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Wireless Standards: Wi-Fi 6 Evolution and Wi-Fi 7

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ABSTRACT

IEEE standardized wireless technologies as 802.11, 802.11a/b/g/n, 802.11ac. 802.11 (legacy) was released by IEEE in 1997. IEEE 802.11b was made available to users through Wi-Fi routers. With 802.11g/n increased the network capacity and data throughput support. 802.11n or Wi-Fi 4 introduced MIMO technology. Downlink MU-MIMO was one of the main features of 802.11ac or Wi-Fi 5. The latest 802.11ax or Wi-Fi 6 supports both downlink and uplink MU-MIMO. The use of OFDMA, dual bands, Target Wake Time technologies will help in handling traffic offloaded from the 5G wireless network and help in catering to dynamic network needs, handling massive dense IoT networks, and high throughput demands. Wi-Fi Alliance started working on the next wireless generation that is IEEE 802.11be or Wi-Fi 7. Wi-Fi 7 will be standardized by 2023.

KEYWORDS: *wireless standard, throughput, 802.11ac, 802.11ax, Wi-Fi 5, Wi-Fi 6, Wi-Fi 7*

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1. INTRODUCTION

Institute of Electrical and Electronics Engineers (IEEE) started working towards the standardization of Wireless Local Area Network (WLAN) technologies in 1991. 802.11 technology was the first standard that was released by IEEE in 1997 and it was known as "Wi-Fi". Wi-Fi Alliance is a global organization founded in 1999 with the purpose of providing interoperability among multiple vendors for wireless networking products and also for bringing stable and reliable connectivity service to the customers. The term Wi-Fi was coined by Wi-Fi Alliance. The next standard i.e., 802.11a and 802.11b were ratified in 1999. 802.11b was widely implemented in Wi-Fi routers that were available to the users for experiencing wireless internet services. 802.11g increased the data rates up to 54 Mbps as compared to 11 Mbps in 802.11b. In 802.11n, when 2 downlink and 2 uplink streams are used in a 40 MHz channel, it was possible to achieve a maximum of 300 Mbps speed. MIMO and multiple streams support were also introduced in 802.11n. In 2013 standardization of 802.11ac started. 802.11 ac wave 1 supported 8 streams, and it was possible to achieve 867 Mbps when 2x2 streams were used in an 80 MHz channel. Downlink MU-MIMO support was introduced in 802.11ac wave 2, and by using 2x2 streams in a 160 MHz channel it was manageable to increase data rate up to 1.73 Gbps. Wi-Fi Alliance gave simple names to these standards such as Wi-Fi 4 for 802.11n and Wi-Fi 5 for 802.11ac. Table 1 summarizes the features of 802.11 standards. Section 2 of this paper discusses the driving factors that led to Wi-Fi 6 or 802.11 ax standard. Section 3 explains the core technologies of Wi-Fi 6. The global market of Wi-Fi and Wi-Fi chipsets is presented in section 4. At last, section 5 presents advancements after Wi-Fi 6 i.e., Wi-Fi 6E, Wi-Fi Aware, Wi-Fi Passpoint, etc. Wi-Fi 7 requirements and candidate core technologies are also disclosed in this paper.

Features	802.11 (legacy)	802.11a	802.11b	802.11g	802.11n	802.11ac
Release year	1997	1999	1999	2003	2009	2013
Frequency Band	2.4 GHz	5.8 GHz	2.4 GHz	2.4 GHz	2.4 GHz & 5 GHz	5 GHz
Bandwidth	20 MHz	20 MHz	20 MHz	20 MHz	20, 40 MHz	80 MHz, 160 MHz
Maximum Data rates	1.2 Mbps	54 Mbps	11 Mbps	54 Mbps	450 Mbps	1.73 Gbps
MIMO	No	No	No	No	SU-MIMO	MU-MIMO
Modulation	FHSS/DSSS	OFDM	HR-DSSS	OFDM	OFDM, 64 QAM	OFDM, 256 QAM
Spatial streams	1	1	1	1	4	8
Range (Indoor)	20 m	35	35	38	70	35
Range (Outdoor)	100 m	120	140	140	250	NA

Table 1: Summary of 802.11, 802.11a/b/g/n/ac standards

2. Wi-Fi 6: Driving factors

In recent times, Wi-Fi is available everywhere and is becoming an integral part of customer lives. The goal till 802.11ac was to increase the peak data rate. The vision for Wi-Fi 6 or the next Wi-Fi generation is to improve the network capacity and performance. Also, the development of a new standard will help in utilizing different bands such as 2.4 GHz, 5 GHz, and 6 GHz. Some of the driving factors are discussed below

Throughput Needs: Market research suggests that nearly two-thirds of the world population will have Wi-Fi access by 2023. With the commercialization of 5G networks, different services that require higher data rates will become popular among users. Services like AR/VR/MR that require a great amount of throughput will be readily available. 4K video services, the smart TV will also be needing high data rates. Other services such as mission-critical services will be needing low latency internet services. Thus, the next Wi-Fi generation should focus on providing high throughput and low latency.

Increasing Device Density: As new and new smart devices are being launched and used by customers, the average number of devices per user keeps on increasing. Apart from these, with 5G massive IoT became popular, and the number of sensor and monitoring devices are also drastically climbing. It is predicted that devices connected to the internet will increase by three times in 2023 [cisco]. Machine-to-machine communication will account for 50% of internet traffic. As the density of devices in an area is surging, the number of devices accessing the Wi-Fi network simultaneously also increases. Most of the IoT networks are wireless and depend on a Wi-Fi network for operation. The goal is to improve power efficiency to save battery and spectral efficiency for providing services to a large number of devices.

Dynamic Network needs: A typical customer uses a smartphone, smartwatch, smart TV, a Tablet, smart speaker, smart kitchen, and home appliances. Home Wi-Fi network should provide internet services at different speeds depending on the applications. As gaming, 4K video streaming, AR/VR applications are becoming popular, the network requirement has also changed. The Wi-Fi network at home should be intelligent enough to decide sufficient data rates for all these requirements and should be able to adapt quickly to the customer's needs. The capability to provide simultaneous and consistent data rates is the key for Wi-Fi 6.

3. Wi-Fi 6: Technical Features

Wi-Fi Alliance and IEEE worked on the goals for the next generation and IEEE 802.11ax or Wi-Fi 6 was launched in 2020. 802.11ax provides an improvement in performance, spectral utilization, and high throughput for highly dense environments.

3.1. OFDMA

Wi-Fi 6 changed from Orthogonal Frequency Division Multiplexing (OFDM) to Orthogonal Frequency Division Multiple Access (OFDMA). Wi-Fi 5 & 4 used OFDM in which users were allocated whole frequency at a particular time. OFDMA introduces splitting in both frequency and space. Now multiple users can be allocated resources simultaneously. This caters to the need of multiple users and reduces interference. In OFDMA, resource units (RUs) are allocated to each user depending on their bandwidth requirement. A channel is divided into multiple subcarriers and RU is formed by grouping subcarriers. This is similar to RUs in LTE. 802.11ax specifications indicate that RU may comprise 26/52/106/242/484/996/2*996 subcarriers. The RU of least size comprises 26 subcarriers. There are 256 subcarriers in the 20 MHz channel and thus it can contain nine RUs, each RU comprising 26 subcarriers and having a bandwidth of 78.125 kHz. Some of the RUs are used for synchronization between AP and client and others might be used for reducing interference i.e., as guard intervals. An AP that supports Wi-Fi 6 can transmit data to a single user by utilizing the whole 20MHz channel or can transmit data to 9 clients by splitting the channel into nine RUs. Thus, new Wi-Fi chipsets can increase efficiency by utilizing a 20MHz channel only without needing 40 or 80 MHz channels. 802.11ax utilizes OFDMA in both uplink and downlink. Downlink OFDMA is controlled by AP and multiple STAs can be supported. The downlink data can be segregated by STA ID, RU, MCS, and coding mode. After determining that the packet received is intended for it, STA proceeds with demodulation of the packet. In uplink OFDMA, a trigger frame is transmitted by AP so that multiple users can properly send uplink packets. The trigger frame comprises uplink data requirements, RUs resource allocation, STA power requirement so that different users can send packets to the AP simultaneously utilizing their allocated RUs or sub-bands.

3.2. MU-MIMO

Multi-user Multiple-Input Multiple-Output (MU-MIMO) technology helps in achieving high bandwidth along with efficient spatial multiplexing. The system capacity can be increased by sending multiple data streams over the same bandwidth. Downlink MU-MIMO was already supported in Wi-Fi 5 and now uplink MU-MIMO is also introduced in Wi-Fi 6. DL MU-MIMO technology is the same in both 802.11ac (Wave 2) and 802.11ax. Maximum 8 users are supported in the downlink. AP monitors the propagation links of different clients and based on that performs beamforming for implementing DL MU-MIMO. 802.11n amendment introduced 8x8 support in AP. Now, 802.11ax can form four 2x2 simultaneous links in both uplink and downlink. Uplink MU-MIMO and OFDMA make it possible to provide spatial multiplexing to multiple users with better performance. In uplink MU-MIMO, AP measures the traffic requirements of clients and allocates RUs to different streams accordingly. It transmits a trigger frame for alerting clients to perform uplink transmission. Once packets are received by AP, it transmits an acknowledgment message to indicate successful reception.

3.3. Spatial reuse (SR) Technology & BSS Coloring

802.11n and 802.11ac supported 8x8 functionality in theory, however, the chipset supports were not available in APs. Now with the advancement in technology, the new 802.11ax chipsets are able to support 8x8 configuration. The greater number of transmitting and receiving antennas will support high throughput in both upstream and downstream. 8x8 AP will provide coverage in a larger area thus reducing the number of AP required to provide a reliable network in an area. With the 5G featuring massive MIMO, AP will be able to utilize 8 antennas for transmission and reception. The co-channel interference in previous standards was adjusted dynamically by utilizing the clear channel assessment (CCA) threshold. In 802.11ax BSS coloring feature is introduced that identifies co-frequency transmissions. It comprises a 6-bit preamble to the PHY header. It can distinguish intra-BSS frames and inter-BSS frames. E.g., an STA is associated with an AP of certain BSS color. If the BSS color received by STA is from its connected AP, then it is an intra-BSS frame, otherwise, the received frame is an inter-BSS frame from neighboring AP. If the received BSS color is the same, then the channel is considered busy and if the BSS colors are different, then the channel is considered available for interference-free transmission.

3.4. 1024 QAM

Quadrature Amplitude Modulation (QAM) utilizes amplitude and phase modulation so that more packets can be transmitted. 256-QAM was supported in 802.11ac. Now with the addition of MCS10 and MCS11, 802.11ax supports the 1024-QAM scheme which increases the data rate by 25% as compared to 802.11ac. The number of bits per symbol also increased from 8 to 10. 1024 QAM technology improves reception over short ranges and utilizes high SNR for reducing noise. This increased density can provide higher data rates with the help of advancements in radio technologies that reduces the error to a great extent even in adverse scenarios.

3.5. TWT

Target Wake time (TWT) is another Wi-Fi 6 feature that is utilized to enhance power saving in IoT networks. AP interacts with STAs and sets the target wake times and sleep times that are unique to that particular station. Once these are defined, STA can enter sleep mode and they wake up at their scheduled wake-up times for receiving a transmission. This helps in saving battery and lowering power consumption. These settings are flexible and can be communicated between AP and STA by transmitting beacons. AP can send a beacon to sleeping STA, to indicate a data transmission for that STA. Thus, Beacon TWT operation enables flexible sleep and wale times without any requirement of a specific protocol. As the target wake time for devices is set, interference possibility is greatly reduced.

3.6. Extended Range (Longer OFDM symbol)

802.11ax provides a larger coverage area than 802.11ac, as it uses a long OFDM symbol transmission scheme. The symbol duration is 12.8 us as compared to 3.2 us in the previous standard, which is almost four times the previous value. Also, FFTs with more sample points are used in 802.11ax. A high number of FFT points result in a higher number of subcarriers and therefore less spacing between them. The long symbol duration and narrow spacing between subcarriers contribute to the expansion of coverage area in Wi-Fi 6. This also improves signal performance, packet loss, and retransmission requirements.

3.7. Dual Carrier Modulation (DCM)

It is a new feature of 802.11ax where the signal can be duplicated in two subcarriers. Also new Modulation and Coding Sets (MCS) i.e., MCS 10 & MCS 11 in 802.11ax contributes to approximately 60% increase in throughput in 20 MHz channel as compared to 802.11ac that utilizes MCS8.

3.8. Dual band

802.11n supported both 2.4 GHz and 5GHz spectrum, however, 802.11 ac only supported the 5GHz band. In 802.11ax, support for both bands along with additional streams support is added to utilize the 2.4 GHz band. 2.4 GHz band can provide efficient network support for greater range and IoT networks.

There are several benefits of Wi-Fi 6 such as larger coverage area, higher reliability, power saving for IoT devices, improved network performance, stable data rates in a dense network of devices, and dual frequency spectrum for supporting IoT sensors or other battery wireless devices.

4. Wi-Fi:Market Analysis

With the current deployment of 5G wireless communication networks, the Wi-Fi 6 capability of providing higher throughput will help in reducing traffic load on 5G. It is predicted that 71% of 5G traffic will be handled by Wi-Fi networks in 2022.

Wi-Fi Global Market

The Wi-Fi market size is expected to increase at a Compound Annual Growth Rate (CAGR) of 17.8 % during the forecast period (2020-2026). The projected market size is predicted to increase from USD 9.4 billion in 2020 to USD 25.2 billion by 2026. Due to Covid-19, the market trends have changed. The requirement of the great demand for Wi-Fi, online retail activity, network security, low interference in highly dense areas, and advancement in healthcare and life sciences play a major role in expanding the Wi-Fi market. Some of the key players in the Wi-Fi market are

USA – Cisco, Extreme Networks, Juniper Networks, Fortinet, NETGEAR, Aruba, Broadcom, Comcast Business, AT &T, Ubiquiti Networks, iPass, Cambium Networks, and CASA systems.

Europe – Ericsson, Alcatel-Lucent Enterprise, Orange Business Services, Vodafone, Lever Technology Group, Redway Networks, and Fon.

Asia – Huawei, Panasonic, D-Link, Airtel, and Fujitsu.

Australia – Telstra, and Superloop.

Wi-Fi chipset Global Market

Wi-Fi chipset market value was USD 19.7 billion in 2020 and is projected at USD 25.2 billion by 2026. The market is expected to grow at 4.2% CAGR. The main driving factors are the increase in IoT deployment, public Wi-Fi hotspots, faster data transfer requirements, and the growth of internet needs. This market face challenges such as the development and success of new Wi-Fi chipsets, long certification time, etc.

Major companies manufacturing Wi-Fi chipsets are Qualcomm Technologies, Broadcom, Intel Corporation, Texas Instruments in the USA, and Media Tek in Taiwan. Wi-Fi chipsets produced by Qualcomm are supplied to D-Link, Song, Fujitsu, and Toshiba companies. The company launched various new products.

Beyond Wi-Fi 6 & Wi-Fi 7

Wi-Fi 6E: It is an expansion of operation of Wi-Fi 6 in the 6GHz band. In 2020, the Wi-Fi Alliance announced Wi-Fi 6E that will provide lower latency, higher data rates, and improved performance. Broadcom and Qualcomm have started manufacturing Wi-Fi 6E chips.

WPA3 security: This is the latest Wi-Fi security that will become a necessity for all Wi-Fi certified products. As digital or virtual activities are increasing, privacy and data security become very important.

Wi-Fi Passpoint certification: With the increase in deployment of public Wi-Fi hotspots, this certification will help users in providing seamless Wi-Fi connectivity by removing the requirement of network authentication every time.

Wi-Fi Aware: It helps in the discovery of devices when they are within a range without the need for Wi-Fi infrastructure. This will lead to the development of different types of application interaction among devices.

Next-Generation Wi-Fi: Wi-Fi 7

Intel published a white paper on Wi-Fi 7 in July 2020. IEEE P802.11be is the next amendment of 802.11 standards that will improve upon the existing 802.11ax standard. The peak throughput is predicted at 30 Gbps. The operating frequency range is between 1 & 7.250 GHz. It will also work on improving low latency and jitter. Wi-Fi 7 will be standardized by 2023-24. The core technology of Wi-Fi 7 will include 320 MHz channels, 4096-QAM, 16 spatial streams, Multi-link operations, Multi-AP operation, Multi-RU (puncturing), and deterministic low latency. It will provide a better user data experience, better network energy efficiency, spectrum efficiency, connection density. The below table presents the comparison of 802.11g/n/ac, 802.11ax, and 802.11be standards. Table 2 presents the comparison of 802.11 g/n/ac, 802.11 ax and 802.11be.

Features	802.11g	802.11n	802.11ac (wave 1)	802.11 ac (wave 2)	802.11ax	802.11be
Name (Wi-Fi Alliance)	Wi-Fi	Wi-Fi 4	Wi-Fi 5	Wi-Fi 5	Wi-Fi 6/6E	Wi-Fi 7
Release year	2003	2009	2014	2026	2020	Expected in 2023
Frequency Band	2.4 GHz	2.4 GHz & 5 GHz	5 GHz	5 GHz	2.4 GHz & 5 GHz (6), 6 GHz (6E)	
Bandwidth	20 MHz	40 MHz	80, 160 MHz	80, 160 MHz	80, 160 MHz	240, 320 MHz
Maximum Data rates	54 Mbps	450 Mbps	867 Mbps	1.73 Gbps	9.6 Gbps	30 Gbps
MIMO	No	No	SU-MIMO	DL MU-MIMO	DL/UL MU-MIMO	
Modulation	OFDM	64-QAM	256-QAM	256-QAM	1024-QAM	4096 QAM

Table 2: Comparison of 802.11 g/n/ac, 802.11 ax and 802.11be

Conclusion

This paper presented Wi-Fi evolution from 802.11b to Wi-Fi 4, 5, and 6. Different driving factors that led to Wi-Fi 6 development include high throughput, dynamic network needs, and massive IoT deployment. Core technologies of Wi-Fi 6 are OFDMA, Uplink MU-MIMO, 1024-QAM, long symbol, extended range, spatial reuse, target wake time, and dual-band support. Then, the global market for Wi-Fi and Wi-Fi chipsets is summarized that provides the projection till 2026. Major companies are Cisco, extreme networks, Huawei, Ericsson, etc., are major players in Wi-Fi, and Qualcomm, Broadcom, and Intel are top companies in the Wi-Fi chipset market. The latest development in Wi-Fi is Wi-Fi 6E, Wi-Fi Aware, Wi-Fi Passpoint certification, etc. The paper also presents the research work for the next generation, Wi-Fi 7.

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