Next Generation Wireless Local Area Network for 5G and IoT

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Abstract --**Wireless Local Area Network (WLAN) is found to be most suitable for providing digital connectivity in both rural and urban areas. Ultra-fast connectivity needed in smart phone applications requires very high data rate transmission and hence, the next generation WLAN (Wi-Fi) access will need to feature a better user experience, specially so in densely populated environments requiring deployment in offices, stadia, shopping malls and coffee shops. The next generation wireless network focuses on increasing transmission data rate. The WLAN based on IEEE802.11 standard initially supported data rate of only 2Mbps, now specifies speeds in excess of 100Mbps to 100Gbps while Terabit speeds are under study. This paper discusses WLAN extending the data rate to 30-40 Gbps.**

Accordingly, wireless technology with simplified architecture, high energy efficiency, and uniform support of IoT based applications is required. In 2G to 5G cellular communication, the end-devices consume high power but provide large coverage. This paper also discusses how a next generation WLAN can be adopted/ integrated for IoT applications, and how Wi-Fi enabled next generation networks can integrate with 5G in 5G cellular Networks.

Keywords: WLAN, Gigabit, Terabit, Wireless, 4k/8k Video, AR/VR, IoT, 5G

I. INTRODUCTION

DRIVING the need for Gigabit capacity, Wireless local area networks (WLAN) received considerable attention recently. Many industrial machines besides consumer electronic devices, smart appliances are becoming Wireless-Fidelity (Wi-Fi) enabled showing that WLAN is being deployed in high densities applications, avoiding the need for cables or complicated connections used with HDTV, PC, or other multimedia systems. WLAN is based on IEEE802.11 family of standards and Wi-Fi is trademark of Wi-Fi Alliance.

The Wi-Fi devices are used in every smart phone sold besides in almost every handheld game, tablet, notebook computer, or laptop computer sold. The new applications like automotive, digital cameras, e-Readers, and Blue-ray and personal video recorders all include a Wi-Fi chip set. With over 20 years of advancements, Wi-Fi has become the world's most common wireless network for consumers and IoT. The rapid growth of IoT has forced to rethink of Wi-Fi to play a role in encompassing connected world.

One of the killer applications of high speed WLAN is wireless transmission of 4k to 8k resolution videos, AR (Augmented Reality/VR (Virtual Reality) with several Gbps data rates within a small range. Video is expected to comprise 75% of all mobile data traffic. The IEEE802.11a/b/g/n is the wireless standard for small office, home networking, and even public Internet access. Combining a 100-fold growth in devices with greater BW per device, it is quickly out-striping the capacity of IEEE802.11n. This is where Gigabit 802.11ac/ax/ax-ext./be ratification can really help. The ubiquitous accessibility is achieved by integrating and updating to a very high speed WLAN (IEEE802.3 Ethernet) in the backhaul and the LAN in the last mile for users.

Internet of Things (IoT) features applications in diverse domains that include manufacturing management, home and building automation, energy management, environmental monitoring, infrastructure management, and large scale development [1]. IoT extends life of sensors attached to a device and improve range capability along with decent data rates in wireless sensor networks at low cost. Current sensor networks work on short range using ZigBee and Bluetooth technology in which nodes consume high power, making life of nodes quite short. Basically, via Internet, smart objects are converted from physical to virtual world to connect with Internet. This results in smart objects to identify and understand the world without assistance from human-beings. IoT comprises set of devices using various communication strategies between them, and different servers (clouds), enabling billions of objects communicate with each other physically and virtually via Internet. Due to large number of remote devices, sensor devices need to operate for many years without requiring battery replacement.

Any object fitted with transceiver chip, sensor and processor becomes a smart device. Every smart device is IP addressed and controlled via the Internet. Billions of devices with IoT IP addresses are required, which can be taken care by IPv6 (Internet Protocol version-6) with 128 bit address. Accordingly, smart devices can be addressed from anywhere, since they are proper Internet participants.

This paper discusses next generation WLAN, and integration of Wi-Fi with IoT and 5G. Section 2 discusses WLAN while section 3 discusses very high speed WLAN IEEE802.11ac, 802.11ax/ax-ext., and 802.11be. Section 4 discusses WLAN for IoT applications while section 5 discusses in brief integration of Wi-Fi with 4G LTE extended to 5G cellular network, and finally Section 6 concludes the paper.

II. WIRELESS LOCAL AREA NETWORK

Historically, WLAN IEEE802.11 standard was passed in 1997. To cater to demand for higher data speeds, 802.11b and 802.11a were passed in Sept.1999. Compared to 802.11 speeds of 1 or 2 Mbps at 2.4GHz band, 802.11b increased it to 11Mbps and 802.11a increased even higher to 54 Mbps by using 5GHz band. In June 2003 the 802.11g was approved which supported 54 Mbps rate at 2.4 GHz band, and finally in 2009 the 802.11n was approved to offer 450 Mbps in first wave and 600 Mbps in the second wave in both 2.4 and 5GHz bands. Applications like video streaming and gaming which are sensitive to packet loss and delays, find that 5GHz band is more suitable. Overflowing demand due to Internet connection necessitated introduction of WiFi-5 (802.11ac), WiFi-6(802.11ax), and WiFi-7 (802.11be). To further enhance the capacity, FCC approved unlicensed band of 6GHz with 1200MHz bandwidth for Wi-Fi in 2020.

III. NEXT GENERATION WLAN

The next generation WLAN standard 802.11ac aims to provide data speeds of 1.3Gbps, much faster than 802.11n (450Mbps). The Wi-Fi products using 2.4GHz ISM band has reached end of life with 802.11n although 802.11ac should support 802.11n. For backward compatibility of 802.11n (WiFi-4), the only way to reach 802.11ac is to use 5GHz band. The introduction of triple-play (Voice, video and data) services and cloud services has increased demand for more high speed data rate for various multimedia applications. The demand will further fuel by increased penetration of broadband 5G mobile networks.

IEEE802.11ac (Wi-Fi 5): Today consumers are streaming video from home media libraries - either directly to their networked TV or through a game console. The 802.11ac significantly improves the playback quality to any point in the house wirelessly. By increasing bandwidth and improved processing, 802.11ac helps to avoid interference and improves the speed for HD video streaming.

802.11ac also focuses on Wi-Fi performance for mobile devices like smart phones and tablets. It solves problems such as dropped connections, poor quality connection, and limited mobility. Besides single video streaming, it enables simultaneous video streaming to multiple receivers, wireless displays, where large Gigabyte files are to be transferred in a few seconds time. 802.11ac will work with 80 MHz or even 160 MHz bandwidth and provide maximum throughput of 1.3 Gbps with transmission range of 10 m.

In a 160 MHz channel, data rate of 866 Mbps is achievable for a single spatial stream using 256-QAM, having coding rate of 5/6, and a short guard interval of 400 ns. With the maximum number of 8 spatial streams, data rate up to 6.9 Gbps is possible [2, 3]. The Multi-Input Multi-Output (MIMO) technique employs multiple antennas both at transmitter and receiver. It exploits interference in environment to improve the throughput. allowing more data to be sent or received in the same time frame in space. MIMO splits data into multiple streams and transmit each stream through different antennas.

MIMO requires more room for multiple antennas to be placed on mobile phones. Interestingly, 802.11ac Physical (PHY) layer is based on OFDM (Orthogonal Frequency Division Multiplexing) used in 802.11a and 802.11n and maintains same modulation, interleaving, and coding scheme of 802.11n. Its feature of beam forming provides directional signal transmission and reception enabling signal to be strengthened in that direction which increases the coverage.

802.11ac products launched in mid-2013 had 1.3Gbps speed, which increased to 6.9Gbps in 2014. In 2013, it supported 1.3Gbps data rate by using 80MHz bandwidth, 256-QAM modulation, coding rate 5/6, 256-point FFT (Fast Fourier Transform) for OFDM, 4X4 MIMO, and short guard interval of 400ns. In 2014 the higher data rate of 6.9Gbps was achieved using 8x8 Multi-User (MU)-MIMO, 512-point FFT for OFDM, 256-QAM, coding rate 5/6, 160MHz bandwidth and short guard interval of 400ns. Transmitting data through 802.11ac in 2013 needed one-third of airtime compared to 802.11n hence 802.11ac may permit administration to increase nearly 3 times of users per AP (Access Point). The MU-MIMO in 2014 allowed APs to send multiple streams to multiple clients at the same time as shown in Fig.1. Wi-Fi with 802.11ac is already available in new gadgets.

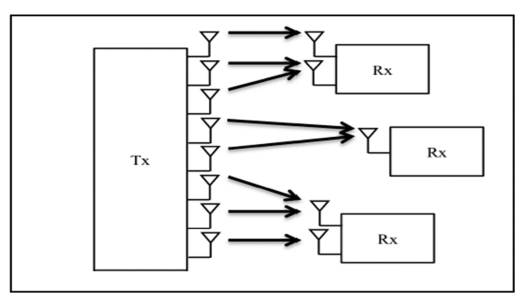

Figure 1. Multi User (MU)-MIMO.

IEEE802.11ax (Wi-Fi 6): The High Efficiency WLAN (HEW) study group worked on high efficiency IEEE802.11ax-2019 based on 802.11ac. The objective of 802.11ax [4, 5] is to support data rate of 9.6Gbps by using 160MHz bandwidth, 1024-QAM modulation, coding rate 5/6, 2048-point FFT for OFDM, 8X8 MIMO and short guard interval of 800ns. The MIMO can be two types: the first type single user (SU)-MIMO where data streams from all the antennas at AP transmitted to a single STA (user station) which increases the data rate effectively. The second type multi user (MU)-MIMO where data streams from different antennas at AP can transmit to different users station (STAs) which increase the capacity of the network.

MU-MIMO is again divided in to two types to connect multi users simultaneously. In the first type MU-MIMO implemented using multiple antennas to transmit data from AP to different STAs while in the second type, number of STAs transmit data simultaneously to AP using OFDMA (Orthogonal Frequency-Division Multiple Access) with frequency division scheme. In OFDMA each STA is connected for short period to AP, as a result when number of STAs increases, each STA has to wait for longer time to get its time slot which results in overall throughput drop. In WiFi-6, AP can communicate simultaneously using MU-MIMO but STAs communicate to AP one at a time.

In OFDMA number of sub-carriers are divided among several STAs is called Resource Unit (RU). Multiple STAs can connect simultaneously to AP in same time slot by using different number of RUs by different users depending on their BW required. This is called Multi-user(MU)- OFDMA. The MU-MIMO and MU-OFDMA enable AP to better schedule traffic among STAs with better control on quality of service. Hundreds or even thousands of STAs can be connected to the AP with limited congestion. The main benefit is higher network efficiency in dense area where more STAs can be connected to the same AP delivering a better user experience with higher throughput and low latency using MU-MIMO and MU-OFDMA. IEEE802.11be (WiFi-7) adopted OFDMA where multiple STAs can connect simultaneously to one AP in the same time slot discussed below in WiFi-7 subsection.

In MU-MIMO down link (AP to STAs), AP sends MU-RTS (Request to Send) to all STAs. Some of the STAs respond by sending CTS (Clear to Send) to AP. AP then sends data to the responded STAs simultaneously, then sends BAR (Block Ack. Request). The STAs reply with individual BACK (Block ACK) after receiving the data as shown in Fig.2. In uplink (STAs to AP), AP sends MU-RTS, STAs respond back with CTS simultaneously. AP sends trigger frame to know number of RUs to be received from each STA and provides sync. and control for uplink transmission. All STAs respond with data according to their assigned RUs which also defines modulation, coding, power level, and duration. The AP sends MU-BACK to STAs. Connecting issue is there when multiple family members try to stream video or games at the same time in a house. The 802.11ax solves the problem by using distributed WiFi. The distributed WiFi places pod in every room in the house, that serves as an AP. The pod connects to the router, which finally connects to the Internet. Now pod can connect more number of user devices.

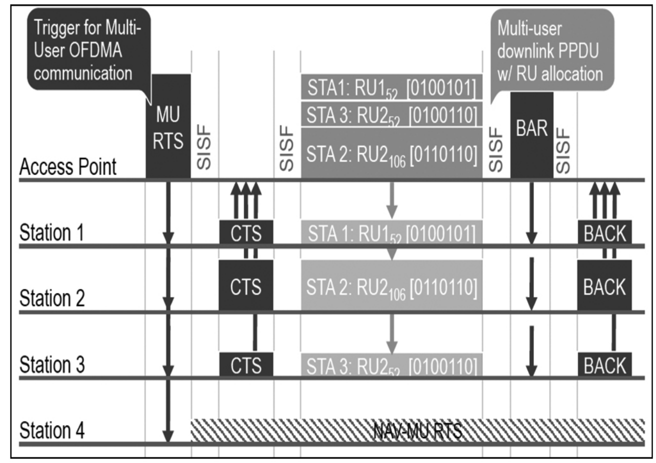

Figure 2. Multi-Link Operation: Down link [5].

C. IEEE802.11ax-Extension (Wi-Fi 6E): WiFi-6 network extended into unlicensed 6GHz band and is named as WiFi-6E. The WiFi-6E plays a powerful role to deliver advanced mobile services via higher performance, lower latency, and faster data rates than WiFi-6. The WiFi-6E uses 1200MHz bandwidth in 5.925-7.125GHz band [6]. It can support seven channels of 160MHz bandwidth compared to two 160MHz bandwidth channels in WiFi-6. But WiFi-6E has shorter range and consumes little bit more power compared to WiFi-6. WiFi-6E chips are built by Qualcomm and Broadcom. WiFi-6E uses 6GHz band along with 2.4GHz and 5GHz bands. It is useful for airports, stadia and densely populated areas. It is poised to play a major role in growth of IoT and 5G related technology to local area wireless.

D. IEEE802.11be (Wi-Fi 7): To address latest applications and services such as video streaming with 4k, 8k resolution, Augmented Reality (AR) and virtual reality (VR) which needs high speed Internet access, a new standard WiFi-7 (IEEE802.11be) extremely high throughput (EHT) development is undergoing standardization, and a final version is expected by May, 2024. It will be much faster and provide large capacity data transmission compared to 802.11ax [7, 8]. It is going to support 6GHz frequency band with three channels each 320MHz bandwidth and throughput exceeding 30Gbps which is 3 times faster than 802.11ax. It will support 16 spatial streams, 4096-QAM modulation, and 5/6 channel coding to achieve 46Gbps data rate. It is expected to achieve data rate more than 100Gbps using 320MHz X3 frequency band links.

WiFi-7 chips are also being built by Qualcomm and Broadcom. It features Multi-Link Operation (MLO) by which one can transmit/receive data on 2 or more frequency bands (2.4, 5, 6GHz) simultaneously in parallel between APs and STAs to achieve high throughput. This allows an AP to save STA resources for more predictable traffic with lower latency and higher reliability. The MLO can switch between different frequency bands (2.4, 5, 6GHz) according to the number of users. MLO can transmit data on one frequency band (5GHz) and can receive on another frequency band (6GHz)[9].

The 802.11be is considering Multi Access Point (MAP) coordination technology which aims to improve both reliability and communication speed by controlling transmit power between APs using beam forming control and allowing multiple APs to coordinate and communicate with clients. The MAP operation features for improving operating efficiency of adjacent APs. This helps to use spectrum more efficiently and improve throughput. The coordinated transmission allows spectrum resources sharing in the time and frequency domain between a sharing AP and one or more shared APs. Beam forming between adjacent APs can be coordinated by forming spatial null beams to non-associated STA in neighborhood. In joint transmission multiple APs transmit/receive to/from one or multiple STA using same frequency in distributed MIMO scheme.

IV. WLAN FOR IOT APPLICATIONS

With over 20 years of advancements, WiFi has become the world's most common wireless network for consumers and IoT. The rapid growth of IoT has forced to rethink of Wi-Fi to play a role in encompassing connected world. Due to the increasing interest of IoT, Machine-to-machine communication (M2M), and wireless sensor applications, the WiFi enabled next generation 802.11ax/ax-ext. for high data rates, 802.11ah, 802.11af standard for mid range led to defining new standards which focus mainly on IoT applications. Next generation wireless connectivity integrates Wi-Fi and IoT. Such platforms support the billions of devices that are already Wi-Fi enabled. High performance Wi-Fi is becoming a requirement for a large range of new devices, applications, and services. This includes low bandwidth, small packet size applications such as IoT sensor nodes that poll data after every few seconds, and large bandwidth applications such as video streaming.

A. *IEEE802.11ax/ax-ext.:* IEEE802.11ax/ax-ext. is designed to support low latency bursty traffic needs and long battery life. For long battery life, it uses Target Wake Time (TWT) by which user station (STA) can sleep longer, thereby reducing power consumption. The TWT first appeared in 802.11ah standard discussed below specifically designed to support large scale deployment of IoT devices. The AP coordinates with STA to wake up at specified interval using beacon to exchange data frames. This is extended to 802.11ax/ax-ext. Multiple APs are deployed in dense environments to deliver required quality of service (QoS) to more applicants.

B. *IEEE802.11ah:* The 802.11ah is a low power midrange IoT solution. It uses sub-GHz frequency band below 900MHz to double the range, better penetration through walls, and low power for long life fit. It permits 8000 devices to connect to a single AP over 1km range and can go for sleep mode (Power saving mode). A single AP connected to a large number of devices simplifies installation and reducing total cost. IEEE802.11ah is based on 802.11ac which operates at 902-928Mhz unlicensed band using one tenth of 802.11ac BW (2,4,8,16MHz). Maxmimum throughput can reach to 347Mbps using 16MHz BW, 256 QAM, 5/6 code rate and 4X4 MIMO.

C. *IEEE802.11af:* Microsoft announced an enhanced type of Wi-Fi called *White-Fi* (IEEE802.11af) in 2008 which provides much higher speed and wider coverage than current Wi-Fi (2.4GHz frequency band) because of better propagation characteristics of the VHF/UHF ((54-216)/(470-698)MHz frequency bands. The IEEE802.11af uses unused TV spectrum called TV white spaces (TVWS). The overall system should not cause interference to the TV users. Cognitive radio technology senses the environment and configures itself accordingly. The 802.11af defines modifications to both 802.11 PHY and MAC layers to meet the legal requirements for channel access and coexistence in the TV white spaces. It can achieve 570Mbps data rate using aour 8Mhz TV channel BW, 256-QAM, 5/6 code rate and 4X4 MMIO. Wi-Fi at TV frequencies could be useful for rural broadband access for subscribers in dense forest areas.

Technologically important applications of TVWS spectrum include (*a*) Wireless distribution networks for future digital homes, smart energy grid, and remotely located industrial plants, (*b*) Licensed-exempt mobile broadband, (*c*) Last mile wireless broadband in urban environments, (*d*) Cognitive femto cells/cellular communication in TVWS.

V. CONVERGENCE OF WI-FI AND 5G

Cellular technology swept across globe over the last three decades and is ideal for outdoor coverage, high mobility, and supports real time voice and multimedia streaming. Wi-Fi and cellular are two different but most successful wireless technologies in existence and have complemented each other for years. WiFi and 5G convergence offer improved visibility into WiFi networks allowing them more control over customer experiences and ability to provide better services while mobile operators are in better position to provide enterprise WiFi network management solutions. Wi-Fi supports high capacity, high density indoors with low mobility and short ranges.

Today most mobile operators around the world rely upon WiFi networks to offload data in buildings or in dense urban environments such as malls and sports stadiums. Wi-Fi runs in unlicensed bands and 5G runs in the licensed bands and both radio technologies are combined together. The 4G LTE-Wi-Fi Aggregation (LWA) enabled by software upgrades allowing smart phones to power both radios and split the data plane traffic to Wi-Fi and LTE. The data flow over Wi-Fi will be collected by Wi-Fi Access Point (AP) and then tunneled back to LTE small cell. The data combined at LTE small cell (eNB) and then sent to evolved packet core (EPC) and then to Internet [15]. Qualcomm announced two WiFi-6E chips and both will be integrated with 5G snapdragon chips already in the market.

The 5G has three pillars namely eMBB (enhanced Mobile BroadBand) provides very high data rates, mMTC (massive Machine Type Communication), and uRLLC (ultra Reliable and Low Latency Communication). The mMTC also named as massive IoT connecting billions of IoT devices, transmitting a low amount of data at low rate, battery operated lasting 15 years. It can be used in applications like utilities, smart cities, smart agriculture, logistics, buildings (airport, hotels, stadiums), and supply chain or transportation.

The uRLLC termed as 'critical IoT', transmits at high rate large amount of data with low latency and high reliability. Applications include transportation (connected vehicles, traffic control), smart health (remote robotic surgery, patient monitoring), and industry (robots, remote manufacturing). Next generation Wi-Fi platform is enabling carrier grade wireless Gigabit services without cost and complexity by deploying in cellular 5G-NR (New Radio). The next wave of Wi-Fi are not intended to replace Macro cellular base station but enable to integrate non-3GPP like IEEE802.11Wi-Fi and 3GPP cellular technology into heterogeneous network [16]. With this licensed and unlicensed spectrum users coexist to provide wireless services to customers at attractive prices.

VI. CONCLUSION

This paper discussed next generation Wi-Fi 802.11ac/ax/ax-ext., 802.11ax/ax-ext./ah/af for IoT applications, and integration of WiFi with 5G cellular network. Increasing number of screens inside our homes from PCs, Internet enabled TVs, tablets, and smart phones, running bandwidth-intensive applications like HD video require very high speeds, higher performance, and more reliable connections. To meet these growing needs from growing Wi-Fi devices the IEEE802.11ac/ax/ax-ext. promises extraordinary improvements in speed, reliability, and quality. The increase in speed is achieved by providing wider frequency bands, faster processing, and array of antennas. Beam forming provides directional signal transmission and reception which results in boosting the reliability of connection at required speed and long range compared to omni-directionl transmit and reception in earlier standards (802.11a/b/g/n) which are subject to significant levels of interference. To support long battery life for IoT devices Target Wake Time (TWT) used in 802.11ah and 802.11ax/ax-ext. for stations. Wi-Fi enabled next generation 802.11ac/ax/ax-ext., 802.11ah, 802.11af, and 5G small cell connectivity enable integration of Wi-Fi with IoT, and Wi-Fi with 5G.

REFERENCES

[1] "The Internet of Things- Executive summary", Intern. Telecom. Union (ITU) Intern. Report-2005, Geneva, ITU, 2005.

[2] L.Ward, "IEEE 802.11ac Technology Introduction", White paper, Rohde & Schwarz, May 2011, pp. 1-23.

[3] L.Verma, M.Fakharzadeh and S.Choi, "Wi-Fi on Steroids: 802.11ac and 802.11ad", *IEEE Wireless Communication*, vol.20, no.6, Dec. 2013, pp.30-35.

[4] B. Bellalta, "IEEE802.11ax: High Efficiency WLANs", Project: arXiv:1501.01496v2[cs.NI], 8th Jan 2015, pp. 1-14.

[5] E. Khorov, *et al*. "A tutorial on IEEE802.11ax high efficiency WLAN", *IEEE Com. Survey and Tutorials*, vol.1, no.1, 2019.

[6] "What 6GHz spectrum means for connectivity, key industry, and technology implementation", A*BI Research for Visionaries*, April 2020.

[7] "Key technologies for IEEE802.11be (WiFi-7)", Anritsu Advancing beyond, Japan, White Paper, 5Aug 2022.

[8] C. S. Nin,"The state of WiFi-6, 6E,7", *RCR Wireless News*, Feature Report, Dec 2022.

[9] Lisaward, Jorg Kopp,"IEEE802.11be technology introduction", White Paper, Rohde & Schwarz.

[10] W. Sun, M. Choi, S. Choi, " IEEE802.11ah: A long range 802.11 WLAN at sub-1GHz", *J. ICT* Standardization, 2013, pp. 83-107.

[11] "IEEE P802.11ah, Specifications frame work for TGah", Doc. IEEE802.11-11/1137r13, Jan 2013

[12] Y. Zuan, *et al.*,"Advances in IEEE802.11ah standardization for machine type communication in sub 1GHz WLAN", *Proc. IEEE Int'l. Conf. Communication,* 2013, pp.1269-1273.

[13] "IEEE802.11af", IEEE Standard 802.11af, 2013.

[14] J.J. Desuse, " What's the difference between IEEE802.11af and 802.11ah", *Microwave & RF*, April, 2015, pp. 69-72.

[15] I. Selinis, *et al.*, " The race to 5G era; LTE and Wi-Fi", *IEEE Access*, vol. 6, 2018, pp. 56598-56636.

[16] C. Sbeglia,"WiFi-6 and 5G why pick?", Feature Report, *RCR Wireless News,* Aug 2020.

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