9
8x8	1147.1	2294.1	4803.9	9607.8