Wi-Fi 6/E

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1. Introduction

1.1 History

A 1985 ruling by the U.S. Federal Communications Commission is Wi-Fi's origin. That releases the bands of the radio spectrum at 900 MHz, 2.4 GHz, and 5.8 GHz for unlicensed used by anyone. At that time, many people started to develop wireless networks and devices but without a common standard, products from different manufactures were rarely compatible. Eventually, it is until 1997 that IEEE creates a standard, IEEE 802.11. Even though IEEE makes the standard, it does not test products. Thus, in 1999, Wireless Ethernet Compatibility Alliance (WECA, changed named to Wi-Fi Alliance in 2000) is established. This non-profit organization helps the manufactures testing products to fit the standard and also check their security. Besides, purchasers can rely on their trademark to make sure equipment interoperation.

Figure 1 Trademark of Wi-Fi 6

1.2 The Evolution of Wi-Fi

Since Wi-Fi was first released in 1997, its standards have been continually evolving. The speeds and network/spectrum are faster and more efficiency for users.

Wi-Fi generations

Generation	IEEE standard	Maximum throughput	Adopted	Radio frequency GHZ
Wi-Fi *"0"**	802.11	2Mbit/s	1997	2.4
Wi-Fi *"1"**	802.11b	11Mbit/s	1999	2.4
Wi Fi *"2"**	802.11a	54Mbit/s	1999	5
Wi-Fi *"3"**	802.11g	54Mbit/s	2003	2.4
Wi-Fi 4	802.11n	600Mbit/s	2008	2.4/5
Wi-Fi 5	802.11ac	6.8Gbit/s	2014	5
Wi-Fi 6	802.11ax	10Gbit/s	2019	2.4/5
Wi-Fi 6E	802.11ax	10Gbit/s	2020	6
Wi-Fi 7	802.11be	46Gbit/s	2024	1–7.25 (2.4/5/6)

*non-official designation

Table 1 Wi-Fi Generations

Table 1 shows the evolution of Wi-Fi. From the table, 2.4GHz and 5GHz have developed for many years. Thus, the way to improving throughputs is not only increasing the radio frequency but also using other technologies. In the next part, I will introduce Wi-Fi 6 SPEC including hardware and software.

2. Wi-Fi SPEC

	Wi-Fi 5	Wi-Fi 6	Wi-Fi 6E
Operating bands	5 GHz	2.4 GHz, 5 GHz	6 GHz
Modulation scheme	OFDM	OFDMA	OFDMA
Channel width	20 MHz, 40 MHz, 80 MHz, 160 MHz	20 MHz, 40 MHz, 80 MHz, 160 MHz	20 MHz, 40 MHz, 80 MHz, 160 MHz
Highest modulation	256-QAM	1024-QAM	1024-QAM
MIMO streams	Up to 8x8	Up to 8x8	Up to 8x8
MU-MIMO	Downlink MU-MIMO	Downlink and Uplink-MU-MIMO	Downlink and Uplink-MU-MIMO
Target Wake Time (TWT)	No	Yes	Yes
BSS Coloring	No	Yes	Yes
Extended Range Improvements	No	Yes	Yes

Table 2 Wi-Fi Generation Comparison

From Table 2, we can compare differences between Wi-Fi 5 and Wi-Fi 6/6E. The first one is Frequency bands. Wi-Fi 5 uses only the 5 GHz band; Wi-Fi 6 uses 2.4 GHz and 5 GHz band; Wi-Fi 6E uses new band: 6 GHz. The second one is Modulation. Wi-Fi 5 is OFDM and Wi-Fi 6/6E is OFDMA. The third one is Channel bandwidth. All of them have 20MHz, 40MHz, 80MHz and 160MHz. The fourth one is High Modulation. Wi-Fi 6/6E moves from 256-QAM to 1024-QAM. The fifth one is MU-MIMO. Wi-Fi 5 only supports DL MU-MIMO. Wi-Fi 6/6E only supports DL and UL MU-MIMO. The last part is that Wi-Fi 6/6E supplies other service like BSS coloring, TWT and WPA3.

3. Technology Analysis

3.1 Frequency band 2.4 GHz, 5 GHz and 6 GHz (Wi-Fi 6E)

2.4 GHz:

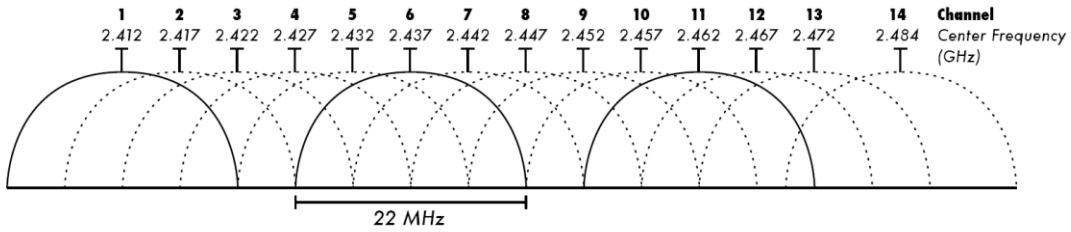

Figure 1 Channels on 2.4GHz Band

There are 14 channels on 2.4 GHz. First channel's central frequency is 2.412 GHz and every 5 MHz will be another channel. Each channel has an around 20MHz bandwidth so they overlap with others. Thus, it recommends using channel 1, 6 and 11. Other combinations (like Channel 2, 7 and 12) are also acceptable in some countries but in others channel 12, 13 and 14 are not allowed or have restrict conditions (For example, U.S.A). Nowadays, it has 40MHz bandwidth on 2.4 GHz but it will waste total bandwidth.

Advantage: Lower frequency can travel further than higher frequency. Besides, lots of IoT applications using 2.4 GHz band.

Disadvantage: Lower frequency has lower data rate than higher frequency. 2.4 GHz is too crowded that transmitting data might be slower.

5 GHz:

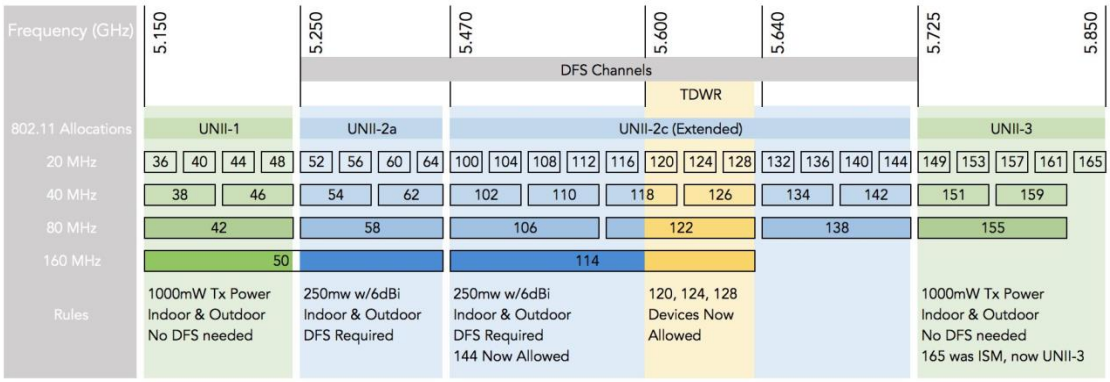

Figure 2 Channels on 5GHz Band

5 GHz provides 20 MHz, 40MHz, 80MHz and 160MHz bandwidths and there are much more channels on it. UNII-1 and UNII-3 are allowed using in most of countries. If someone wants to use UNII-2a and UNII-2b, he is asked to using DFS (Dynamic Frequency Selection). DFS make access points to switch to another channel if it detects weather or military radar on those channels. Moreover, in Europe, the Wi-Fi 5 routers are asked to have not only DFS but also TCP (Transmit Power Control). Otherwise, they are not allowed to be sold in Europe.

Advantage: 5 GHz provides more bandwidth than 2.4GHz. Furthermore, it supplies higher data rate.

Disadvantage: UNII-2a and UNII-2b overlap with military and weather radar. Besides, the travel distance is less than 2.4GHz.

6 GHz:

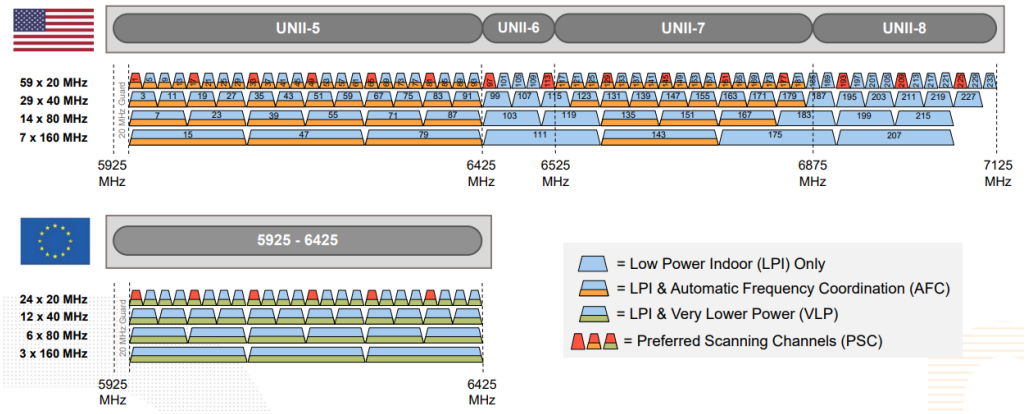

Figure 3 Channels on 6 GHz Band

6 GHz is new frequency band which is only supported by Wi-Fi 6E. Total bandwidth of 6 GHz supplies around 2.4 times wider than 5GHz. 6 GHz allows for up to seven 160 MHz channels. It is 2 kinds of rules for 6 GHz. One is from 5925 MHz to 7125 MHz in America and another is 5925 MHz and 6425 MHz in Europe.

Summary:

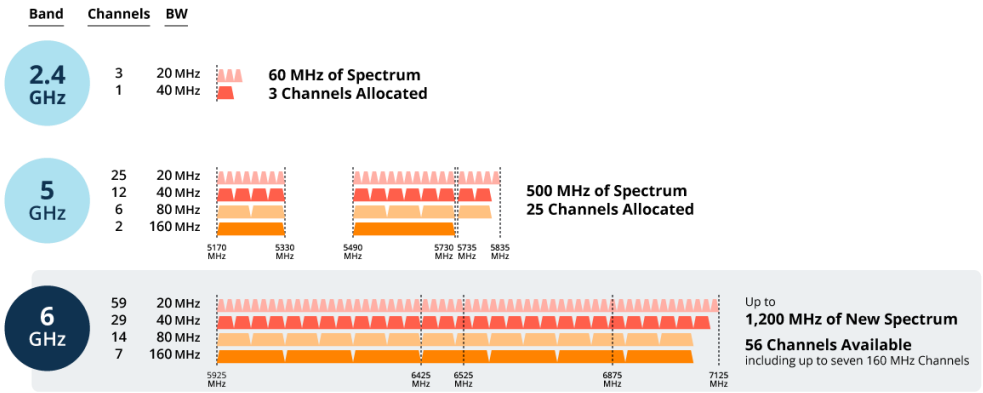

Figure 4 Comparison of frequency band

Total bandwidth on 2.4 GHz is 60MHz (3 channels); total bandwidth on 5 GHz is 500MHz with DFS (25 channels); total bandwidth on 6 GHz is 1200MHz (56 channels).

3.2 Modulation

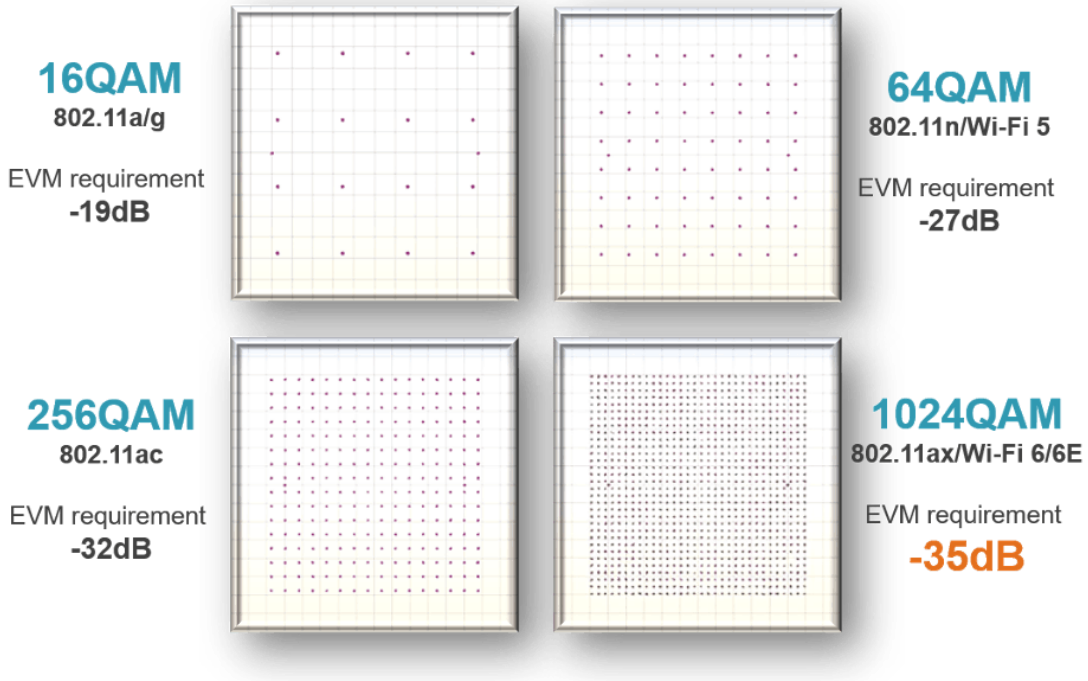

Figure 5 256-QAM vs. 1024-QAM

Wi-Fi 6 increases the modulation from 256-QAM to 1024-QAM. A signal represents from 8 bits to 10 bits. Therefore, it improves the peak data rate 25% higher than Wi-Fi 5. Besides, the IEEE-defined EVM specification requirements for 1024-QAM require -35 dB, which is 3 dB better than 256QAM.

3.3 OFDMA

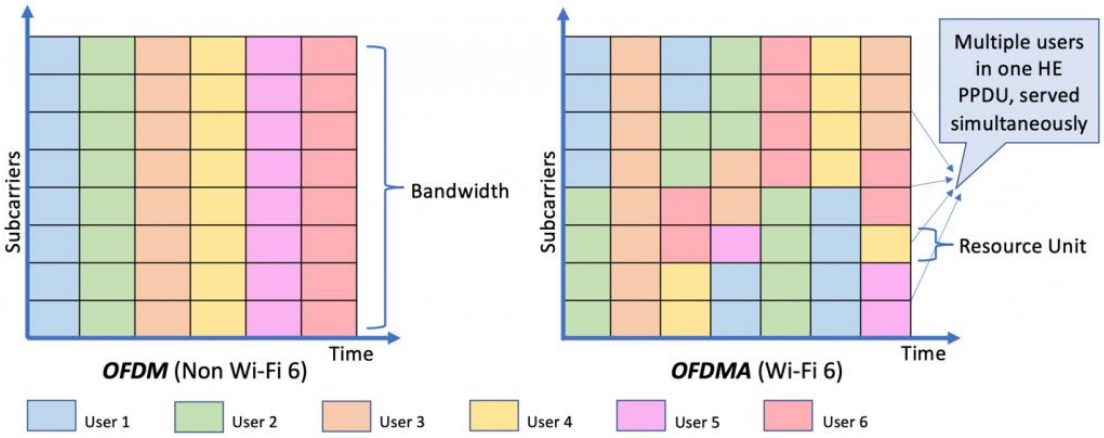

Figure 6 OFDM vs. OFDMA

In Figure 7, it shows that the difference between OFDM (Wi-Fi 5) and OFDMA (Wi-Fi 6/6E). With OFDMA, more users can receive data simultaneously. Following will explain how OFDMA is more efficient in frequency domain.

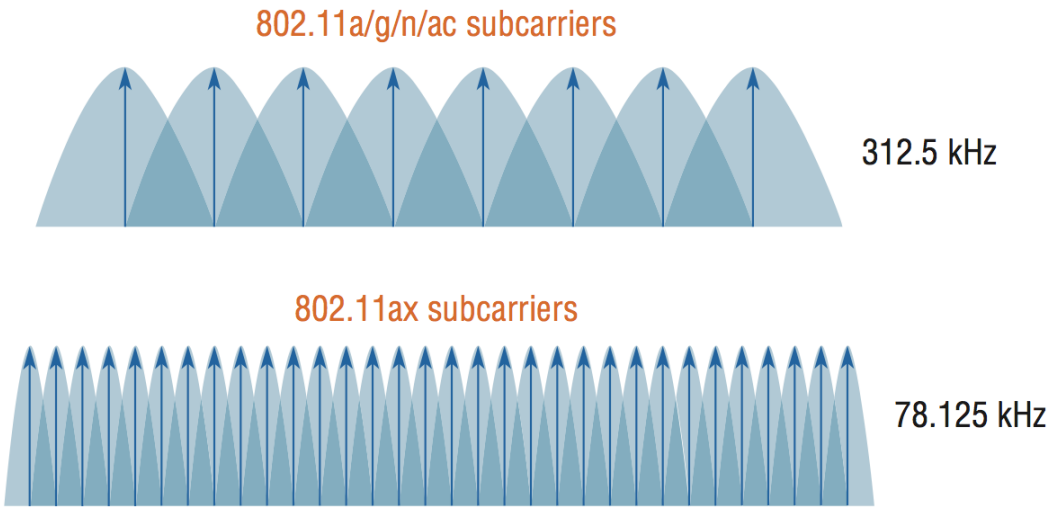

Figure 7 Subcarriers in Wi-Fi 5 and Wi-Fi 6

First, both of them uses subcarriers but in Wi-Fi 6 the bandwidth of subcarriers are 78.125 kHz which is smaller than those in Wi-Fi 5.

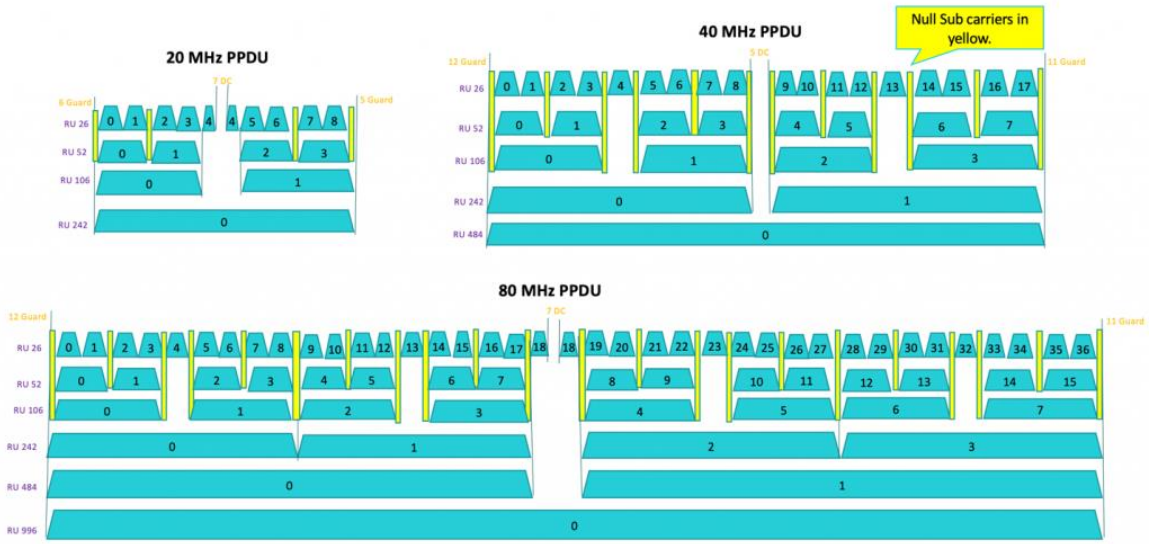

Figure 8 Subcarriers in Different Bandwidths

RU type	20 MHz BW	40 MHz BW	80 MHz BW	80+80/160 MHz BW
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
2x996-tone RU	N/A	N/A	N/A	1

Table 3 Subcarriers in Different Bandwidths

Second, with OFDMA, the basic unit is called “Resource Unit (RU)”. RUs are groups of subcarriers. The size of an RU is from the smallest 26 subcarriers (around 2MHz) and up to 996 subcarriers (around 77.8 MHz). Each RU can be allocated to one user. For example, in 20MHz bandwidth, it services most 9 users in the same time (in Table 3). Thus, OFDMA uses a more efficient way in frequency domain than OFDM does. Finally, not all of subcarriers in OFDMA are used to transmit data. There are different types of subcarriers. It can be divided in three types.

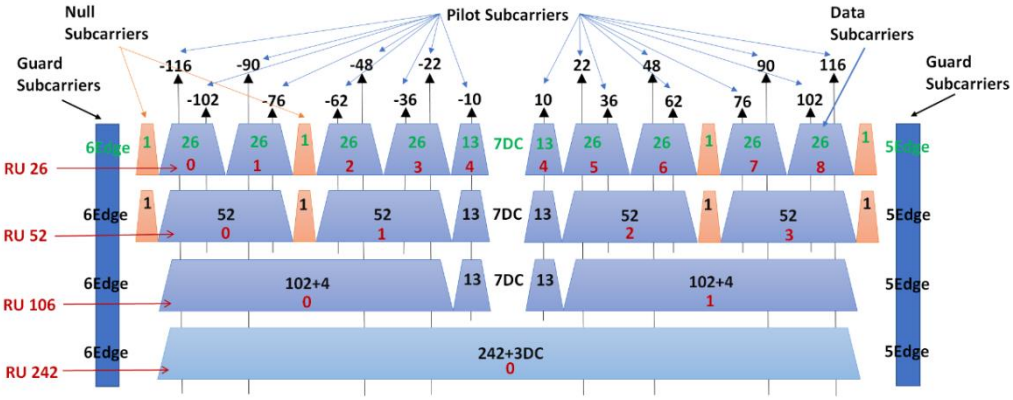

Figure 9 Details of Subcarriers in Wi-Fi 6/6E

They are **Data Subcarriers, Pilot Subcarriers** and **Unused Subcarriers.**

Data Subcarriers: Data subcarriers are used to transmit the data. They will use the same modulation and MCSs as Wi-Fi 5 and two new MCSs with the addition of 1024-QAM.

Pilot Subcarriers: The pilot subcarriers do not carry modulated data. However, they are used for synchronization purposes between the receiver and transmitter. Usually, there are 2 pilot subcarriers in 26-tone RU.

Unused Subcarriers: There are also three types of unused subcarriers.

DC subcarrier: The DC subcarrier is the subcarrier whose frequency is equal to the RF center frequency of the transmitting station.

Guard carrier: Guard subcarrier is to against interference from adjacent channels. It usually uses 6 subcarriers (on the left side) and 5subcarriers (on the ride side).

Null subcarrier: Null subcarrier is to against interference from adjacent sub-channels. It usually uses only one subcarrier.

3.4 MU-MIMO

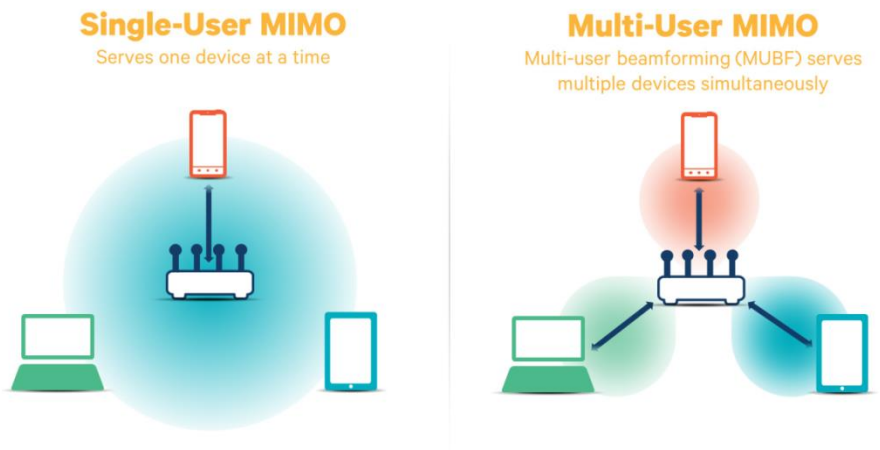

Figure 10 SU-MIMO vs. MU-MIMO

If a router has 8X8 antennas with Single-User MIMO (SU-MIMO), it will service one user at the same time. Nowadays, phones or laptops have 1X1 or 2X2 antennas. As a result, the rest of antennas will be idle and it is waste. However, with Multi-User MIMO (MU-MIMO), the router can communicate with multiple devices simultaneously. This decreases the time each device has to wait for a signal and dramatically speeds up the network.

3.5 Basic Service Set (BSS) Coloring

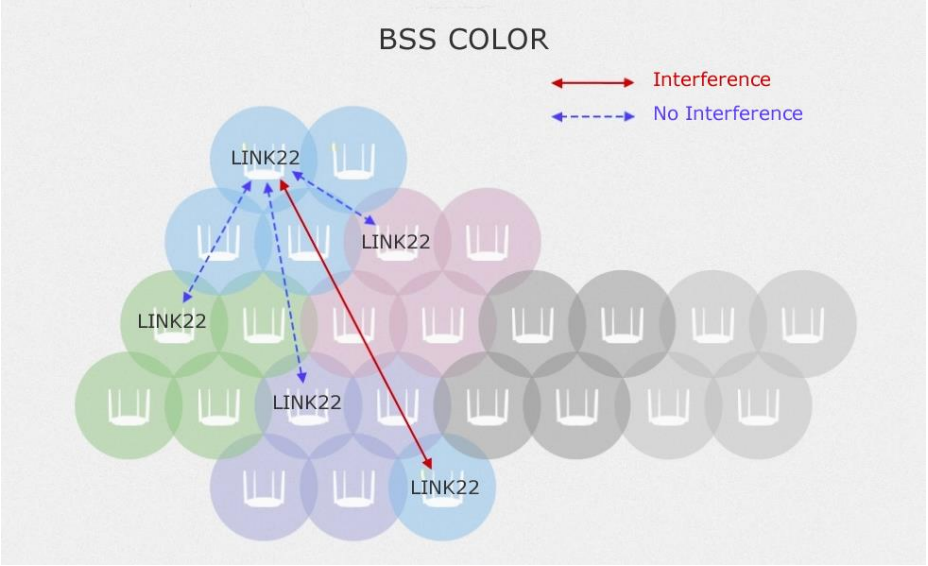

Figure 11 BSS Coloring

Although 5 GHz band is wider than 2.4 GHz, it is still crowded in these days. Therefore, many channels might be overlapping in a small region. Basic Service Set (BSS) Coloring is used to solve this problems. BSS Coloring is like coloring the channel between devices. The devices will recognize the same color. Then, it will be considered as intra-BSS frame and station will have to contend for the medium as normal process. Otherwise, it is considered as inter-BSS. On the other word, the BSS Coloring enables a router to determine fast if an incoming frame is send from a device within the same BSS or not. Besides, the “color” actually is a 6 bit number (0~63).

3.6 Target Wake Time (TWT)

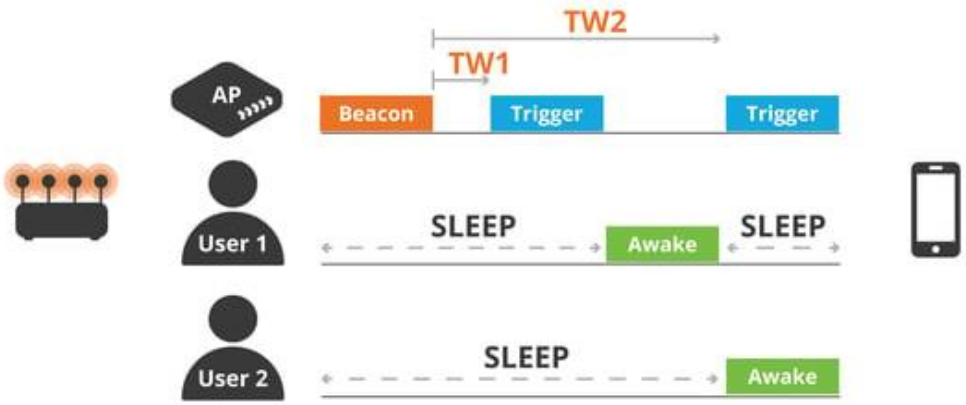

Figure 12 Target Wake Time (TWT)

The Target Wake Time (TWT) mechanism first emerged in 2017 in the 802.11ah standard, which is also called “WiFi HaLow”. Then, Wi-Fi 6 greatly improves it. TWT allows devices when and how often they wake up to send or receive data. In this way, the devices can save power by using more efficient way to communicate. Besides, it also reduces contention and overlap between users. Nowadays, IoT devices are more and more common in daily life. Thus, TWT plays a major role in this situation.

4. Industry Analysis

4.1 Smartphones with Wi-Fi 6 (2019) Compatibility

	Smartphones	Date
Samsung Galaxy	S10, S10+, S10e	March 2019
iPhone	11 Series	September 2019
5G → Xiaomi	Mi 10 5G, Mi 10 Pro 5G	February 2020
Vivo	iQOO 3 5G	February 2020
Sony Xperia	1 II	February 2020
Realme	X50 Pro 5G	February 2020
LG	V60 ThinQ 5G	March 2020
OnePlus	8, 8 Pro	April 2020
Motorola	Edge Plus	May 2020
ASUS	ROG Phone 3, Phone 3 Strix	July 2020
Google	Pixel 6 and 6 Pro	October 2021

Table 4 Smart phone with Wi-Fi 6

After Wi-Fi 6 was released in 2019, Samsung and Apple launched new products subsequently. However, iPhone 11 could not support 160 MHz bandwidth in Wi-Fi 6. Thus, it was not upgraded fully. Then, with 5G coming out, many companies launched their new products supporting 5G and Wi-Fi 6 technology. On the other hand, when Wi-Fi 6E was released in 2020, there were not many products to support it.

4.2 Router SPEC

Take Qualcomm IPQ8071 for example

Specifications	
Chipset	CPU: Qualcomm IPQ8071 (optional IPQ8072/IPQ8070)
	2.4 AX Chip: Qualcomm 2X2; SINGLE-BAND; 802.11AX QCN5024
	5GHZ AX Chip: Qualcomm 4X4; SINGLE-BAND; 802.11AX QCN5054
	Ethernet 5 Giga port switch: Qualcomm QCA8075
	Power management: PMP8074
System Memory	Default DDR3-2400 512Mbyte
NAND Flash	Default 256Mbyte
M2 LTE Module	1x 3G/4G/5G M.2 Module with SIM card
Interface	1* WAN 1000M with POE PD 25W Support (802.3at & af standard)
	3* LAN Giga Ethernet RJ45 Port
	1x SIM Card Slot
Reset Button	Yes
DC Power	1x DC Jack Connector: 12V@2A
Power Consumption	20 Watt (Max)
Software	OpenWRT or Qualcomm QSDK which includes Uboot, Kernel and Tool Chain
Environmental	Temperature: Operating: -20ºC to 85ºC, Storage: -40ºC to 90ºC
	Humidity (non-condensing): Operating: 5% to 95%, Storage: Max. 90%
PCBA	Dimensions: 155 x 120 x 16 mm

Table 5 IPQ8071 SPEC

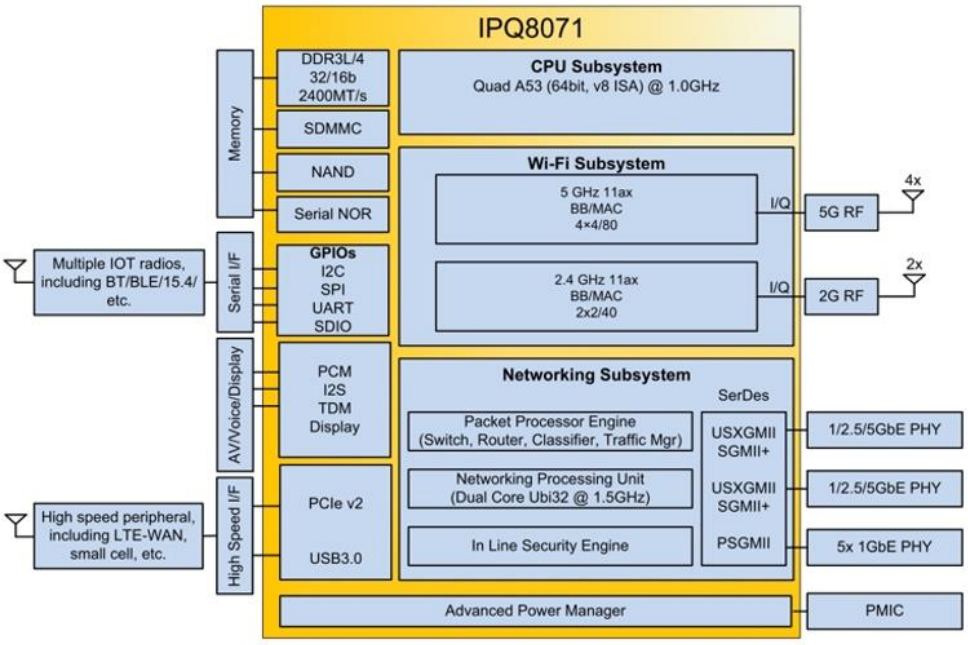

Figure 13 IPQ8071 Block Diagram

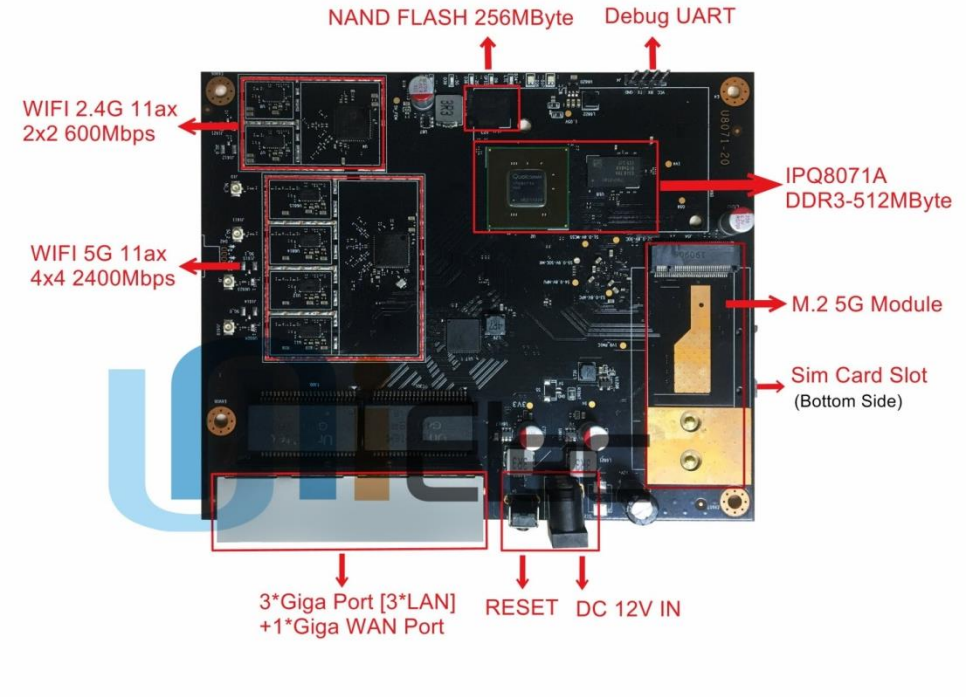

Figure 14 Picture of IPQ8071

The CPU of the router is Qualcomm IPQ8071 and it is with 14 nm process. It has DDR3-512 MB and NAND Flash 256 MB. Besides, it supports 2.4GHz band (2x2) and 5 GHz band (4x4). 2.4 GHz and 5 GHz band provide highest internet speed 600 Mbps and 2400Mbps. The name of Wi-Fi router is decided by Wi-Fi standards and its internet speed. For example, if it is Wi-Fi 5, it will use AC (802.11ac). Then, if it is dual mode and can reach speeds of up to 1300Mbps on the 5GHz band and 450Mbps on the 2.4GHz band. It will use 1750 (1300 + 450). The Wi-Fi router is named AC1750. Therefore, IPQ8071 is named AX3000.

4.3 Wi-Fi 6E

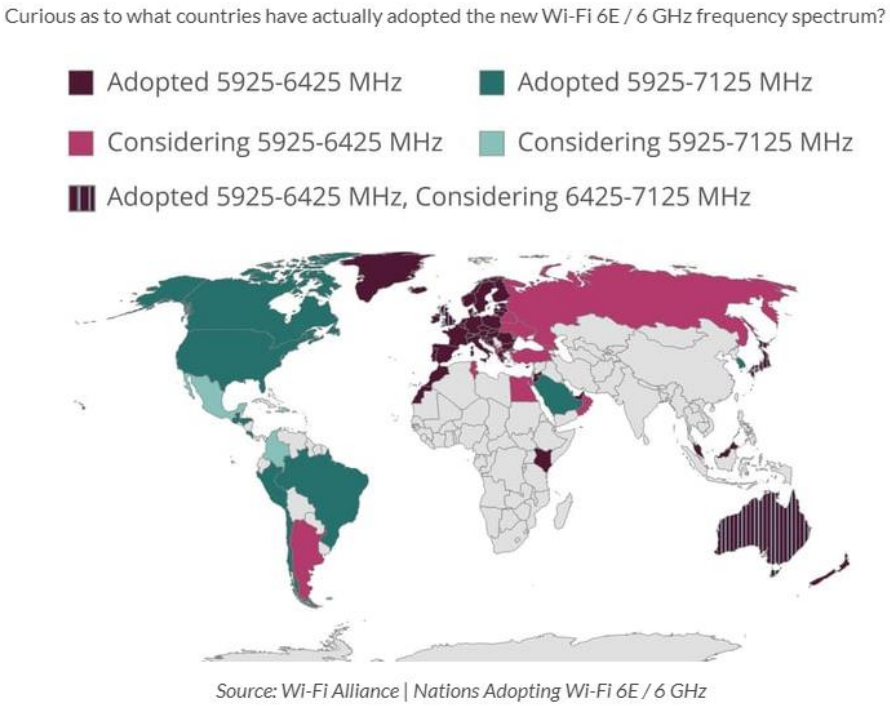

Figure 15 Nations Adopting Wi-Fi 6E/ 6 GHz

Although Wi-Fi 6E was released in 2020, nations adopted the 6 GHz are not available everywhere. Besides, there are two standards. One is like the United States has already fully adopted 5925-7125 MHz (around 1200MHz). The other one is like the EU has already adopted 5925-6425 MHz (around 500NHz). In Figure 15, many countries still consider to adopt the new frequency band. Especially, in Asia, there are only few countries to adopt or consider 6 GHz band. Thus, it makes Wi-Fi 6E devices not to be released in many Asian countries yet.

4.4 SWOT

Figure 16 SWOT of Wi-Fi 6/6E

Strengths: Compared with Wi-Fi 5, Wi-Fi 6/6E provides higher data rate, lower latency, not crowded frequency band (6 GHz), etc.

Weaknesses: Although Wi-Fi 6/6E brings a lot of benefits, its upgraded process is too complicated and expensive for customers. The customers not only buy the newest routers and devices which support Wi-Fi 6 but also upgrade to faster internet plans. Therefore, it might reduce their willingness to upgrade Wi-Fi 6.

Opportunities: Nowadays, eSport and IoT devices are required better and faster internet connection. Their users might spend more money on it.

Threats: Although Wi-Fi 6/6E provides faster speed, they still have many spaces to upgrade. While Wi-Fi 7 is coming, Wi-Fi 6E acts as a bridge between Wi-Fi 6 and Wi-Fi 7. Users might choose Wi-Fi 7 instead of Wi-Fi 6E.

5. Conclusion

Wi-Fi is a mature technology and it is used in a lot of place. Its development strategies are clear including lower latency, higher throughputs, increasing access point capacity, etc.

To summary, new features of Wi-Fi 6/6E are the following. First, 6 GHz band first is used in Wi-Fi 6E and it brings much more bandwidth. Second, the modulation is from 256-QAM to 1024-QAM and modulation scheme change OFDM to OFDMA. That makes data rate higher and latency lower. Last, Wi-Fi 6/6E also provides others service like BSS coloring to reuse channels, TWT to save power and WPA3 to improve its security.

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