A Comparative Analysis of Wi-Fi HaLow and Wi-Fi 6 For Effective support of IoT

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CERTIFICATE

This is to certify that the course work submitted on the topic "A Comparative Analysis of Wi-Fi HaLow and Wi-Fi 6 For Effective support of IoT" is done by Swetha Srikanth Pai, bona fide student of Manipal Academy of Higher Education, Dubai Campus, in partial fulfillment of the Bachelor's Degree in Engineering Program for the course CSE-4297: Seminar during the year 2019-2020.

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DECLARATION

I hereby declare that the matter embodied in this report entitled “A Comparative Analysis of Wi-Fi HaLow and Wi-Fi 6 For Effective support of IoT” is the result of the analysis and research carried out by me under the guidance of Dr. M. I. Jawid Nazir, faculty of the School of Engineering and Information Technology, Manipal Academy of Higher Education Dubai Campus, UAE.

This work has not previously been submitted by any other candidate of any university.

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ABSTRACT

IoT or Internet of Things specifies how sensors, electronic devices, software, and human interface collect and communicate data on the same network. In recent times IoT has become very popular for a large number of applications including health care, smart homes, industrial internet, smart farming and so on. From the time IoT has been introduced many technologies were proposed for wirelesses communication between the IoT devices. Some of the common technologies include ZigBee, Wi-Fi, Bluetooth and cellular. This report will focus on Wi-Fi technology used as the network on which data is collected and communicated between the IoT devices. IoT applications have different connectivity requirements in terms of range, throughput, energy efficiency, and device cost. The popularity of Wi-Fi has increased significantly in recent years as a result of its ability to provide increased mobility, flexibility, ease of use along with reduced cost of installation and maintenance, but Wi-Fi was not preferred as a network for IoT devices due to its limited range and high-power consumption. So, two new standards were proposed by the IEEE 802.11 Working Group to overcome these limitations. In 2016, 802.11ah and 802.11ax were proposed. Further, this report will compare 802.11ah (Wi-Fi HaLow) and 802.11ax (Wi-Fi 6) and see how each of them overcomes challenges in IoT.

Keywords: IoT (Internet of Things)*, wireless communication, Wi-Fi 6, Wi-Fi Hallow.*

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ABBREVIATIONS

AID	Association Identifiers
AP	Access Points
BSS	Basic Service Set
CB	Channel Bonding
DCM	Dual Carrier Modulation
DTIM	Delivery Traffic Indication Map
DL	Down Link
DL MU-MIMO	Down Link Multi-User Multiple-Input and Multiple-Output
DPP	Device Provisioning Protocol
GHz	Giga Hertz
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
MAC	Media Access Control
MHz	Mega Hertz
MIMO	Multiple-Input and Multiple-Output
M2M	Machine-To-Machine
MU-MAC	Multiuser Media Access Control
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OPS	Opportunistic Power Save
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
RAW	Restricted Accesses Window
RU	Resource Unit
SR	Spatial Reuse
TWT	Target Wake Time
UL	Up Link
UL MU-MIMO	Up Link Multi-User Multiple-Input and Multiple-Output
Wi-Fi	Wireless Fidelity

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Since 1997, when 802.11 standard was first released to consumers, 802.11 standard has been continuously evolving resulting in faster speeds and further coverage. This report will discuss and compare the two standards 802.11ah and 802.11ax that can be used for IoT applications.

The first standard, 802.11ah also known as Wi-Fi HaLow was specially introduced to provide high range by using 900 MHz frequency which can penetrate through the walls according to [1]. It also provides low power consumption and supports connectivity with a large number of devices as mentioned in [2].

The second standard compatible with IoT is the 802.11ax standard also called Wi-Fi 6 which operates at a dual frequency of 2.5 GHz and 5Ghz [3]. It provides a very high theoretical throughput of 9.6 Gbps and it supports connectivity for dense environments [4]. It allows low power consumption for the connected devices [5].

Since IoT applications involve a large number of sensors and electronic devices that require low power consumption and long range or high Throughput, 802.11ah and 802.11ax can be appropriate for providing communication support in IoT applications.

1.2 ORGANIZATION OF THE REPORT

The subsequent sections of the report have been organized as follows: Chapter 2 describes the motivation and objective for this research. Chapter 3 introduces and describes the background of IoT, the wireless communications used in IoT and application of Wi-Fi for IoT. Chapter 4 presents a literature review of related work for application of Wi-Fi for IoT. Chapter 5 outlines the methodology of the research. The comparative analysis is presented in Chapter 6. Chapter 7 concludes the outcome of the research and presents future research possibilities.

CHAPTER 2

PROBLEM DEFINITION & MOTIVATION

In a world that runs over digital technology, IoT plays an important role in our lives. It has created an ecosystem that links many systems together to give smart performances in every task.

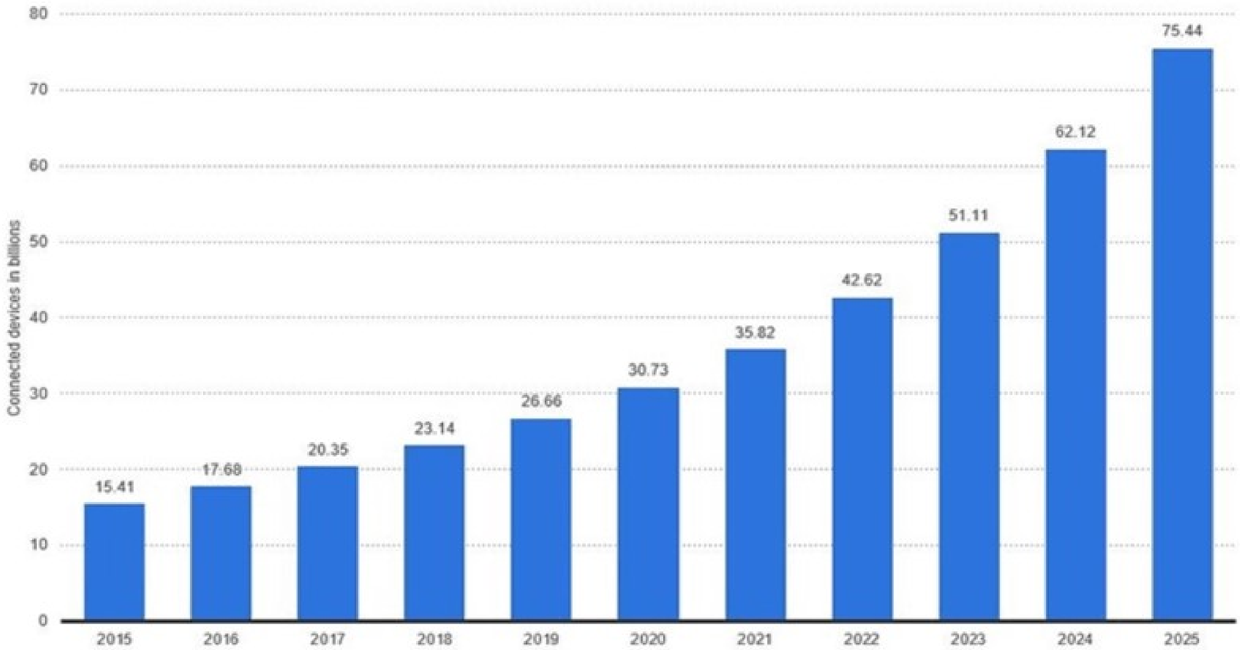

Fig 1.1 Expected increase in the number of connected devices worldwide from 2015 to 2025. [6]

The earlier IEEE wireless standards 802.11b/a/g/n/ac were not an appropriate choice for IoT applications. The reasons for this include: -

1. The first being, in most IoT applications, the IoT devices operate on batteries, thus low-power operation is a key requirement of IoT devices. The IEEE 802.11b/a/g/n/ac standards consume high-power which is not suitable for IoT devices.

2. Secondly, these standards are not appropriate as they have a limited range and some IoT applications require long ranges such as weather and agriculture.
3. The third reason is that, these standards cannot be used is because IoT applications involve large number of sensors and electronic devices and these standards can only connect to a limited number of devices.

Thus, two new IEEE wireless standards were introduced, the IEEE 802.11ah and 802.11ax. The motivation of this paper is to find how these standards overcome these challenges faced by the earlier standards in IoT applications.

CHAPTER 3

BACKGROUND

3.1 IoT

The term Internet of Things is coined by Kevin Ashton in 1999 when he proposed to use RFID in the supply chain. IoT is an umbrella term used for all technologies that enable the connection of a device to the Internet.

A complete IoT systems is an integration of four distinct components:

1. **Sensors and/or Devices:** The sensors and/or devices are responsible for collecting data from the environment. The collected data can be as simple as a temperature reading or as complex as a full video feed. [7]
2. **Connectivity:** The data collected by the sensors or devices need to be sent to the cloud or to another device. The sensors and/or devices can be connected to each other and the cloud through a variety of methods including: Zigbee, Bluetooth, Wi-Fi, NFC, RFID. [7]
3. **Data Processing:** Once the data gets to the cloud or a device, a software performs processing on it. It could be as simple as checking that the temperature reading is within an acceptable range or it could also be as complex as using computer vision on video to identify objects. [7]
4. **User Interface:** The information generated from the processed data can be used by the user to proactively check in on the system or set predefined rules so that some actions are performed automatically rather than waiting for user. [7]

Some of the Applications of IoT are:

1. **Smart Home:** Smart homes are automated homes with installed detection and control devices, such as air conditioning and heating, ventilation, lighting, hardware, and security systems. These modern systems, which include switches and sensors that communicate with a central axis called “gateways.” These “gateways” are control systems with a user interface that interacts with a tablet, mobile phone, or computer. The connectivity of the systems is managed by IoT. [8]
2. **Industrial Internet:** Industrial Internet also called industrial Internet of Things and Industry 4.0. The term Industrial internet refers to a collection of sensors, intelligent machines, electronic devices and instruments networked using IoT together with computers and industrial applications that include manufacturing and energy management. The Industrial Internet allows higher degree of automation by using cloud computing to refine and optimize the process controls. [9]
3. **Smart Farming:** The agriculture industry has employed information and communication technologies which is called smart farms. Smart farm systems are built with diverse wireless sensor devices and actuators. They can monitor the environmental conditions and control the deployed devices according to the collected data using smartphones or tablets. [10]
4. **Health care:** Smart healthcare is a system that uses technology such as wearable devices and IoT to dynamically access information, connect people, materials and institutions related to healthcare, and then actively monitors, manages and responds to healthcare needs in an intelligent manner. Smart healthcare can promote interaction between all users in the healthcare field, ensure that the users get the services they need, help the users make informed decisions, and facilitate the rational allocation of resources. [11]

3.2 WIRELESS COMMUNICATION TECHNOLOGY USED IN IoT

As mentioned in section 3.1 the sensors and/or devices need to be connected to communicate with each other and send data to the cloud for processing. The different wireless communication technologies used in IoT are:

1. **Zigbee:** The Zigbee specifications are maintained and updated by the Zigbee Alliance. Zigbee is a wireless technology developed to enable low-cost, low-power wireless M2M and IoT networks. Zigbee is based on the IEEE Standards Association's 802.15 specification. The Zigbee network operate on 2.4 GHz, 900 MHz and 868 MHz frequencies radio waves. [12]
2. **Bluetooth:** Bluetooth short-range, low-power, low-cost, small-form-factor wireless technology that allows devices to communicate with each other over radio waves. It originated as a cable replacement technology mainly to replace the serial data cables that connect various devices, now it is used in many IoT applications to provide a wireless for the IoT sensors and/or devices. Bluetooth is based on the IEEE standard IEEE 802.15.1 and operates on 2.4 GHz frequency radio waves. [13]
3. **Wi-Fi:** Wi-Fi is a high speed and high throughput wireless technology used to connect to the internet. It is based on the IEEE standard 802.11 and operates mostly on 900 MHz, 2.4 GHz, 5GHz, 60 GHz frequency radio waves.
4. **Cellular:** Cellular is a high-power consumption, high range, high bandwidth wireless communication technology. It involves many transceiver stations to which the devices connect, to transmit data and communicate with other devices. The transceiver station to which the device is connected is called base transceiver station. It operates on three bands 900/1,800/1,900 MHz or 850/1,800/1,900 MHz or four bands 850/900/1,800/1,900 MHz frequency radio waves.

3.3 APPLICATION OF Wi-Fi FOR IoT

The Focus of this report is how Wi-Fi can be used for connectivity in IoT applications.

From the table 3.1 two Wi-Fi standards have been introduced for IoT application i.e. 802.11ax and 802.11ah

Table 3.1 Table showing the different IEEE 802.11 standard versions with their specification and applications. [14]

IEEE Standard	Year Adopted	Frequency	Throughput	Max. Range	Applications
802.11a	1999	5 GHz	54 Mbps	400 ft.	Internet connectivity and data transfer
802.11b	1999	2.4 GHz	11 Mbps	450 ft.	Internet connectivity and data transfer
802.11g	2003	2.4 GHz	54 Mbps	450 ft.	Internet connectivity and data transfer
802.11n	2009	2.4/5 GHz	600 Mbps	825 ft.	Internet connectivity and data transfer
802.11ac	2014	5 GHz	1 Gbps	1,000 ft.	Internet connectivity and data transfer
802.11ad	2016	60 GHz	7 Gbps	30 ft.	High data rate application
802.11af	2014	54 MHz — 790 MHz (depending on channel)	26.7 Mbps – 568.9 Mbps (depending on channel)	1,000 m.	Internet connectivity and data transfer
802.11ah	2016	900 MHz	347 Mbps	1,000 m.	IoT
802.11ax	2019 (expected)	2.4/5 GHz	10 Gbps	1,000 ft.	IoT
802.11ay	late 2019 (expected)	60 GHz	100 Gbps	300-500 m.	High data tate applications
802.11az	2021 (expected)	60 GHz	Device tracking refresh rate 0.1-0.5 Hz	Accuracy <1m to <0.1m	Position tracking applications (Approval is due in march 2021)

The IEEE standard 802.11ah is a long-distance communication network for outdoor scenarios and supports the IoT applications. It works in a frequency band below 1 GHz. The physical layer defines the OFDM transmission for the 1 MHz channel to 16 MHz channel using CB technology. It supports MIMO and DL MU-MIMO technology for transmission and reception. The MAC layer introduced the concept of Relay AP, TWT mechanism for energy saving and sectorized BSS technology. [15]

The IEEE Standard 802.11ax is a high throughput communication network for large data transfer scenarios and IoT applications. It works in a frequency band of 2.4 GHz or 5 GHz and the goal is to achieve efficient WLANs in high-dense deployment scenarios. The PHY introduces OFDMA, UL MU-MIMO, 1024-QAM and DCM technologies, and further enhances the CB technology. The access mechanism in the MAC layer is significantly improved by including MU-MAC and SR. Extended TWT helps for saving energy. [15]

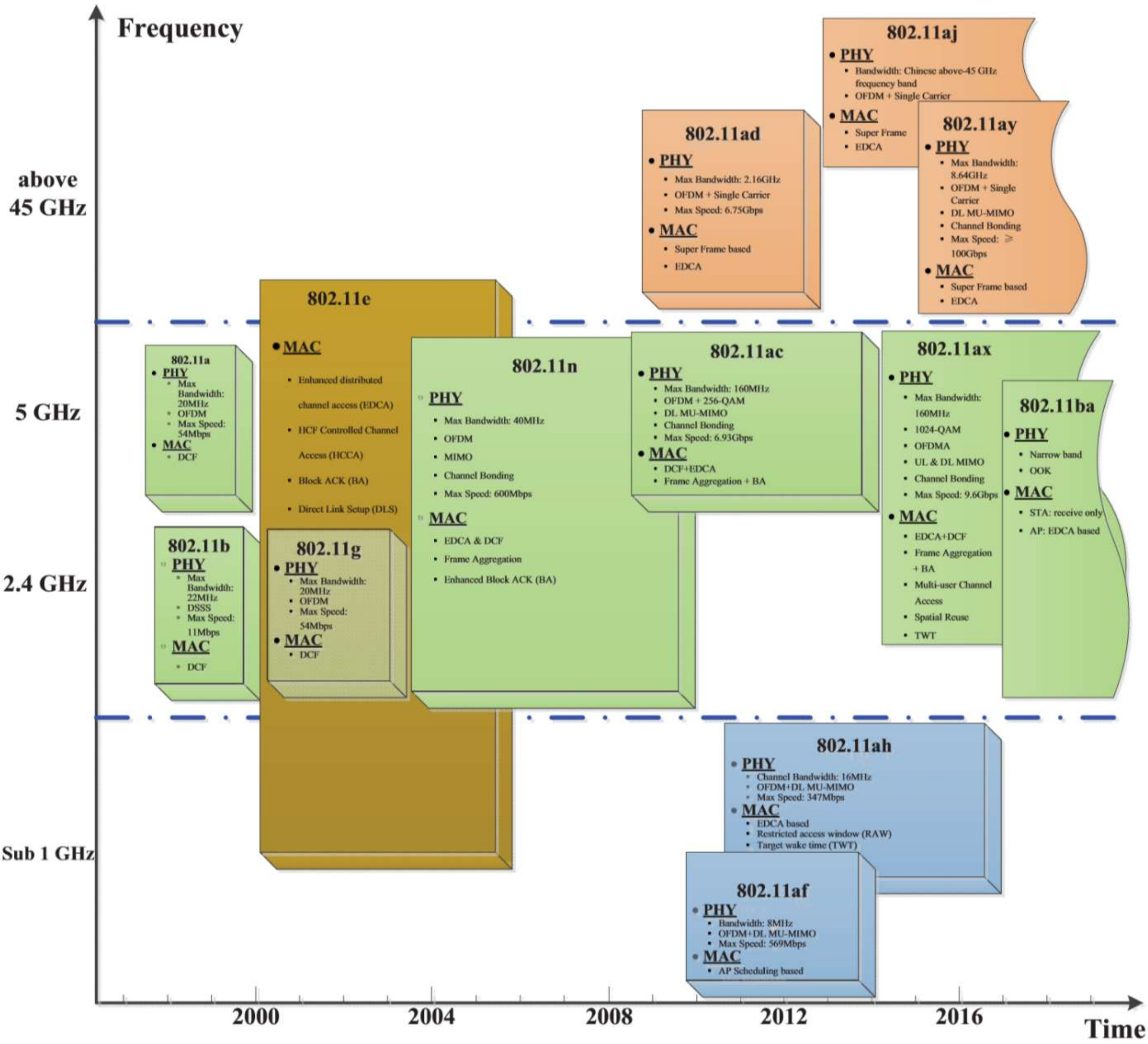

Fig 3.1 Evolution of IEEE 802.11 WLANs. [15]

Further the report will compare the two standards based on various parameters to find the best standard for different IoT applications.

CHAPTER 4

LITERATURE REVIEW

Wi-Fi was not considered as the best connectivity solution for IoT applications. The research continued to improve the Wi-Fi standard and thus two standards 802.11ah and 802,11ax were proposed. In this chapter, a few recent and important works that are closely related to the research have been presented.

IoT

In [7], Calum McClelland defines what is meant by IoT simple terms. It also gives detailed of the different components of an IoT system. The articles [8], [9], [10] and [11] give the basic understanding of different IoT applications like Smart Homes, Industrial Internet, Smart Farms and Smart healthcare respectively.

Wireless Communications technologies

The articles [7], [12] and [13] give the basic understanding of different wireless communication technologies used for IoT which include Zigbee, Bluetooth, Wi-Fi and cellular.

Wi-Fi

Article [14] identifies that 802.11ah and 802.11ax are the two standards that are suitable for IoT applications. The articles [3], [2], [5], and [15] provide knowledge of the different technologies in 802.11ah like OFDM, MIMO etc. and in 802.11ax like OFDMA and MU-MIMO etc.

CHAPTER 5

METHODOLOGY

Researchers have identified two Wi-Fi standards that are designed to cater the need of IoT application. The methodology of the research is conducted as shown if Fig 5.1.

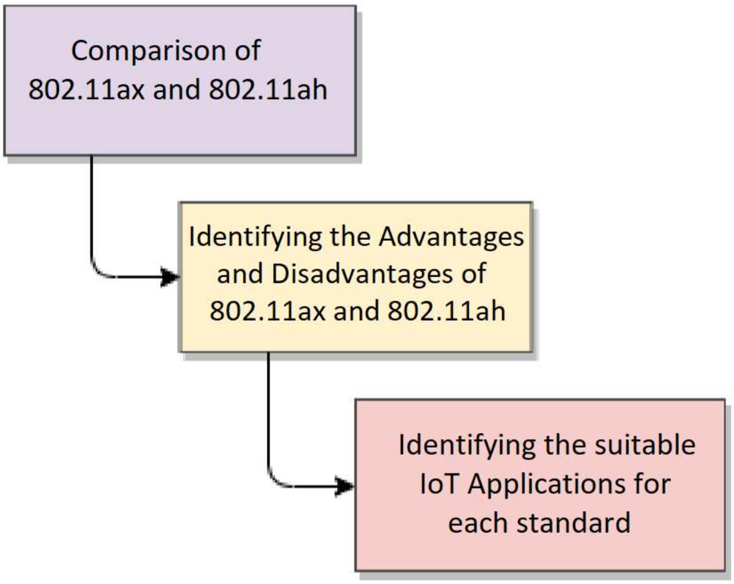

Fig 5.1 Research Methodology

5.1 COMPARISON OF 802.11ax AND 802.11ah

The paper will also compare the two standards based on the following:

1. **Power consumption:** Most IoT devices are battery driven, thus, to improve the battery life of these devices the energy consumption should be minimized
2. **Scalability:** Since IoT applications involve large number of sensors and electronic devices, the access points should be able to connect to all the IoT devices and accommodate additional devices.
3. **Frequency band:** It is the radio frequency at which the Wi-Fi signals operate. The common radio frequency used by 802.11 standard are 900 MHz, 2.4 GHz and 5 GHz.

4. **Range:** Range stands for how far data can travel. Higher frequency wireless signals have shorter range. The range requirement for IoT devices can vary from short distances for IoT devices such as wearables to Long distances for IoT applications like weather and agriculture.
5. **Throughput:** It specifies the amount of data that can be transferred from the source to the destination at a given time.
6. **Security:** Wi-Fi security includes ensuring Confidentiality, Integrity, and Availability of the data being communicated over it. IEEE 802.11ah and 802.11ax are certified with WPA3 standard.

5.2 IDENTIFYING THE ADVANTAGES AND DISADVANTAGES OF 802.11ax AND 802.11ah

Based on the comparison between the IEEE standards as mentioned in section 5.1, the research will identify the advantages and disadvantages.

5.3 IDENTIFYING THE SUITABLE IoT APPLICATIONS FOR EACH STANDARD

Based on the advantages and disadvantages identified, the report will conclude by stating which standard will be best suited for the different IoT applications, including Smart Homes, Industrial Internet and Smart Farms.

CHAPTER 6

COMPARITIVE ANALYSIS

6.1 FREQUENCY BAND AND RANGE

Frequency Band is the radio frequencies used by the IEEE 802.11 standard to transmit and receive data on the network. Range is the maximum data that can travel on the communication channel. Frequency and Range are inversely proportional i.e. if frequency is high then range is low and visa versa.

Table 6.1 Frequency Band and Range of IEEE 802.11ah and IEEE 802.11ax

Standard	802.11ah	802.11ax
Frequency band	Sub 1 GHz (900 MHz is mostly used)	1Ghz – 7GHz (2.4 GHz and 5GHz is mostly used)
Range	1000 meters and upto 1Km in outdoor scenario	300 meters

IEEE 802.11ah

The IEEE 802.11ah amendment operates at sub1 GHz frequency band for communication.

The Advantage of using sub 1 GHz frequency band are: -

1. It provides long range as 1 GHz radio frequency signals can travel and penetrate through the walls bend around corners.
2. The sub 1 GHz faces less interference because there are fewer existing products on air at sub 1 GHz.
3. Low frequency band consume less power from the stations.

The disadvantages of using sub 1 GHz frequency band are: -

1. The 802.11ah spectrum is not harmonized globally, It operates at 900 MHz in the US, 850 MHz in Europe, 700 MHz in China, and does not even have the operating spectrum in many countries. [3]
2. It is not backward compatible with the older IEEE 802.11 amendments.

3. Some devices do not support Sub-1 GHz communication systems for band communication.

IEEE 802.11ax

The IEEE 802.11ax amendment operates at a frequency band of 1 GHz to 7 GHz for communication.

The advantages of using 1GHz – 7GHz bands are: -

1. IEEE 802.11ax devices consistently uses 2.4 GHz and 5GHz frequency globally.
2. It is backward compatible with older IEEE 802.11 amendments.

The disadvantages of using 1GHz – 7GHz bands are: -

1. 2.4 GHz and 5 GHz provide shorter range as it cannot travel long distances and penetrate through the walls.
2. The 2.4 GHz frequency band faces interference from devices such as microwave oven and devices using Bluetooth or 2.4 GHz Zigbee.
3. Higher frequency bands consume more power from the stations.

6.2 POWER CONSUMPTION

As discussed in the research before, most IoT devices are battery operated, thus low power consumption is an essential requirement for all IoT applications so that the devices have a long battery life.

Table 6.2 Low Power Consumption Technologies in IEEE 802.11ah and IEEE 802.11ax

Standard	Technologies Used for Low Power Consumption
802.11ah	RAW, TIM, TIM Segmentation, TWT
802.11ax	Microsleep, Enhanced TWT, Opportunistic Power Save

Power management in 802.11 networks is based on alternating between two states i.e. awake state and doze state. In the awake state, a station can transmit and receive frames, while it remains idle in the doze state. An active station is always awake, while a power saving station alternates between these states.

IEEE 802.11ah

IEEE 802.11ah introduces RAW, that is a time window during which only the stations specified by the AP in a beacon frame can attempt to access the medium. RAW divides the stations into groups. Each group has one or more RAW slots over which the stations belonging to that group are evenly divided. Only the stations that belong to a RAW slot are allowed to access the channel. RAW allows stations to sleep outside of their assigned slots, thus saving power. [16]

Through the use of a TIM it is possible for the AP to communicate to the stations if there is buffered information for them to retrieve. The stations need to only wake up to listen to their corresponding TIM beacon, thus they can maintain a longer power-saving state. This allows IEEE 802.11ah to reduce channel congestion and increase energy efficiency for highly populated networks. [17]

In the legacy 802.11 standards, beacons trigger power saving station to contend for the channel, which is the drawback of the whole power management system as the stations have to wake up to listen to every beacon that is broadcasted by the AP. Thus IEEE 802.11ah has also introduced the TIM segmentation mechanism to divide information transmitted in the TIM into several segments and transmit them separately. In addition to using TIM beacons for station-level signaling, it also uses DTIM beacons for TIM group-level signaling. The AP uses the DTIM beacon to broadcast to stations which TIM segments have pending data so that only those stations need wake up to listen to their corresponding TIM beacon, hence they maintain longer power-saving state. [18]

Power consumption can be further reduced by TWT for stations transmitting data less frequently. TWT allows the TWT requesting station to periodically negotiate with another TWT responding station or AP when the TWT requesting station wakes up for some time, called TWT Service Period and exchanges frames with the TWT responding station. This mechanism allows the TWT requesting station to doze always except during the TWT Service Period intervals. Thus, having established TWT Service Periods with the AP, the station is not required to wake up to respond to the beacons, which significantly reduces energy consumption. [19]

IEEE 802.11ax

The microsleep operation was introduced in 802.11ac. In 802.11ac, the PHY header contains the Partial AID which indicates the transmitter and the receiver of a frame. Thus, all the other stations can go to the doze state for that frame duration. 802.11ax extends microsleep operation by allowing a station to doze during uplink transmissions or the transmission opportunity of another station in the same BSS. [19]

IEEE 802.11ax has adapted the TWT mechanism introduced in 802.11ah as a power saving mechanism. In 802.11ah, the TWT operation is tightly connected with other 802.11ah enhancements such as RAW and the modified control frames. These enhancements are not supported by 802.11ax stations, Thus IEEE 802.11ax has reimplemented and extended the concept of TWT. In 802.11ax networks, TWT Service Periods can be either individually agreed or broadcast. Individually agreed TWT Service Periods are negotiated between a pair of devices. The broadcast TWT Service Periods are not negotiated but they are scheduled by the AP which distributes information about them in beacons. Those stations which have received this information but have not established individual TWT Service Periods with the AP, should transmit information only within the announced broadcast TWT Service Periods. [19]

The OPS mechanism allows an AP to divide a beacon interval into several sub-intervals and at the beginning of each subinterval. it provides information on which stations are going to be served in this subinterval. Based on this information, the non-AP stations can opportunistically go to doze state until the next broadcast TWT Service Period. This mechanism is based on the combined usage of TWT and the legacy TIM element. TIM is used in legacy power management mechanisms to indicate the set of stations for which the AP has buffered data. In OPS, TIM is transmitted by the AP together with the broadcast TWT Service Period advertisement at the beginning of the TWT Service Period. In this case, TIM indicates a set of Stations that should be awake during the current TWT Service Period since the AP is going to transmit to them or trigger them for UL traffic. If a Station is not indicated in TIM, it can doze during the current TWT Service Period. The idea of OPS is close to the TIM Segmentation used in 802.11ah. However, in contrast to TIM Segmentation, OPS reduces time granularity. [19]

6.3 THROUGHPUT

Throughput is the amount of data that can be transmitted from one location to another in a given period of time. Some IoT applications may transmit small data like temperature reading or large video files from CCTVs.

Table 6.3 Throughput in IEEE 802.11ah and IEEE 802.11ax

Standard	Technologies Used for Providing throughput	Throughput
802.11ah	Compact frame format	347 Mbps
802.11ax	1024-QAM, DL/UL MU-MIMO, Long OFDM symbol	10 Gbps

IEEE 802.11ah

The overhead associated with frame headers for example MAC Header may be considerable when compared to the size of the payload. In order to reduce overheads and to increase the efficiency and thus, increase the overall throughput, the MAC design of IEEE 802.11ah introduces compact frame formats. The new header design is significantly changed by including only two mandatory address fields as compared to four addresses fields present in the legacy MAC header. The Quality of Service and High Throughput fields have been shifted into SIG field in PHY header and Duration/ID field has been removed. Thus, reducing the size of the MAC header. [20]

IEEE 802.11ax

IEEE 802.11ax leverages the MU-OFDMA and MU-MIMO for better efficiency of UL and DL transmissions. OFDMA transmits big chunks of data over a single noisy channel. This technique works by dividing a single signal into multiple smaller signals and then transmitting them. IEEE 802.11ax has introduced UL MU-MIMO is a new key feature. By leveraging UL MU-MIMO, multiple clients connected to the access point will be able to simultaneously send acknowledgement responses, thus saving airtime. OFDMA and MU-MIMO together allow IEEE 802.11ax to achieve increased capacity, improved coverage and performance in ultra-high-density environments. This ultimately improves network throughput and efficiency. [21]

QAM is a technique used by IEEE 802.11 standard to modulate binary digits to an analogue signal. These signal transmissions are called symbols. Each symbol is transmitted for a certain period called symbol time, and the transmissions are separated by guard intervals. IEEE 802.11ax supports 1024-QAM which is an increase from 256-QAM on IEEE 802.11ac. Compared to 8 bits for 256 QAM, the number of bits transmitted per OFDM symbol for 1024-QAM is increased to10 bits. This results in a 25% increase in throughput by cramming more data into each packet. [21]

Longer OFDM Symbols increases the duration of OFDM symbol transmission to 12.8ms on IEEE 802.11ax from 3.2ms on IEEE 802.11ac and supports a longer cyclic prefix for each symbol. This results in up to 20% increase in the throughput. [21]

6.4 SCALABILITY

The main characteristic of IoT networks have is that they are formed by a large number of autonomous devices generally ranging from hundreds to few thousands. Collisions occur frequently when a large number of devices try to simultaneously communicate. Overall throughput in the network is reduced due to excessive collisions. Thus, finding appropriate methods to reduce collisions is a necessary to meet IoT requirements. Spatial Reuse enhances frequency reuse in dense deployments. Thus the connectivity mode used should provide spatial reuse.

Table 6.4 Scalability in IEEE 802.11ah and IEEE 802.11ax

Standard	Technologies Used for Providing Scalability	No of Stations Supported Per AP
802.11ah	RAW, Hierarchical 13-bit AID	8000
802.11ax	OFDMA, MU MIMO, SR and BSS colour	8000

IEEE 802.11ah

The IEEE 802.11ah defines a channel access mechanism RAW discussed in 6.2. In this access mechanism, by dividing stations into different groups and restricting channel access only to a group at a particular time period improves the channel efficiency, thus reducing collisions. [20]

The Legacy IEEE 802.11 standard supports up to 2007 associated stations per AP), as only a limited number of AIDs are available, that can be assigned to each associated station. To increase the number of stations supported by the AP, IEEE 802.11ah uses a hierarchical AID structure. Now, the new AID consists of 13 bits and thus the number of supported stations is $2^{13} - 1$, which increases from 2007 to 8191. [20]

IEEE 802.11ax

IEEE 802.11ax introduces OFDMA, which divides the channels into several RUs, each RU consists of multiple subcarriers. Then, each station is supported in one RU for UL or DL transmission. By enabling parallel transmission, OFDMA reduces the overhead and collision, and further enhances spectrum efficiency. [15]

DL MU-MIMO is adopted from IEEE 802.11ac by 802.11ax and it further introduces UL MU-MIMO to ensure symmetrical high throughput for both DL and UL. IEEE 802.11ax allows up to eight stations to transmit through MU-MIMO simultaneously. MU-MIMO and OFDMA work together, i.e., multiple stations can parallelly send or receive frames in the same RU through MU-MIMO, which further increases transmission efficiency. [15]

The concept of BSS colour was proposed in the IEEE 802.11ah amendment by filling the colour field in SIG to distinguish whether the receiving packet is from intra-BSS or inter-BSS. However, IEEE 802.11ah does not focus on how to detect and avoid conflict in BSS colour. IEEE 802.11ax extends the BSS colour into the SR mechanism. Based on BSS colour, stations can differentiate whether the received packets is from intra-BSS or inter-BSS. The BSS colour mechanism is an innovative mechanism to increase frequency reuse for dense WLAN networks, where each BSS is assigned a specific color so that the nodes can distinguish the source of the packet and then perform appropriate SR operations. When a station receives frames from neighboring BSS, it can abandon the reception process assuming that the channel is idle during that transmission and thus increasing the transmission opportunities. [15] [2]

6.5 SECURITY

The data transmitted over the wireless medium is vulnerable and prone to attacks. This can compromise the confidentiality, integrity and availability of the data. For IoT most of the data coming from the sensors are processed and used for decision making thus security of the data is crucial requirement for IoT. Both the IEEE standers 802.11ah and 802.11ax implement the latest WPA3.

The WPA3 protocol incorporated new features for personal and enterprise use such as:-

1. It provides authenticated encryption by using 256-bit Galois/Counter Mode Protocol (GCMP-256).
2. The 384-bit Hashed Message Authentication Mode (HMAC) with Secure Hash Algorithm (SHA) is used for Key derivation.
3. The Elliptic Curve Diffie-Hellman (ECDH) exchange and Elliptic Curve Digital Signature Algorithm (ECDSA) is used for Key establishment.
4. Frame protection is based on 256-bit Broadcast/Multicast Integrity Protocol Galois Message Authentication Code (BIP-GMAC-256). [21]

WPA3 is more secure and comprehensive than WPA2 as WPA3 includes the following notable features:

1. **Simultaneous Authentication of Equals protocol:** This is used to create a secure handshake, when a network device connects to a wireless AP and both the devices communicate to verify authentication and connection. WPA3 provides a more secure handshake even if a user’s password is weak, using Wi-Fi DPP.
2. **Individualized data encryption:** When a new device is logging on to a public network, WPA3 signs up a that device without using shared password. Instead it uses a system called Wi-Fi DPP that allows users to use NFC tags or QR codes to allow devices to log on to the network. WPA3 security also uses GCMP-256 encryption, instead of 128-bit encryption used previously.
3. **Stronger brute force attack protection:** WPA3 protects against offline password guesses by allowing a user only one guess, making the user have to interact with the Wi-Fi device directly, meaning they would have to be physically present every time they want to guess the password.
4. **Bigger session keys:** WPA3 supports larger session keys sizes i.e. upto 192-bit security. [21]

CHAPTER 7

CONCLUSION & FUTURE WORK

This report identifies the two Wi-Fi standards used for IoT i.e. IEEE 802.11ah and IEEE 802.11ax. It also compares the two standards based on Range and frequency band, Throughput, Power consumption, Scalability and Security. During the comparison, terms such as RAW, TIM, TIM segmentation, TWT, Compact frame format and Hierarchical AID were discussed for IEEE 802.11ah, and Terms such as Microsleep, Enhanced TWT, Opportunistic Power Save, OFDMA, MU-MIMO, SR and BSS colour, 1024-QAM, DL/UL MU-MIMO, Long OFDM symbol were discussed for IEEE 802.11ax in the report.

From the comparison, the report finds that both the standards provide Low Power Consumption, Scalability and latest WPA3 security. The differences are in the frequency band used, range provided, and throughput provided. The 802.11ah amendment operates at sub 1GHz, provides very long range upto 1 km but less throughput of 347 Mbps. Whereas, the IEEE 802.11ax amendment operates at a dual band of 2.4 GHz and 5 GHz, provides very high throughput upto 9.6 Gbps but shorter range of upto 300 meters.

Thus, we can conclude that the decision making parameters for choosing between IEEE 802.11ah and IEEE 802.11ax for a particular IoT application will be the Frequency band, Range, and throughput requirements of that IoT application.

The future scope of this research will be to use a Network Simulator such as NS3 to simulate different IoT application scenarios with IEEE 802.11ah and IEEE 802.11ax and use the simulator to compare and find the most suitable Wi-Fi standard.

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