HUAWEI

whitepaper

802.11ac Wave 2 Technology White Paper

WLAN 802.11ac Wave 2 Technology White Paper

Keywords: 802.11ac, Wave 1, Wave 2, 160 MHz, MU-MIMO

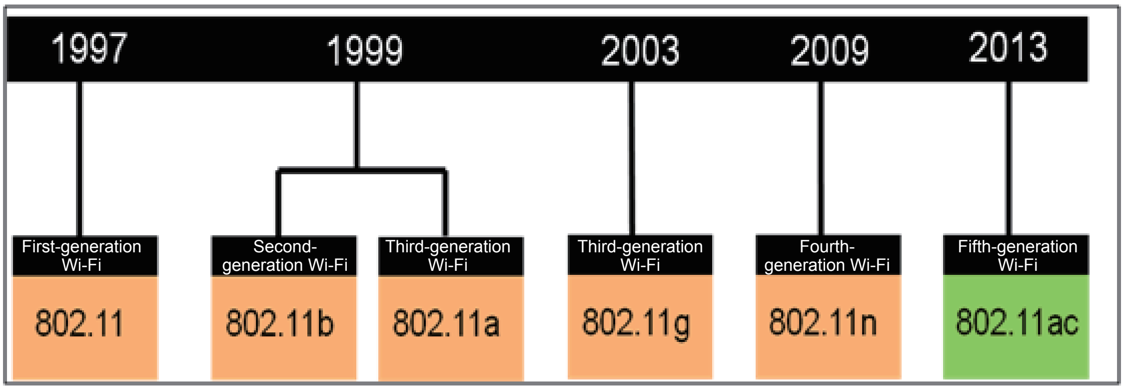
Abstract: Since the first-generation 802.11 standards were released in 1997, Wi-Fi has achieved great developments and has become popular in the past 19 years. Nowadays, 802.11ac is released, greatly promoting the development of 802.11 standards. 802.11ac is coming to market in two releases: Wave 1 and Wave 2. This document describes 802.11 Wave 2 and key features of 802.11ac Wave 2.

Acronyms and Abbreviations

Abbreviation	Full Name
IEEE	Institute of Electrical and Electronics Engineers
TxBF	Tx Beamforming
STA	Station
AP	Access Point
WFA	Wi–Fi Alliance
MIMO	multiple–input multiple–output

1 Background of 802.11ac

Since the first-generation 802.11 standards were released in 1997, Wi-Fi has achieved great developments and has become popular in the past 19 years. Nowadays, Wi-Fi becomes the first choice for an increasing number of users to access the Internet, and tends to replace the wired access. To meet requirements of new service applications and reduce the gap with wired network bandwidth, each generation of 802.11 standards among four generations of Wi-Fi systems (801.11, 802.11b, 802.11a/g, and 802.11n) greatly improves the Wi-Fi rate. In the fifth-generation 802.11 standards, the Wi-Fi rate improvement is undoubtedly a highlight in industry.



The wired Ethernet and applications drive 802.11ac development. As wired Ethernet GE access gradually becomes the mainstream, Wi-Fi needs to provide good user and service experience. In practice, 802.11n products face the following challenges:

1.Large-bandwidth application

Large-bandwidth applications are widely used in the Wi-Fi field:

(1)Apple iClound service synchronization

(2)Youtube video services

(3)Vine (Twitter) video shooting and sharing application services

(4)Video conference services transferred from fixed devices to mobile devices

(5)Video services for product and solution promotion by more and more enterprises

(6)...

These applications require higher Wi-Fi bandwidth. As predicted by Ericsson, video traffic on mobile networks will increase by 60% every year until the end of 2018. In 2018, video traffic will account for half of global mobile data traffic.

2.Access from a large number of STAs

(1)Facing the BYOD development trend, an employee may have two or more Wi-Fi STAs, each of which consumes network resources.

(2)In football fields, new product release conferences, or classrooms, concurrent access from a large number of users poses a great challenge to 802.11n products.

(3)As there is more wireless access and fewer wired access, an increasing number of STAs use Wi-Fi.

3.3G/4G offload

In the case of an explosive increase of data services in the cellular system, more traffic is offloaded to Wi-Fi networks to reduce the load of the cellular system. Wi-Fi shoulders the crossbeam as an "N" network. Wi-Fi networks are required to provide larger capacity and access for more users.

To meet the preceding requirements, the fifth-generation 802.11 standard (802.11ac) is developed. 802.11ac is innovated in a large number of technologies. It will take a long time to release Wi-Fi products using all these technologies to the market. Therefore, the Wi-Fi Alliance (WFA) defines 802.11ac into two releases to release it to the market: Wave 1 and Wave 2. This not only facilitates introduction of 802.11ac technology to the market, meeting the rapidly increasing traffic requirements, but also supports the evolution of 802.11ac technology, ensuring Wi-Fi competitiveness.

This document describes 802.11ac Wave 2 technology. For details about 802.11ac technology , see *WLAN 802.11ac Technology White Paper.*

2 What is 802.11ac Wave 2?

Wave 1 and Wave 2 are two phases of the 802.11ac standard that are defined by the WFA to release the 802.11ac standard to the market. Before introducing 802.11ac Wave 2, the following describes 802.11ac technology.

2.1 802.11ac and 802.11n

To better understand 802.11ac, 802.11ac is compared with 802.11a that works in the same frequency bands and 802.11n. The following table compares 802.11a, 802.11n, and 802.11a.

Feature	802.11a	802.11n	802.11ac
Channel width	20 MHz	20 MHz	20/40/80 MHz
		40 MHz (option)	160 and 80+80 MHz (option)
OFDM	Y	Y	Y
SGI	N	Y	Y
MIMO	Single antenna	SU–MMO Up to 4 antennas	Single–user multiple–input multiple–output (SU–MIMO) and multi–user multiple–input multiple–output (MU–MIMO) Up to 8 antennas
Preamble	Legacy	Mixed Format (MF)	Mixed Format (MF) only
		Green Field (GF)	
Modulation and coding schemes	Expressed as rates	76 MCS	9 MCS
Beamforming (option)	NA	Staggered and NDP	NDP
Feedback format	NA	Compressed and non–compressed V matrix	Compressed V matrix
Link adaptation	N	Y	Y
Coding	BCC	BCC/LDPC (option)	BCC/LDPC (option)
Media Access Control (MAC)	CSMA/CA	CSMA/CA	CSMA/CA
QoS (802.11E)	4 access categories TXOP support	4 access categories TXOP support	4 access categories TXOP support
MAC protection	RTS/CTS	RTS/CTS spoofing	RTS/CTS spoofing
TXOP sharing	NA	NA	Support for MU–MIMO
Static/Dynamic BA operation	NA	N	Y
MSDU	2304B	2304B or 7920B	2304B or 7920B
MPDU	3895B	3895B or 7991B	3895B, 7991B, or 11454B
A–MSDU	N	3839B or 7396B	3839B or 7396B
A–MPDU	N	65 KB	1 MB
MAC protocol data unit	MPDU only	MPDU or A–MPDU	A–MPDU only

At the PHY and MAC address layers, 802.11ac optimizes channel bandwidth, MIMO, and modulation mode, and improves or uses new technologies. 802.11ac architecture is the same as 802.11n architecture. That is, 802.11ac is evolved from 802.11n

802.11ac provides the maximum throughput of 6.93 Gbit/s, which is almost 11 times the maximum throughput of 802.11n. Initially launched 802.11ac Wave 1 products provide the maximum throughput of up to 1.3 Gbit/s, meeting expectations for Gbit/s Wi-Fi networks. In addition to the great increase of the maximum throughput, 802.11ac also enhances the concurrent user access capability. 802.11ac improves channel management when multiple bandwidth values are used and enhances compatibility with 802.11a and 802.11n.

2.2 Wave 1 and Wave 2

802.11ac Wave 1 products start to enter the market in 2013. 802.11ac Wave 1 is supported and used widely by USB terminals, household wireless routers, APs used by enterprises and carriers, as well as smart STAs. Various types of STAs and devices supporting 802.11ac Wave 2 have come into the markets since 2015. The following table lists differences between 802.11ac Wave 1 and Wave 2 defined by WFA and the IEEE 802.11ac standard.

Item	802.11ac Wave1 (WFA)	802.11ac Wave 2 (WFA)	802.11ac (IEEE)
Band	5 GHz	5 GHz	5 GHz
MIMO	Single User (SU)	Multi User (MU)	Multi User (MU)
Channel width	20, 40, and 80 MHz	20, 40, 80, 80–80, and 160 MHz	20, 40, 80, 80–80, and 160 MHz
Modulation	256QAM	256QAM	256QAM
Spatial streams	3	4	8
PHY rate	1.3 Gbps	3.47 Gbps	6.9 Gbps
MAC throughout*	845 Gbps	2.26 Gbps	4.49 Gbps

Note: The MAC throughput value is provided assuming that the MAC layer efficiency is 65%.

Compared with 802.11ac Wave 1, 802.11ac Wave 2 supports MU-MIMO that provides higher channel bandwidth and more MIMO streams. Therefore, 802.11ac Wave 2 provides higher user access capabilities, a more flexible bandwidth combination, and a higher throughput.

1.Supports MU-MIMO.

802.11ac Wave 1 supports only SU-MIMO, that is, an AP can communicate with only one user at a time. 802.11ac Wave 2 supports MU-MIMO, that is, an AP can concurrently communicate with multiple users. MU-MIMO increases the number of access STAs, meeting requirements for the access of a large number of STAs in the all Wi-Fi and Internet of Things (IoT) era when one user has multiple STAs.

2.Supports up to 160 MHz channel bandwidth (a combination of adjacent channels or two non-adjacent 80 MHz channels).

802.11ac Wave 1 supports a maximum of 80 MHz channel bandwidth, while 802.11ac Wave 2 supports up to 160 MHz channel bandwidth. The 160 MHz bandwidth can be the total bandwidth of a combination of adjacent channels or two non-adjacent 80 MHz channels. This increases the peak throughput and channel combination flexibility. When larger-bandwidth channels are configured, the usage of channels on the 5 GHz frequency band can also be improved.

3.Supports up to four MIMO spatial streams.

802.11 Wave 1 supports three MIMO spatial streams, while 802.11ac Wave 2 supports up to four MIMO spatial streams. The increase of MIMO spatial streams improves users' peak throughput or expands the coverage scope of a Wi-Fi network.

The increases of channel bandwidth and MIMO spatial streams improve the throughput of 802.11ac Wave 2 products. The peak throughput provided by 802.11ac Wave 2 products increases to 3.47 Gbit/s (4 MIMO spatial streams) from 1.3 Gbit/s (3 MIMO spatial streams) provided by 802.11ac Wave 1 products.

The preceding table also demonstrates that 802.11ac Wave 2 defined by the WFA is different from the 802.11ac standard defined by IEEE in the number of spatial streams. This is because costs (complexity) need to be considered when the standards are applied to products.

2.3 Products Supporting 802.11ac Wave 2

Various types of STAs and devices supporting 802.11ac Wave 2 have come into the markets since 2015. Currently, most smart STAs supporting 802.11ac Wave 2 run the Android operating system. 802.11ac Wave 2 is supported only by a few models of STAs running the Windows Phone operating system, while STAs running iOS do not support 802.11ac Wave 2 currently. The following table lists products (including laptops and smartphones) available in the market that support 802.11ac Wave 2.

Brand	Model	Type
Acer	Aspire E14, E14, R13, V13, V Nitro, Predator	Laptop
Dell	DW1820, Alienware13,15,17	Laptop
Fujistu	Arrows NX F-04G	Smartphone
HTC	One M8	Smartphone
LeTV	LeMAX, LePro1	Smartphone
Google	Nexus 5X	Smartphone
Microsoft/Nokia	Lumia 950XL, Lumia 950	Smartphone
Oppo/OnePlus	OnePlus 2	Smartphone
Samsung	Galaxy S5, Galaxy S6	Smartphone
TCL	Evoque (Aurora)	Smartphone
Xiaomi	Mi Note Pro (7 variants)	Laptop
Xiaomi	Mi 4i (9 variants), Mi 4C	Smartphone
ZTE	Nubia Z9 (7 variants), Axon (2 variants)	Smartphone

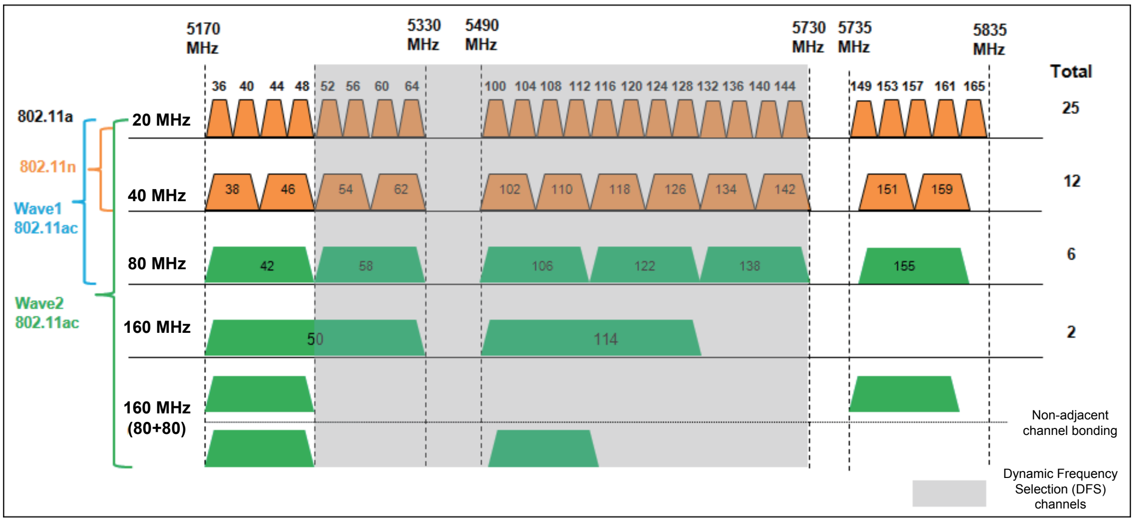
3 Key Features of 802.11ac Wave 2

802.11ac Wave 2 introduces two features: MU-MIMO and wider channel bonding.

3.1 Wider Channel Bonding

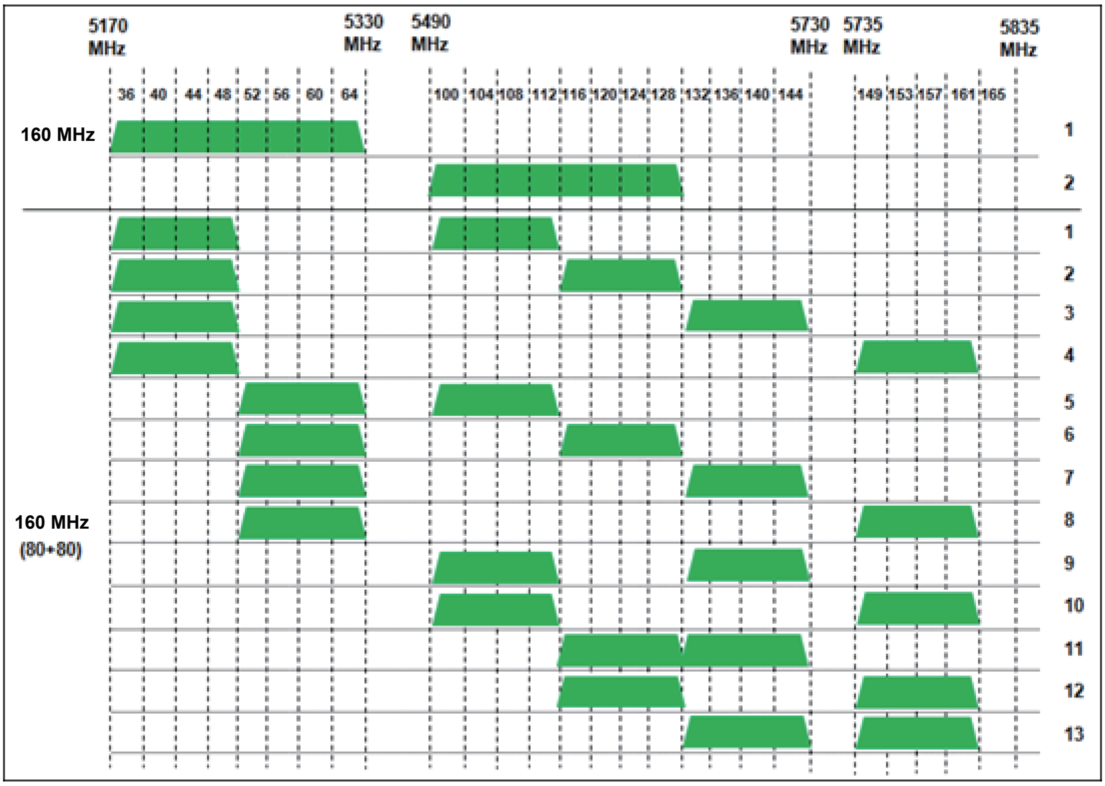
IEEE 802.11n supports only two bandwidth modes: 20 MHz and 40 MHz. The 20 MHz mode is mandatory while the 40 MHz mode is optional. IEEE 802.11ac supports 20 MHz, 40 MHz, 80 MHz, 80+80 MHz (non-adjacent), and 160 MHz channel bandwidth. The 20 MHz, 40 MHz, and 80 MHz modes are mandatory while the 80+80 MHz and 160 MHz modes are optional. 802.11ac Wave 1 defined by the WFA supports 20 MHz, 40 MHz, and 80 MHz channel bandwidth. 802.11ac Wave 2 defined by the WFA supports adjacent and non-adjacent 160 MHz channel bonding. Figure 3-1 uses the frequency spectrum in North America as an example to compare channel bonding in 802.11ac Wave 1, 802.11ac Wave 2, 802.11n, and 802.11a.

Figure 3-1Bandwidth in 802.11ac Wave 2



As shown in Figure 3-1, if the channel bandwidth is 20 MHz, 40 MHz, or 80 MHz, there are 25, 12, or 6 channels respectively. If the channel bandwidth is 160 MHz, there are two adjacent channels. The 160 MHz channel can be a combination of two non-overlapping 80 MHz channels. Channel bonding allows a flexible combination of channels. For example, to avoid the use of DFS channels, users can bind two non-DFS 80 MHz channels into a 160 MHz channel. In 80+80 MHz channel bonding mode, up to 13 bonding methods are supported.

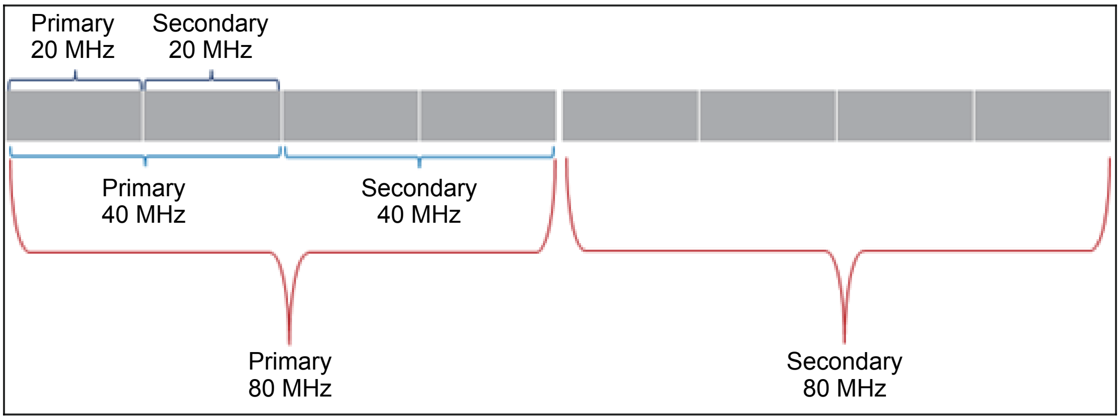
Figure 3-280+80 MHz channel combination in 802.11ac Wave 2



Wider channel bonding can provide wider channel bandwidth. Channel bonding helps avoid some interference and can improve the utilization of scattered channels.

Similar to HT20, HT40, and HT80 channels, an HT160 channel consists of one primary 80 MHz channel and one secondary 80 MHz channel. As shown in the following figure, an 80 MHz channel consists of one primary 40 MHz channel and one secondary 40 MHz channel, and a 40 MHz channel consists of one primary 20 MHz channel and one secondary 20 MHz channel.

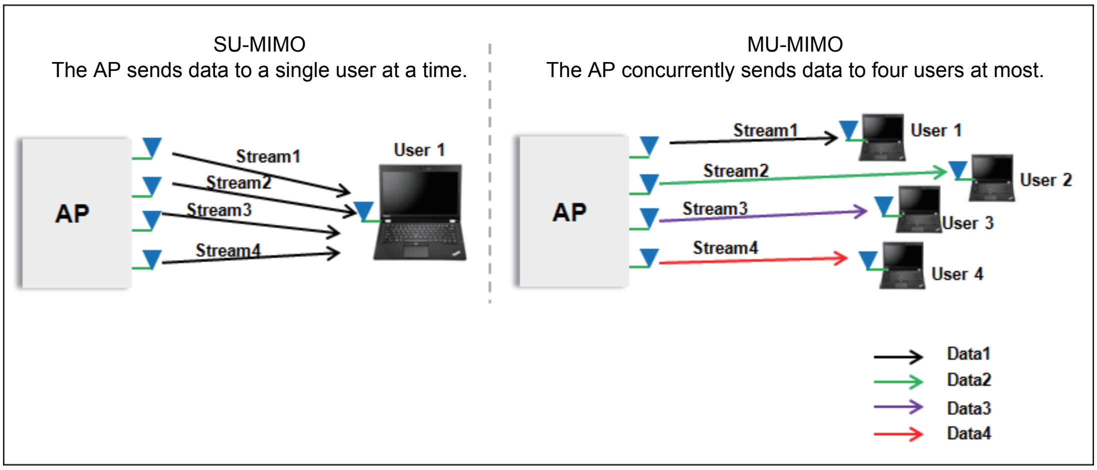
Figure 3-3HT160 channel in 802.11ac Wave 2



3.2 MU-MIMO

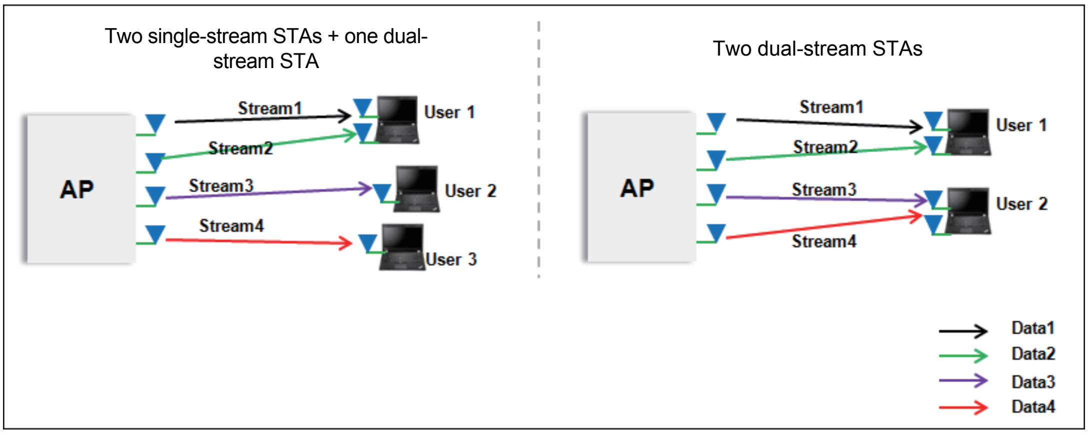
SU-MIMO can increase the throughput of a single user significantly. However, most STAs, especially mobile smart STAs, on live networks support one stream only. Compared with multi-stream STAs, single-stream STAs occupy air interfaces for a longer period when they transmit data of the same size. Therefore, single-stream STAs become a bottleneck for increasing the number of access users. MU-MIMO is a good solution to this problem. With the user bandwidth and frequency unchanged, an AP can concurrently transmit different data to four users at most. Figure 3-4 compares the SU-MIMO and MU-MIMO transmission modes of a 4x4 MIMO AP. In the SU-MIMO transmission mode, all antennas of the AP send the same data. Although this transmission mode provides diversity gains, the gains are limited. In the MU-MIMO transmission mode, antennas of the AP transmit different data to different users. A single AP can send four different data packets, increasing the efficiency by four times than that in single-MIMO transmission mode.

Figure 3-4Comparison between SU-MIMO and MU-MIMO



MU-MIMO is also applicable to scenarios where both multi-stream and single-stream STAs exist. For example, Figure 3-5 shows two application scenarios: one dual-stream STA + two single-stream STAs and two dual-stream STAs.

Figure 3-5Application scenarios where both multi-stream and single-stream STAs exist



MU-MIMO is an outstanding feature of 802.11ac Wave 2, which depends on explicit transmit beamforming (TxBF). This feature requires that STAs support explicit TxBF. The reason is that when an AP concurrently transmits data to multiple users over the same frequency, signals are interference to users who are not target receivers of the signals. MU-MIMO uses TxBF to detect channels and uses precoding technology based on the feedback to mitigate such interference.

Figure 3-6Communication between one 3x3 MIMO AP and three 1x1 MIMO STAs

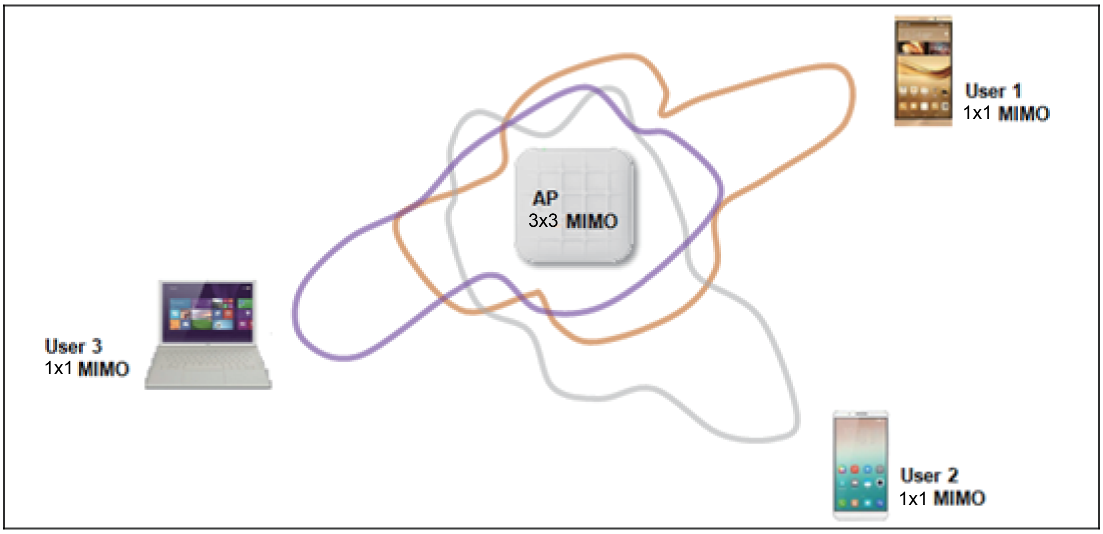


Figure 3-6 shows a MU-MIMO application scenario with one 3x3 MIMO AP and three 1x1 MIMO STAs. To obtain channel information about each STA, the AP sends a sounding frame to each STA. The STAs reply the AP with channel information. The AP uses precoding technology to implement beamforming to generate strong signals in the respective direction to each STA but weak signals in other directions (including directions to other STAs). In this way, the AP ensures good wireless coverage and mitigates interference to other users.

MU-MIMO applies to downlink transmission only and can concurrently transmit data to four users at most. In the uplink, data frames of a single user are transmitted one by one. If lengths of concurrently-transmitted frames are different, frame padding is used to adjust the frame lengths. The scheduled BA mechanism is used to schedule ACK responses from each user so that ACK responses are sent one by one.

MU-MIMO increases the number of concurrent users on a single AP, enhancing the concurrent user access capability. In single-stream STA scenarios especially, MU-MIMO improves the downlink throughput of APs significantly. In multi-user transmission, interference between streams limits the usage of higher-order modulation modes, for example, 256QAM.

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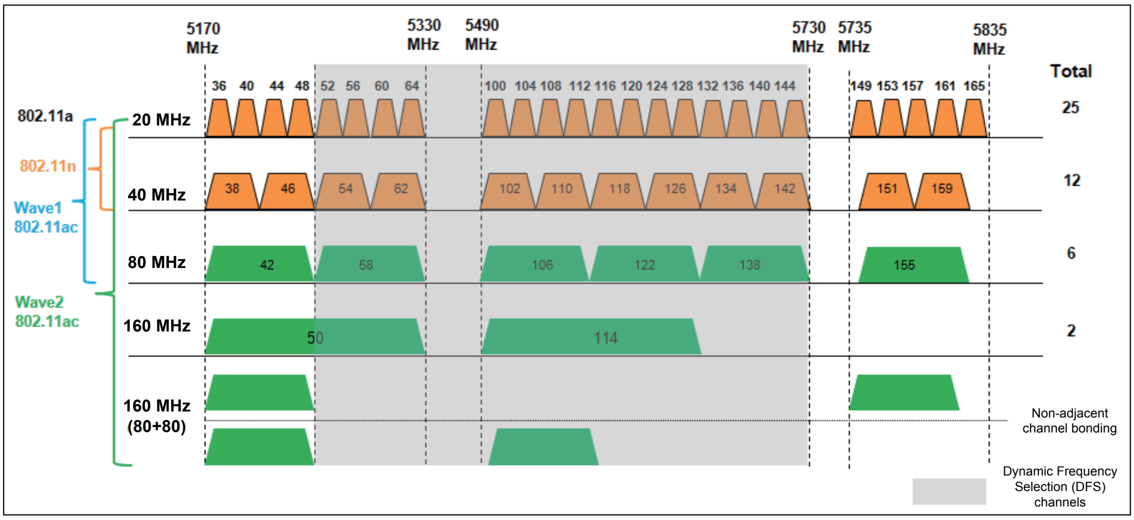

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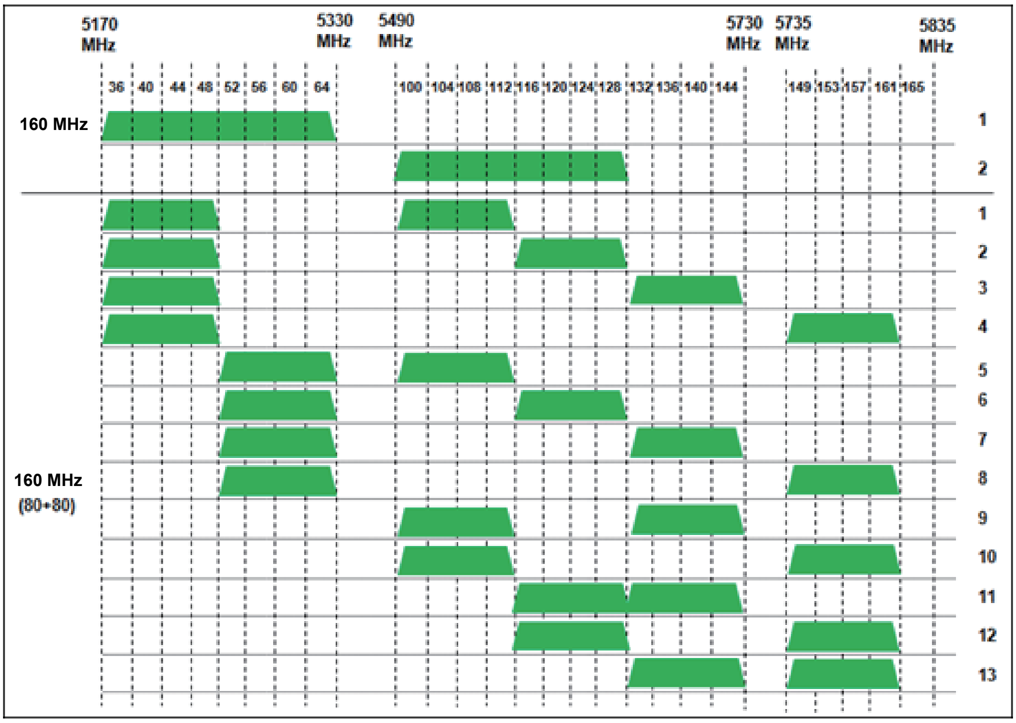

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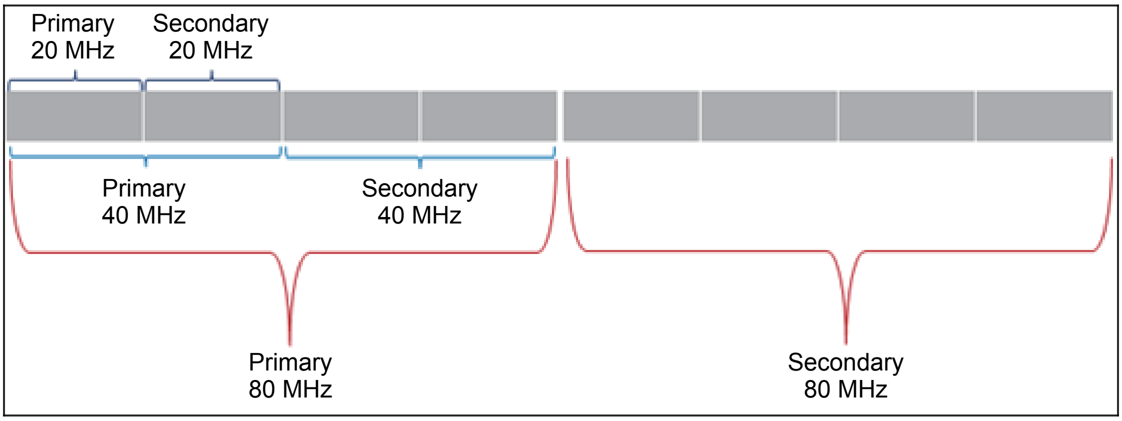

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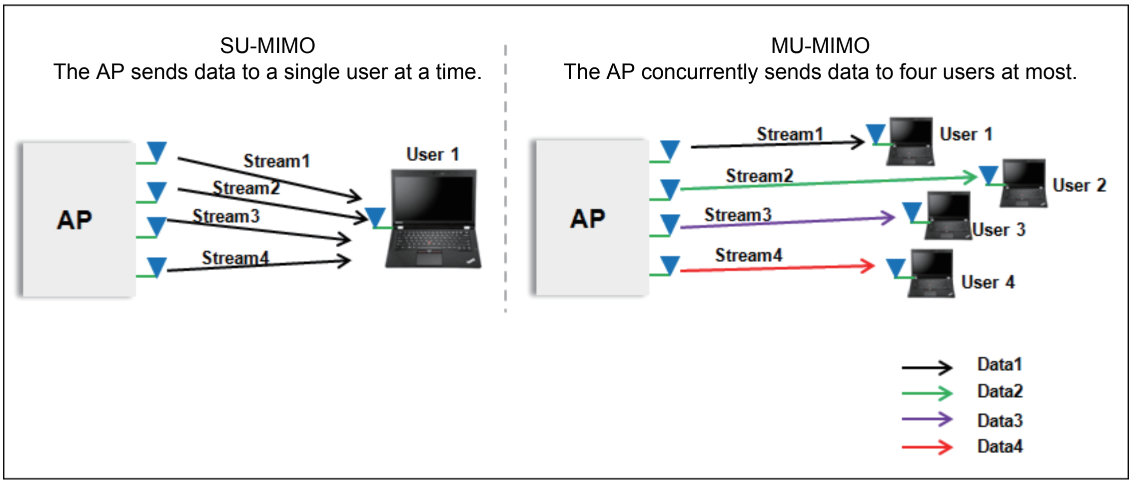

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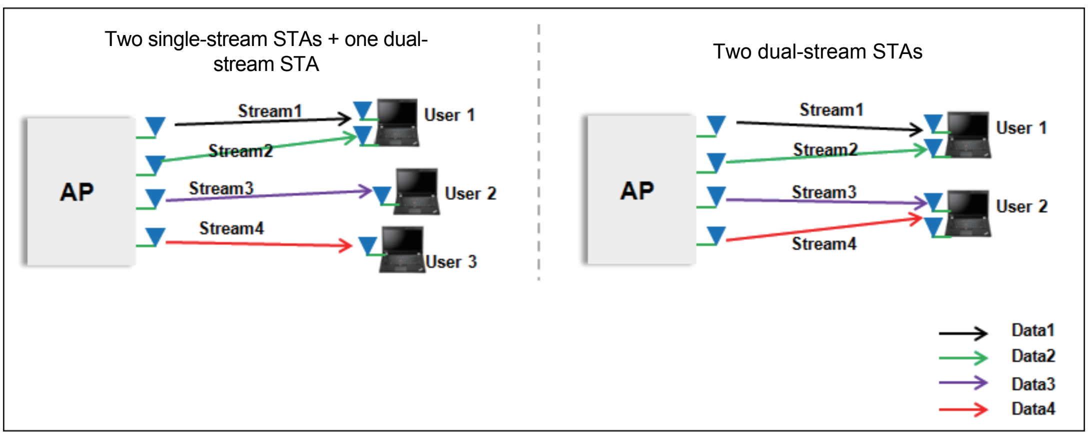

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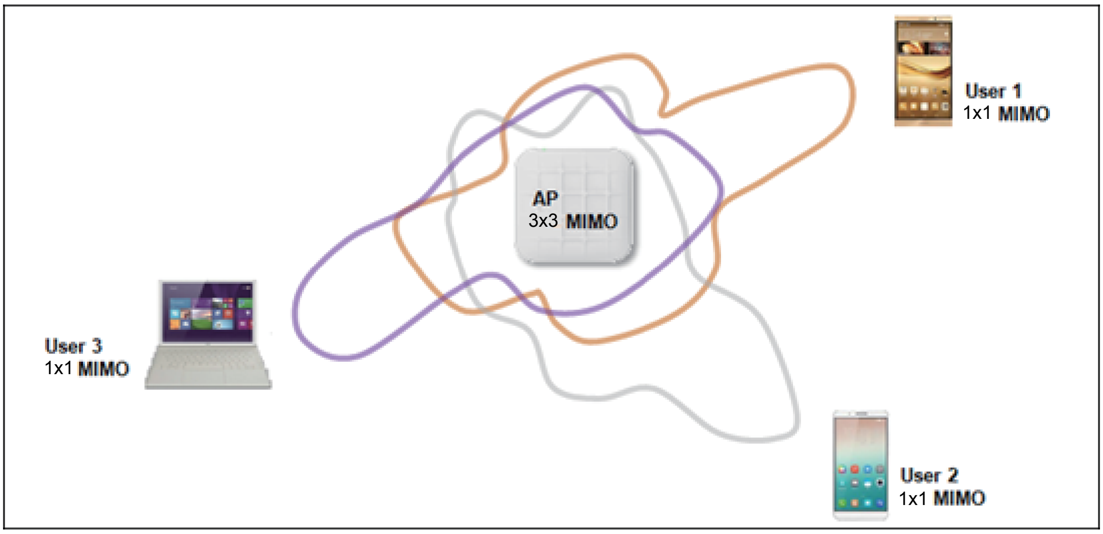

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4 Customer Benefits

In the second quarter of 2016, WFA Wave 2-certified products started to be launched to the market. Compared with earlier products, 802.11ac Wave 2 products significantly improve the air interface throughput and concurrent user access capability.

1.Higher throughput

High throughput has always been the goal of Wi-Fi standards. The throughput is being improved from the first-generation Wi-Fi standards to the latest-generation standards, as shown in the following table.

Standard	Channel Bandwidth	Max. Modulation	Max. Spatial Streams	Max. Data Rate
802.11	20 MHz	DQPSK	1	2 Mbps
802.11b	20 MHz	CCK	1	11 Mbps
802.11g	20 MHz	64QAM	1	54 Mbps
802.11a	20 MHz	64QAM	1	54 Mbps
802.11n	40 MHz	64QAM	4	600 Mbps
802.11ac Wave 1	80 MHz	256QAM	3	1.3 Gbps
802.11ac Wave 2	160 MHz	256QAM	4	3.47 Gbps

Higher throughput can meet the requirements of rapidly growing video services and data services. Moreover, higher throughput provides Wi-Fi networks with more advantages in competition with wired networks. This is a step toward achieving the goal of making Wi-Fi become the first choice for wireless access.

2.More access users

Although 802.11ac Wave 2 does not change the multiple access modes on Wi-Fi networks, it provides higher throughput and MU-MIMO, improving the user access capability. Higher rates lead to shorter air interface occupation duration of each user. In the same time period, an AP can allow access of more users. MU-MIMO also provides stronger concurrent access capability. An AP can concurrently transmit data to multiple users. In the all Wi-Fi and IoT era when one user has multiple STAs, stronger access capabilities can better meet the access requirements of a large number of STAs.

Figure 4-1One user with multiple STAs

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