The Evolution of Wi-Fi Technologies: Wi-Fi 7 (802.11be)

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The evolution of Wi-Fi technology has launched its seventh generation, representing a significant leap in wireless communications. Wi-Fi 7, also known as IEEE 802.11be EHT (Extremely High Throughput), brings high-speed connectivity, increased data rates, reduced latency and enhanced reliability. In this whitepaper, we will cover the history of Wi-Fi technologies, explore Wi-Fi 7 capabilities, popular end applications and discuss the role of frequency control in Wi-Fi 7 systems.

History

After nearly 30 years of Wi-Fi (Wireless Fidelity) technologies being ubiquitously deployed worldwide, it has become the modern standard for wireless connectivity. The demand for Wi-Fi continues to grow in parallel to the number of wireless devices being deployed to it. The history of Wi-Fi technologies has evolved with each generation of rollouts, bringing advancements in wireless communication and connectivity.

The first adopted Wi-Fi standard, introduced in 1999, was Wi-Fi 1 (802.11b). This protocol operated in the 2.4 GHz band with data rates up to 11 Mbps, utilizing a DSSS (Direct Sequence Spread Spectrum). As the demand for wireless communication grew, the need for advancements to Wi-Fi protocols continued to press on. In the early 2000s, Wi-Fi 2 (802.11a) and Wi-Fi 3 (802.11g) rolled out bringing higher data rates reaching up to 54 Mbps. Wi-Fi 2 operated on a 5 GHz band while Wi-Fi 3 utilized the 2.4 GHz band, however both utilized an OFDM (Orthogonal Frequency Division Multiplexing) modulation technique. Enhanced frequency control components were crucial in supporting the Wi-Fi 2 band operations and ensured improved connectivity. In 2009, Wi-Fi 4 (802.11n) was released marking a revolutionary turn in wireless communications. Wi-Fi 4 (802.11n) included MIMO (Multiple Input, Multiple Output) technology, dual-band utilization (2.4 GHz and 5 GHz) and expanded data rates up to 600 Mbps. With better communication range, high-precision oscillators and resonators were required to support the multiple spatial streams and wide bandwidth.

Launched in 2014, Wi-Fi 5 (802.11ac) focused on improving data rates (up to 3.5 Gbps) and efficiency with beamforming and 160 MHz channels. The increased bandwidth and higher-order modulation schemes required more precision from frequency control components resulting in the need for ultra-low phase noise oscillators and high-stability timing components like crystals and resonators. In 2019, Wi-Fi 6 (802.11ax) was launched boasting OFDMA, data rates up to 9.6 Gbps and improved performance for the 2.4 GHz and 5 GHz bands. The introduction of the Wi-Fi 6E standard and the added use of the 6 GHz band allowed Wi-Fi devices to operate in a very busy RF environment while achieving nearly 10 Gbps data rates.

The evolution of Wi-Fi technologies is driven by increased demand for higher data rates, improved user experience, expansion of connected devices and advancements in technology. The requirement for increased internet speeds for online-based applications and services has also grown exponentially. Consumers have an insatiable demand for content and applications that require extensive bandwidth, such as video streaming, music streaming and gaming. The continuous innovation of Wi-Fi standards aims to meet the needs of consumers and support the progression of technology.

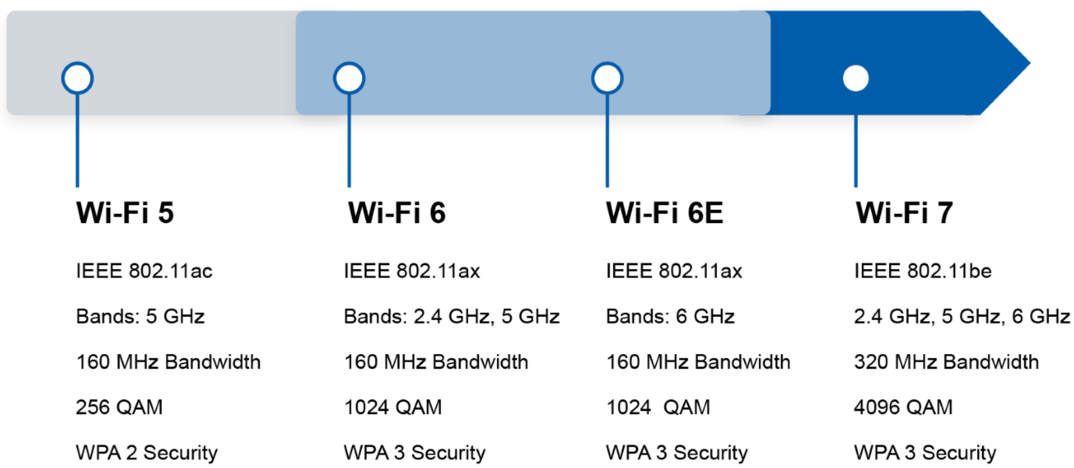

Fig. 1 above shows the evolution timeline of Wi-Fi technologies from Wi-Fi 5 to Wi-Fi 7.

New Technologies for Wi-Fi 7

In 2024, Wi-Fi 7 (802.11be) was rolled out with significant advancements in wireless connectivity. With data rates exceeding 30 Gbps, this protocol focuses on delivering high-speed, low-latency coverage for a wide range of applications such as augmented reality (AR), virtual reality (VR), high-resolution video streaming and IoT connectivity. There are several groundbreaking developments rolled out with Wi-Fi 7 including features such as 4K QAM, UMAC, MLO, OFDMA with MRUs, 320 MHz channel bandwidths (double from Wi-Fi 6) and MIMO. Let’s take a closer look at some of these features:

4K QAM (Quadrature Amplitude Modulation):
The 4K QAM (Quadrature Amplitude Modulation) is an advanced modulation scheme that translates digital packets into analog packets to transfer data wirelessly. It does this by adjusting the phase and amplitude of the RF signal. By incorporating more data into each transmission packet, this technology significantly increases bandwidth efficiency. Wi-Fi 7 offers a bandwidth of 320 MHz when using the 6 GHz band, this is double the channel bandwidth of Wi-Fi 6 and increases throughput by 20%. Wi-Fi 7 4K QAM can carry 212 symbols (12 bits) compared to 1K QAM used in Wi-Fi 6, which only carries 210 symbols (10 bits).

UMAC:
Wi-Fi 7's MAC (Medium Access Control) layer includes a new UMAC (Upper Medium Access

Control) layer that coordinates multi-link operations in an MLD (Multi-Link Device) architecture. The UMAC generates high-layer protocols using a single MAC address for data transfers, while still managing data flow at the lower link level. The lower-layer function does not affect the higher-layer protocols thus eliminating the need to know how many radios are being used.

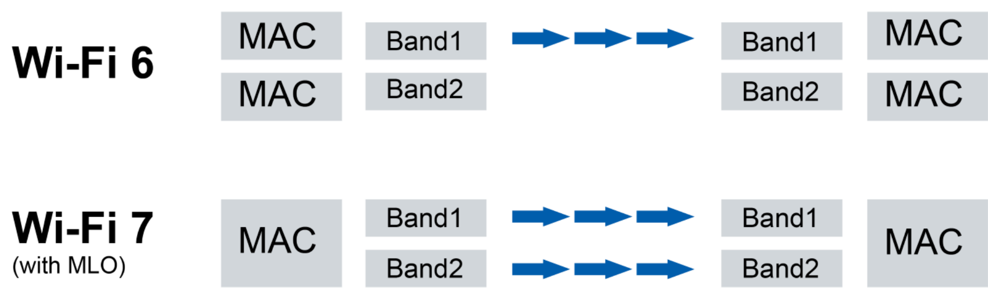

Fig. 2 above shows the medium access control layer for both Wi-Fi 6 and Wi-Fi 7 (with MLO).

MLO:

MLO (Multi-Link Operation) is an aggregation of multiple bands or channels. With MLO, MLDs can simultaneously use the 2.4 GHz, 5 GHz and 6 GHz bands for load balancing according to traffic needs or data aggregation across multiple bands, improving channel speeds and significantly reducing latency. This is a significant improvement for applications like gaming, wireless VR headsets, cloud gaming or any latency-sensitive applications

Current Wi-Fi technologies allow a device to connect and jump between either 2.4 GHz, 5 GHz and 6 GHz bands, but it can only send data via one band at a time. The newly introduced MLO in the MAC layer enables link synchronization across multiple bands and channels with significantly lower latency. MLO can deliver bandwidth speeds 4X faster than today's Wi-Fi 6/6E. The current switching overhead as it hops frequencies can lead to delays of up to 100msec, whereas with an aggregated Wi-Fi 7 connection that latency is expected to drop as low as 1ms.

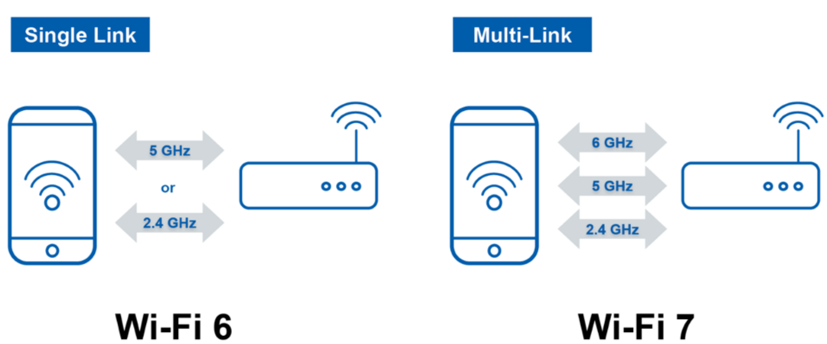

Fig. 3 above shows the rate of data transmission between Wi-Fi 6 and Wi-Fi 7 MLO displaying more bandwidth aggregation and lower latency throughput.

OFDMA with MRUs:
OFDMA (Orthogonal Frequency Division Multiple Access) was pioneered and introduced in Wi-Fi 6 802.11ax. It divides the channels into frequency allocations called RU (Resource Units). By dividing the channels, you can send smaller data packets to multiple users simultaneously. This increases throughput and reduces latency on a busy network. Wi-Fi 7 further expands on this technology with MRU (Multiple Resource Units). An MRU is made up of combinations of either 26-, 52-, 106-, 242-, 484-, 996-, 2x996-, or 4x996-tone.

The channel bandwidth of an EHT is divided into RUs. An RU is a group of subcarriers assigned to one or more users, it is defined by the size and number of subcarriers with an index. The index defines the location of the RU within the channel.
In EHT, the RU sizes in tones are 26, 52, 106, 242, 484, 996, 2x996 or 4x996, where 242, 484, 996, 2x996 and 4x996 are correlated to the 20 MHz, 40 MHz, 80 MHz, 160 MHz and 320 MHz channel bandwidth. An EHT access point will assign one of these 3 RU tones to a single user: 26-, 52- or 106-tone, or 242-, 484-, 996-, 2x996- or 4x996-tone RU to a single or multiple users. RUs can be aggregated to form multiple resource units.
There are two types of RUs including small RUs and large RUs. Small RUs consist of 26-, 52- and 106-tone. Small RUs can only be combined with other small RUs to form a small MRU. Small-size MRUs are used for both uplink and downlink transmission in OFDMA format. These combinations of small-sized MRUs can be assigned to a single STA:

- 52+26-tone MRU
- 106+26-tone MRU

Large RUs are 242-, 484-, 996-, 2x996- and 4x996-tone. Large RUs can only be combined with other large RUs to form a large MRU. The large MRUs are defined for both uplink and downlink transmission in non-OFDMA and OFDMA formats.

- 484+242-tone MRU
- 996+484-tone MRU
- 996+484+242-tone MRU (can only be assigned to non-OFDMA STAs)
- 2x996+484-tone MRU
- 3x996-tone MRU (2x996 + 996 tones)
- 3x996+484-tone MRU (2x996 + 996 + 484 tones)

The MRU provides enhanced noise reduction and better efficiency of the OFDMA. The illustration below shows that the OFDMA-MRU can mitigate interference losses from 75% to just 25%. This is how a Wi-Fi 7 MRU station can offer 4X more effective data bandwidth availability than a Wi-Fi 6 station in a dense network environment.

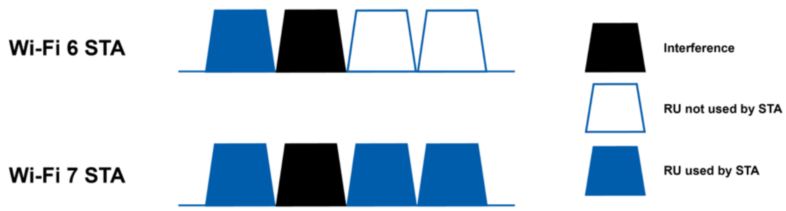

Fig. 4 gives a visual comparison of RU utilization between Wi-Fi 6 and Wi-Fi 7.

320 MHz Bandwidth:
The 320 MHz band in Wi-Fi 7 plays an important role in delivering higher data rates and improved network performance. Using double the bandwidth as compared to Wi-Fi 6, the 320 MHz band utilized in Wi-Fi 7 technology brings a wider channel width, significantly increasing the amount of data transmitted. This enhanced bandwidth also enables faster internet speeds, lower latency and better support for high-density environments, such as densely populated arenas or urban areas. Additionally, the 320 MHz band reduces interference and enhances overall network reliability, making it a paramount evolution in wireless communication.

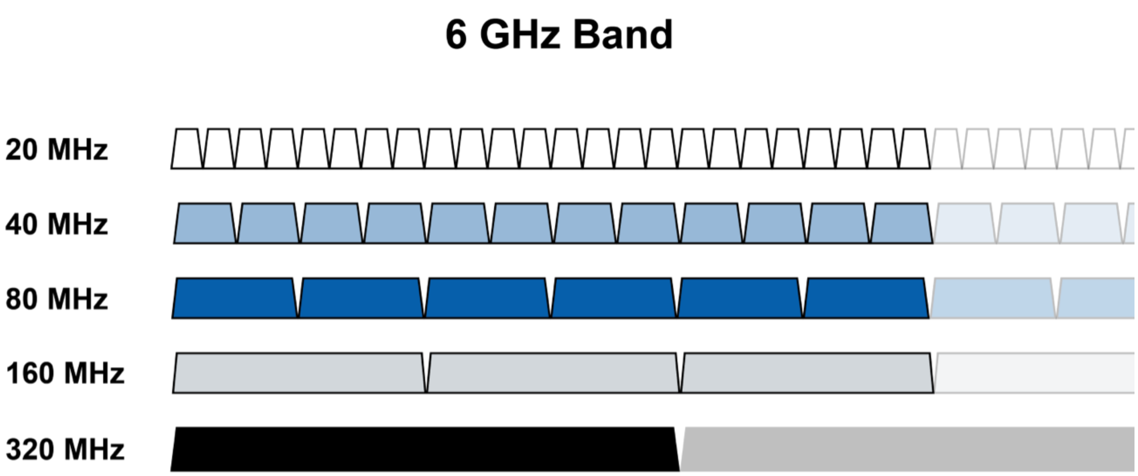

Fig. 5 above gives a visual depiction of the channel width across the 6 GHz band.

What are the highlights for Wi-Fi 7

- **Faster:** Close to 4X the wireless datalink performance, delivering over 36 Gbps
- **More Reliable:** New MRU (Multiple Resource Unit) lowers multiple user latency by 25%
- **Always-on Connected:** New MLO (Multi-Link Operation) improves single user latency by 80% and throughput gains of up to 300%

Applications for Wi-Fi 7

Looking ahead, the demand for connectivity is driving the rapid growth of real-time applications like 4K/8K/16K video streaming, AR/VR, internet browsing, smart home devices, remote office and business collaborations, cloud storage, gaming and other cases utilizing network environments. This includes markets such as healthcare, education, logistics and transportation, financial services, manufacturing and telecommunications, and many others. To meet the needs of these emerging technologies, continuous improvements in Wi-Fi technology are essential. Additionally, the expected increase in the density of wireless devices over the next 5 to 10 years further emphasizes the need for ongoing advancements in connectivity solutions.

Role of Frequency Control in Wi-Fi Technology

Timing components are crucial in maintaining the stability and accuracy of carrier frequencies in Wi-Fi technology. Components such as crystals, oscillators and resonators play a key role in ensuring the transmitter and receiver are synchronized, which is pivotal in the reliability and efficiency of communications. There are key specifications to look out for when integrating frequency control in Wi-Fi systems such as:

- **Phase Noise and Jitter:** Low phase noise and jitter are essential in minimizing error rates and maintaining high data integrity in Wi-Fi 7 communications.
- **Frequency Stability:** High-frequency stability over temperature and time is necessary to ensure consistent performance.
- **Aging and Environmental Factors:** Environmental factors such as vibration and shock resistance along with long-term aging need to be considered to establish reliability.

There are many enhancements and features that come with the Wi-Fi 7 rollout including increased speeds, lower latency, enhanced reliability and better support for multiple devices, but with these enhancements come certain obstacles. The challenges design engineers may face in relation to frequency control for Wi-Fi 7 systems may include wide channel bandwidths, high modulation schemes, MLO (Multi-Link Operation) and enhanced Multi-User MIMO. Depending on the application, these challenges could pose a significant impact on design reliability and long-term performance. Let’s look at some of the main challenges:

- **Wider Channel Bandwidths:** Wi-Fi 7 supports channel bandwidths up to 320 MHz, which requires oscillators with extremely low phase noise and high stability to ensure stable signal transmission.
- **High Modulation Schemes:** Advanced modulation techniques like 4096-QAM demand precise frequency control to maintain signal integrity and reduce error rates.
- **Multi-Link Operation (MLO):** Wi-Fi 7 enables simultaneous transmission across multiple frequency bands, necessitating highly stable and low-jitter oscillators to manage high-speed data transfer between multiple links without bit error rates.
- **Enhanced Multi-User MIMO:** MIMO technology uses a signal processing technique called beamforming which allows up to 16 individual spatial streams from a single antenna. Beamforming requires precision timing to improve signal-to-noise ratio and minimize radio frequency interference. This results in optimized throughput and reduced latency.

Summary

As technology grows and innovation expands, we will continue to see the evolution of Wi-Fi capabilities. The latest Wi-Fi 7 represents a leap forward in wireless communications bringing advancements in higher data rates, lower latency and improved reliability. Frequency control components such as crystals, oscillators and resonators are fundamental to the performance of Wi-Fi 7 systems. As wireless communication technology continues to advance, the role of timing and synchronization will become even more critical in delivering the next generation of wireless connectivity.

ECS Inc. International brings over 40 years of technical expertise in frequency control solutions. We offer technical design support, engineering tools and resources, as well as product samples for testing and prototyping.

Explore ECS Inc. International's recommended series for Wi-Fi 7 applications:

32.768 kHz Tuning Fork Watch Crystals

Part Series	Frequency	Tolerance/Temperature Range	Package Size	Inventory
ECX-1210	32.768 kHz	20ppm, -40°C ~ 105°C	1.2 x 1.0 mm	Search Inventory
ECX-16	32.768 kHz	20ppm, -40°C ~ 85°C	1.6 x 1.0 mm	Search Inventory
ECX-12Q	32.768 kHz	20ppm, -40°C ~ 125°C	2.0 x 1.2 mm	Search Inventory

Crystals

Part Series	Frequency	Stability/Temperature Range	Package Size	Inventory

ECX-1637B	16 ~ 50 MHz	20ppm, -40°C ~ 105°C	2.0 x 1.6 mm	Search Inventory
ECX-2236B	12 ~ 50 MHz	20ppm, -40°C ~ 105°C	2.5 x 2.0 mm	Search Inventory
ECS-33B	10 ~ 54 MHz	20ppm, -40°C ~ 105°C	3.2 x 2.5 mm	Search Inventory

Oscillators

Part Series	Frequency	Stability/Temperature Range	Package Size	Inventory
ECS-2520MV	0.750 ~ 160 MHz	10ppm, -40°C ~ 105°C	2.5 x 2.0 mm	Search Inventory
ECS-2520SMV	8 ~ 60 MHz	10ppm, -40°C ~ 105° C	2.5 x 2.0 mm	Search Inventory

Power Inductors

Part Series	Inductance Range	Temperature Range	Package Size	Inventory
ECS-MPI2520	0.47 – 4.7 µH ± 20%	-40°C ~ 105°C	2.5 x 2.0 mm	Search Inventory
ECS-MPI4040	0.09 – 22 µH ± 20%	-55°C ~ 125°C	4.7 x 4.31 mm	Search Inventory
ECS-MPIL0530	0.68 – 22 µH ± 20%	-55°C ~ 125°C	5.49 x 5.18 mm	Search Inventory

For more technical resources, please reference our library of technical guides, educational video library on frequency control and product information, our reference design library or our current product catalog.

Please contact us if you need additional information or have a specific requirement in your application.

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