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Wireless Internet Connectivity: 5G and Wi-Fi 6

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Abstract

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The thesis describes wireless internet connectivity, 5G, and Wi-Fi 6 and studies in detail its differentiation from the previous version. This research aims to provide comprehensive information on the developments in mobile networks, the advancement of wireless networks, and their operating principles.

This study went through a thorough literature review of the most recent materials regarding wireless networks to accomplish this. Furthermore, the practical implications of these developments have also been considered and discussed in this thesis. The thesis includes a theoretical background of wireless networks along with their brief history and working with wireless technology. The study especially considered the 5G and Wi-Fi 6 innovations in detail, their architecture, and critical principles.

The final part of this thesis compares as well as details the advantages and disadvantages of both 5G and Wi-Fi 6.

Keywords: Wireless Networks, Wi-Fi 6, 5G

Contents

List of Abbreviations

IEEE	Institute of Electrical and Electronics Engineers
RF	Radio Frequency
WLAN	Wireless Local Area Network
WEP	Wired Equivalent Privacy
WPAN	Wireless Personal Area Network
WMAN	Wireless Metropolitan Area Network
WWAN	Wireless Wide Area Network
GSM	Global System for Mobile Communication
ETSI	European Telecommunication Standards Institute
LTE	Long-Term Evolution
NSSF	Network Slice Selection Function
MIMO	Multiple Input Multiple Output
LAN	Local Area Network
WAN	Wide Area Network
OFDMA	Orthogonal Frequency-division Multiple Access
TWT	Target Wake Time
AP	Access Point

1 Introduction

Mobile network providers have been focusing a lot of effort on the fifth generation of wireless communication, known as 5G, which is presently under implemented. Beyond the third generation, universities, industries, government sectors, and international organizations have discussed and explored the technology. As a result, the perception of wireless continues to shift, signaling the start of substantial changes in wireless networking systems.

The rising global market's need for faster, higher-quality wireless services propelled wireless into a type of revolution that combined the internet's and the PC's ubiquitous nature.

Concepts and technologies for novel architectures, spectrum allocation, and use in radio communications, networks, services, and applications make up the next generation. [1].

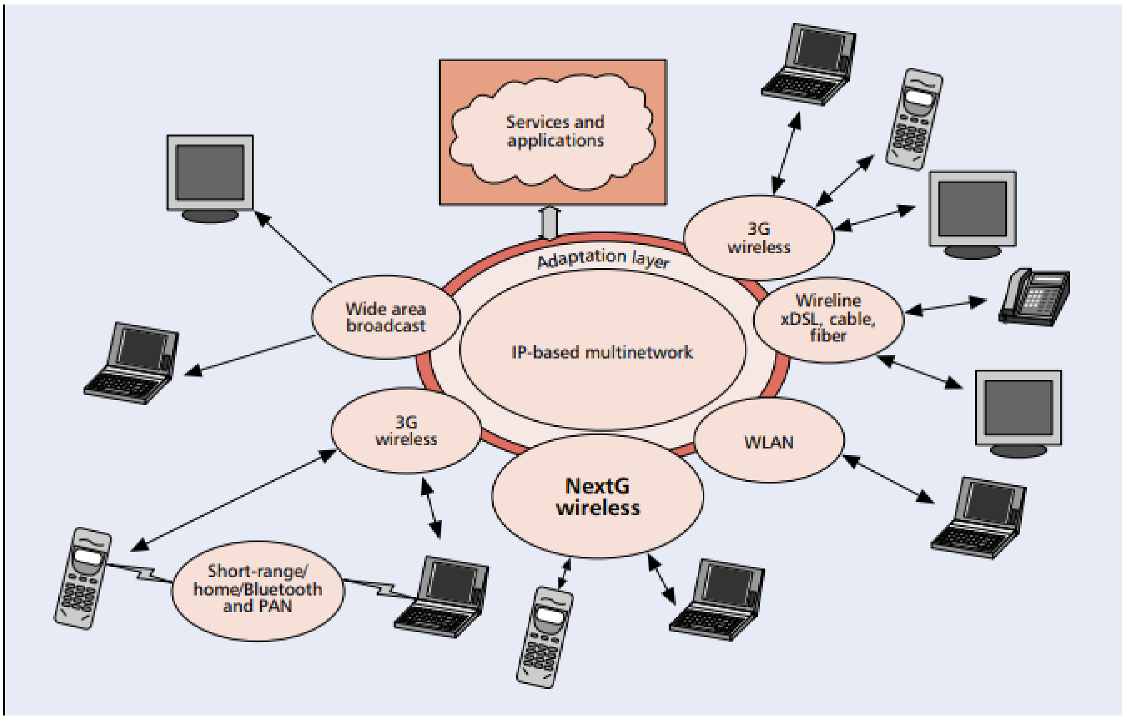

Figure 1: Approaches and networks in a multinetwork. [1, p.108]

Hundreds of billions of devices are expected to be connected to the internet as the Internet of Things (IoT), smart cities, and other technologies gain traction. With new technologies like these, there are various environmental and energy issues.

5G, or fifth generation, is the most recent version of preceding mobile network generations such as 1G, 2G, 3G, and 4G. In comparison to its predecessor, 5G will offer faster speeds, more throughput, more capacity, and lower latency. [2].

Ericsson estimates that 3.5 billion 5G subscriptions will be in use by the end of 2026, accounting for roughly 40% of worldwide mobile subscriptions.[3]. 5G and 802.11ax, also called Wi-Fi 6, refer to the fastest growing technology. As a result, many networking companies have invested in this sector and are already making progress and selling them to consumers. Surprisingly Wi-Fi 6 has received less attention. Both technologies aim to give a much-improved performance, allowing them to provide much faster wireless broadband access and provide additional support for the Internet of Things and Machine-to-Machine interactions, effectively making them technical alternatives in many cases.

As a result, the components of mobile networks will be reviewed in this study to grasp the basics of mobile networks better. It's critical to comprehend how 5G differs from previous LTE network architectures and how it achieves efficiency. [1].

The thesis is divided into two sections. In the first section, wireless connectivity, 5G, and Wi-Fi 6 have been described briefly, and in the second section, some use cases have been discussed.

2 Wireless Technology

The deployment of the next generation of wireless technologies for both cellular and Wi-Fi connectivity has been underway for a long time now. While the new version of cellular technology 5G has garnered a lot of excitement worldwide, the next version of the Institute of Electrical and Electronics Engineers (IEEE) 802.11 Wireless Local Area Network (WLAN) standard is, known as Wi-Fi 6, also made comparable enthusiasm.

Communicating one or more devices over distances without cables or wires is referred to as wireless technology. It uses radio signal advantages that can be easily installed, more scalable, and allows multiple devices to use the same wireless connection simultaneously.

Heinrich Hertz (1857-1894) discovered electromagnetic waves, which started the paving for wireless technology. After that, Guglielmo Marconi established the first commercial RF communications. But the first commercial wired telegraph was demonstrated in 1832 by Samuel F.B Morse. Wireless technology has always come before wired technology because of its mobility and the possibility for the user to receive and transmit information on the move, but it is also more expensive.

In the 1990s, market-leading companies like Ericsson, IBM, Intel, Nokia, and Toshiba announced the development of Bluetooth technology jointly. For that reason, a committee named 802.11 was set up, which released the Wi-Fi network for consumers. The committee used IEEE802.11 standards to set up the WLAN. From 2000 consumers were more interested in WLAN other than WEP. [4, p.3].

2.1 Types of Wireless Network

There are four types of wireless networks-WLAN, WMAN, WPAN, WWAN- each with its function. Below is a summary of these:

- Wireless Personal Area Network (WPAN)- covers a minimal area for individual workspace ranging between 5-10 meters like Bluetooth, apple pay, or Zigbee. It has a capacity of 10bps to 10 Mbps. WPAN represents an example of ad-hoc networks such as PDAs, Web-pad organizers, computers, and cameras.
- Wireless Local Area Network (WLAN) - WLAN focus on the ability to connect the AP to a switch and either have it managed by a wireless LAN controller or act autonomously of a wireless LAN controller range less than 100 meters so the radio waves being emitted from the wireless access point either in an autonomous architecture or a centralized architecture can travel out to about 100 meters.
- Wireless Metropolitan Area Network (WMAN) - A range of greater than 100 meters and used mainly by municipalities. Typically, the APs located on the sides of buildings or a telephone pole and broadcast a wireless signal over the region. A wired network is used to connect the Aps through the internet.
- Wireless Wide Area Networks (WWAN) – Cellular technology is used in wireless WANs when the range of a wireless LAN or metropolitan network is not enough. Users can use these networks for phone calls to those connected to them via a wireless WAN or a wired telephone connection. Furthermore, they can also access web pages or server-based apps by connecting to the internet. [5].

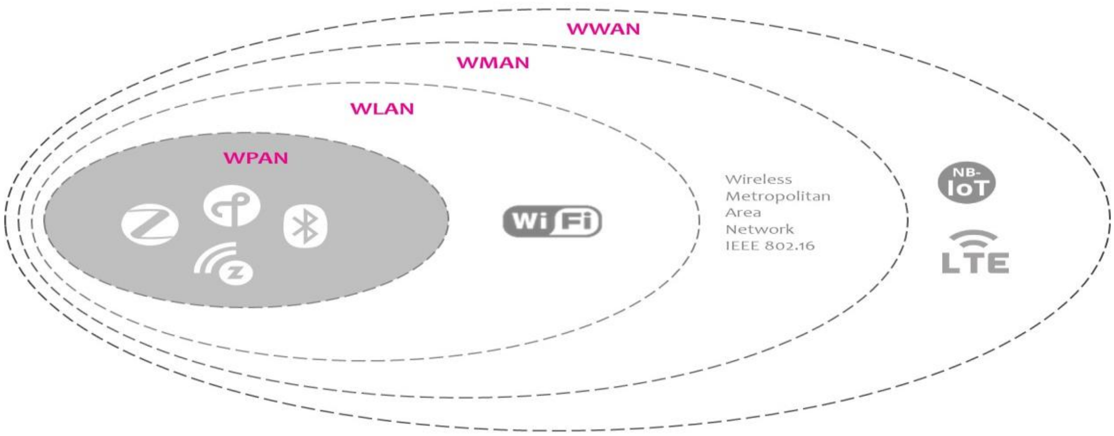

Figure 2: Examples of Wireless Technology. [6].

2.2 Utilizing Wireless Technology

The WLAN standard's security, which applies to 802.11b, 802.11a, and 802.11g, has been scrutinized and tested extensively. Researchers, as well as hackers, have discovered flaws in the specification's authentication, data privacy, and message-integrity systems. IEEE defines the Wi-Fi standard under 802 networking specifications, where 802.3 defines the Ethernet, 802.15 defines the Bluetooth, and 802.11 defines the Wi-Fi networking standards. A Wi-Fi network is built with the help of several hardware components. WLAN architecture is based on three elements:

- Wireless end stations
- Access points
- Basic service sets

RF technology has been used to transmit and receive the data over the air by WLAN, where the first step is the scanning function. A wireless station is needed to find other access points for the scanning function, as with tuning into a radio station. As a result, the 802.11 standard distinguishes between two scanning modes, active scanning, and passive scanning. [7].

The radiofrequency (RF) is responsible for transporting energy from the sender to the receiver/transmitter (transceiver). In wireless technology, access points (AP) serve as the transceiver. Data is received, buffered, and disseminated via APs. A single AP can work at several meters and with a limited number of users.

Most wireless devices that operate in the RF spectrum, such as cell phones, Wi-Fi, and Bluetooth, employ RF fields. L.f., m.f., and h.f., which stand for low, medium, and high frequency, respectively, split the radio frequency spectrum into numerous bands. [8, p,27].

f	λ	Band	Description
30–300 Hz	10^4–10^3 km	ELF	Extremely low frequency
300–3000 Hz	10^3–10^2 km	VF	Voice frequency
3–30 kHz	100–10 km	VLF	Very low frequency
30–300 kHz	10–1 km	LF	Low frequency
0.3–3 MHz	1–0.1 km	MF	Medium frequency
3–30 MHz	100–10 m	HF	High frequency
30–300 MHz	10–1 m	VHF	Very high frequency
300–3000 MHz	100–10 cm	UHF	Ultra-high frequency
3–30 GHz	10–1 cm	SHF	Superhigh frequency
30–300 GHz	10–1 mm	EHF	Extremely high frequency (millimeter waves)

Table 1: Designations for frequency bands

The relationship between frequency (f) and wavelength (λ) is seen in Table 1. The following equation represents the relationship in a vacuum:

$$C = f \bullet \lambda$$

Where *c* represents the speed of light, here Frequency and wavelength have a negative correlation. For comparison, a 1 GHz wave has a wavelength of about 1 foot, whereas a 100 MHz wave has a wavelength of about 10 feet. [9].

3 5G

3.1 5G: A Quick Review

In 1900 the fixed phone was spreading in the world. Following the 1930s, when the mobile phone system was invented, it kickstarted the idea of going wireless. It was a simple system where communication happened through two radio connections between the networks and the transceiver in a car.

In the 1980s, Bell Labs introduced advanced mobile phone systems, which marked the 1G or the first generation of cellular communication. It only had the capacity of voice calls, frequency of narrow bands, and a maximum speed of 2.4Kbps. However, this was not free of specific issues, such as poor voice quality, poor battery life, and poor security.

Soon after the rollout of 1G, work began on digital cellular communications. In 1987, 13 European countries signed an agreement in Copenhagen to develop and implement a standard cellular telephone system all over Europe, resulting in GSM specifications from ETSI.

In 1991 the commercial launch of GSM in Finland took place. 2G was introduced, which offered bandwidths of 30KHz to 200KHz and allowed users to send SMS and MMS. After creating the MMS, network companies looked for more about social connectivity. To search for this, back in 2001, 3G was introduced with high-speed data and allowed data rates up to 14Mbps. With 3G, end-users could make video calls, web surf, play games, and watch TV online. [10].

In the late 2000s came the complete packet-switched to technology based on LTE, making the fourth generation of telecommunications. 4G utilized channels and can have a bandwidth from 1.4 MHz to 20 MHz. Before 2023 the global mobile data traffic will increase to 39 percent of the Compound Annual Growth Rate, according to Ericsson, a technology giant. Realizing the capacity level, the requirements specifications for 5G were determined by International Telecommunications Union in 2015. [11]

The increasing necessities and new ideas require more and more machines to access the mobile internet. To meet the demand of the growing requirements, 5G developed in recent years and continues to evolve regularly. 5g supports bandwidth up to 400MHz.

Technology	1G	2G/2.5G	3G	4G	5G
Deployment	1970/1984	1980/1999	1990/2002	2000/2010	2014/2015
Bandwidth	2kbps	14-64kbps	2mbps	200mbps	>1gbps
Technology	Analog cellular	Digital cellular	Broadbandwidth/ cdma/ip technology	Unified ip & seamless combo of LAN/WAN/WLAN/PAN	4G+WWWW
Service	Mobile telephony	Digital voice, short messaging	Integrated high quality audio, video & data	Dynamic information access, variable devices	Dynamic information access, variable devices with AI capabilities
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit/circuit for access network&air interface	Packet except for air interface	All packet	All packet
Core network	PSTN	PSTN	Packet network	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal& Vertical	Horizontal& Vertical

Table 2: Comparison of mobile network technology. [12].

Table 2 compares the generation of mobile networks in terms of deployment years, bandwidth, used technology and switching. From 1G to 5G, the mobile networks evolved rapidly and started from voice calls to low latency video streaming, where latency is 1mSec.

3.1.1 The 5G System

The 3G system has three major sections, UE, RAN-UTRAN, and a service network reached through the core network. Smartphones and modems are examples of User equipment, and the RAN called UTRAN consists of all the functions that make wireless access possible. NodeB on the radio network controller performs functions such as subscriber data storage, security, and policy administration in the 3G RAN. [13]. Similarly, the 4G system also has the user equipment that accesses the network, RAN, and core network. RAN termed EUTRAN for 4G system comprised of eNodeB and evolved packet core termed for 4G core network. [14].

5G system also has significant sections like 3G and 4G consisting of User equipment, RAN, and the core network. The UE are the laptops, smartphones, tablets, and modems capable of a 5G network. The 5G RAN is comprised of gNodeB, which supports the new ad interface. The core network contains functions that support Access and Mobility Management Function, Session Management Function, User Plane Function, etc. It is also built using modern software development technologies like the service-based architecture and network virtualization. [13].

	MME	S-GW	P-GW	HSS	PCRF	AF	New
AMF	✓						
SMF	✓		✓				
UPF		✓	✓				
PCF					✓		
AUSF				✓			
UDM				✓			
AF						✓	
NEF							✓
NRF							✓
NSSF							✓

Table 3: Transformation of core network functions from 4G to 5G [15].

The table above shows the transformation of the core network functions. 5G has some new core network functions than 4G, like NSSF. Its primary function is to provide a virtual slice of RAN, core, and transport networks that is required.

3.2 5G Radio Access Network

Radio Access Network is the system that connects individual devices via radio connections to the other network parts, shortly RAN. User equipment such as mobile phones, computers, or any remotely controlled machine has the RAN, which provides a connection to its core network. [16].

The 5G interface has two major requirements. It must make the best use of the new spectrum, many of which are in the millimeter wave bands. Second, it must support the new use cases, which led to the development of unique wireless access called NR or new radio that will be used with other wireless access like LTE.

Figure 3: 5G NR

Our phone is connected to the internet today by 4G LTE, 5G NR will make the connection a lot faster, efficient. [17].

3.2.1 Massive MIMO

To increase network capacity for 4G, MIMO (multiple input, multiple output) is the critical technology. It provides diversity gain between transmitter and receiver by sending the same signals through different paths and multiplexing gain by transmitting independent signals in parallel through spatial channels.

Massive MIMO consists of arrays of antennas to serve the terminals simultaneously and time-frequency resources. Millimeter waves (mmWaves), also known as high band frequencies and Massive MIMO, are inter-relatable, making each other viable.

Massive MIMO has three key concepts:

- Spatial Diversity
- Spatial Multiplexing
- Beamforming

When a signal is sent from the transmitter to its receiver, it can deflect in many forms, in particular reflections from buildings and other obstacles, filtered by its environment, which is the fact that builds MIMO.

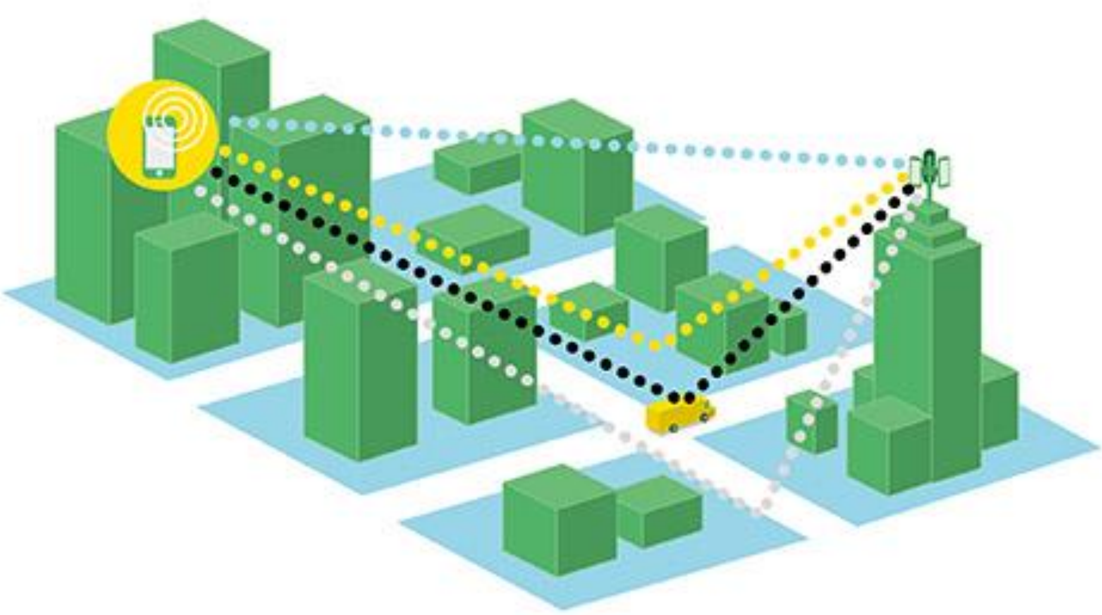

Figure 4: Multiple paths for a signal [18].

In the figure above, a signal from the transmitter reflected in various ways will arrive at the receiving antenna after slight time delays, attenuation level, and travel direction. Each antenna will receive a slightly different version of signals, later will combine all signals mathematically for better-transmitted signal quality. This is also called spatial diversity.

By using the multiple transition paths, the capacity of the radio links is increased by spatial multiplexing, which allows various, unique streams of data to be sent between the transmitter and receiver. Increasing throughput and a single transmitter support multiple users, thus MU-MIMO. [19].

3.2.2 Beamforming

Beamforming is another critical concept of MIMO, which works to increase network capacity and throughput. It focuses on one direction of the wireless signal, ignoring a wide area. By this technique, the same signal is emitted from each of the transmit antennas with appropriate face adjustment such that the signal power is maximized at the receiver input.

Massive MIMO systems have a large number of antennae that enables 3D beamforming. Channel State Information provides information on how the signal transfers from transmitter to receiver and how it reflects from fade and power decay over distance. The MIMO system decoder performs signal processing to recover the data; a calculation has been used in matrix form.

The formula for the calculation is:

[R] = [H] * [T]

Where R is the series of signals received, H is the properties of the signal path, and T represents the various data streams being transmitted across the network. [18]

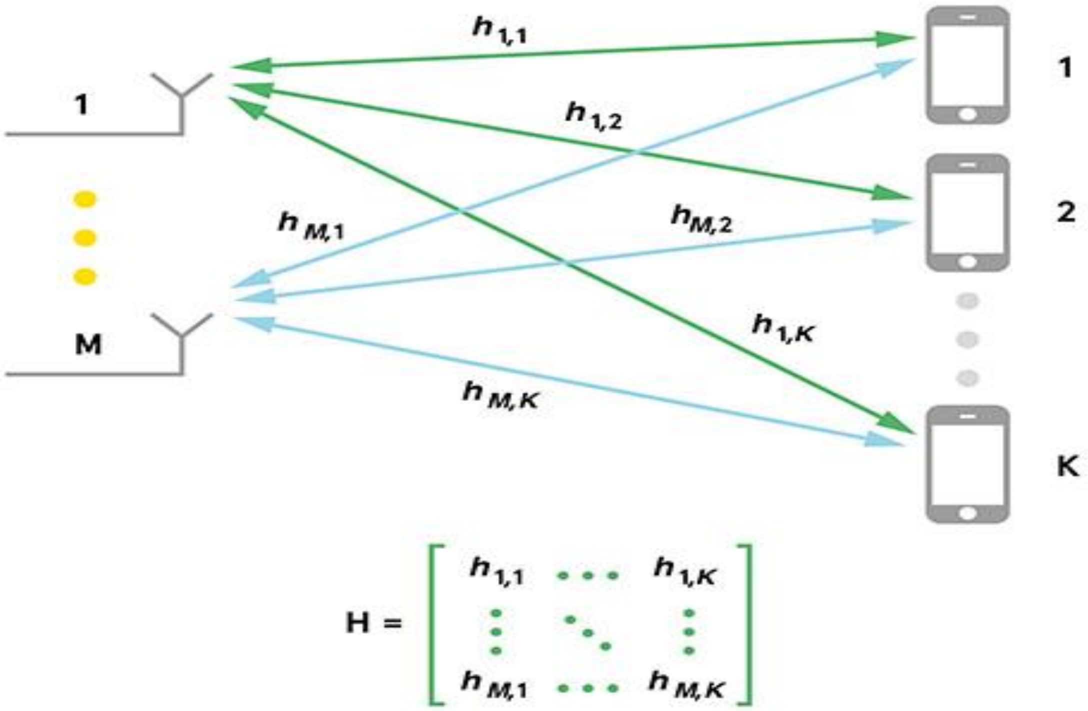

Figure 5: Massive MIMO System [18].

3.2.3 Spectrum

Spectrum is the heart of wireless technology. Operators have their own choice to use the combination of different spectrum bands to deliver 5G. 5G intends to provide faster service and low latencies, and the operators must access a large amount of spectrum to make that.

The spectrum is organized into three categories, low-band, mid-band, and high-band. The bands are grouped in two frequency ranges, frequency range one and frequency range 2. That bands which are under 6GHz are in frequency range one. The carriers in this range can have a bandwidth from 5MHz-100MHz. And the bands above 24GHz are frequency range two and have a channel bandwidth between 50 -400MHz. [20].

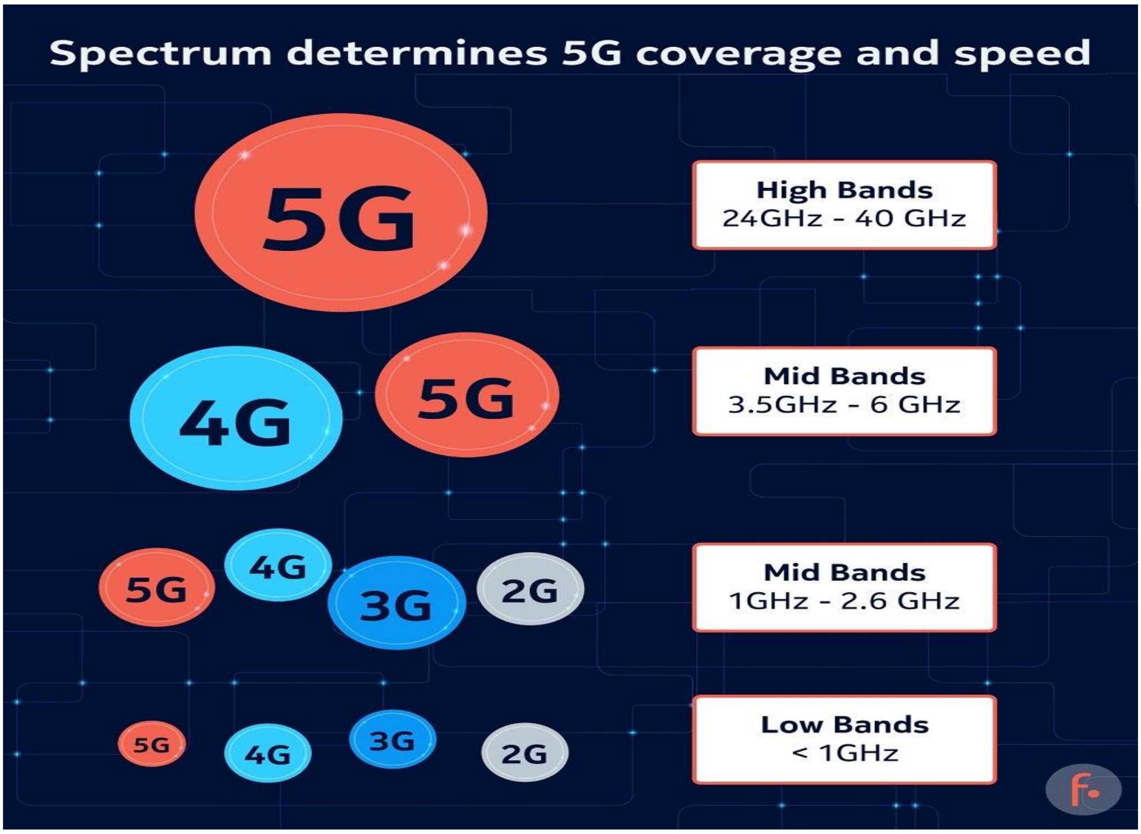

Figure 6: Spectrum Bands [20].

3.2.4 Dual Connectivity

To provide improved network coverage and data rate, mobile devices utilize both mid-band and mmWave frequencies. The feature which allows the option is called 5G NR Dual Connectivity. Carrier aggregation is the technique by which mobile operators combine the carriers into a single data channel that increases the network's capacity.

Dual connectivity brings many advantages. Since user equipment is connected to two nodes simultaneously, load balancing is fast. By using dual connectivity, mobility and robustness are improved. In addition, it helps accomplish higher per-user throughput by making use of both technologies at the same time. [21].

3.3 Core Networks

LTE was designed with two core services: voice and mobile broadband. LTE supported these two primary services using two kinds of bearers. GBR stands for guaranteed bit rate for voice and non-guaranteed bit rate for broadband applications. 5G, on the other hand, is based on the premise that 5G will support an extensive range of services with various performance requirements. This ranges from massive missions to communications that carry very little data to enhanced mobile broadband, which brings a lot of data.

The 4G evolved packet core is relatively straightforward. A mobility management entity provides mobility management, session management, and UE authentication. The serving gateway transport user traffic between the 4G RAN and the packet gateway. And the packet gateway transport users' traffic between the serving gateway and external data networks like the internet. The packet gateway also assigns UE IP address, packet routing, and Quality of service enforcement.

The 5G core network aggregates the data from the end-users and authenticates and manages the devices and subscriptions. The 5G core provides virtualized software-based network functions rather than physical network elements. [22].

3.3.1 Network Slicing

By 2025 more than 1.2 billion of 5G connections will be required, predicted by GSMA. Approximately one-third of the world's total population will use 5G, and by using network slicing, the connections will be faster and more secure.

A single infrastructure network will be sliced into many virtual ones; each slice has its configuration based on its needs and specifications. The purpose of each slice is to ensure efficient use of resources and less cross-over between them. [23].

One enterprise or many tenants of a building can use one slice, which will be dedicated to that. Each slice can have its network functions. A slice could, for example, include dedicated radio, transport, and core resources, as well as a dedicated user plane function at the edge. Another slice for radio and transport to the customers while providing specialized core network operations for each. [24].

3.3.2 Service Based Architecture

Traditional software development, also known as monolithic architecture, contains several software components built and packaged together as one piece. After building a new version of the software, it must integrate and make all the features. After that, it should be replaced by a more recent version.

The modern world has the opportunity to use various kinds of architecture for their development, known as service-based architecture. In SBA, a software product can be broken down into communicating services. The services can register themselves and subscribe to other services.

The 5G network will be based on service-based architecture.

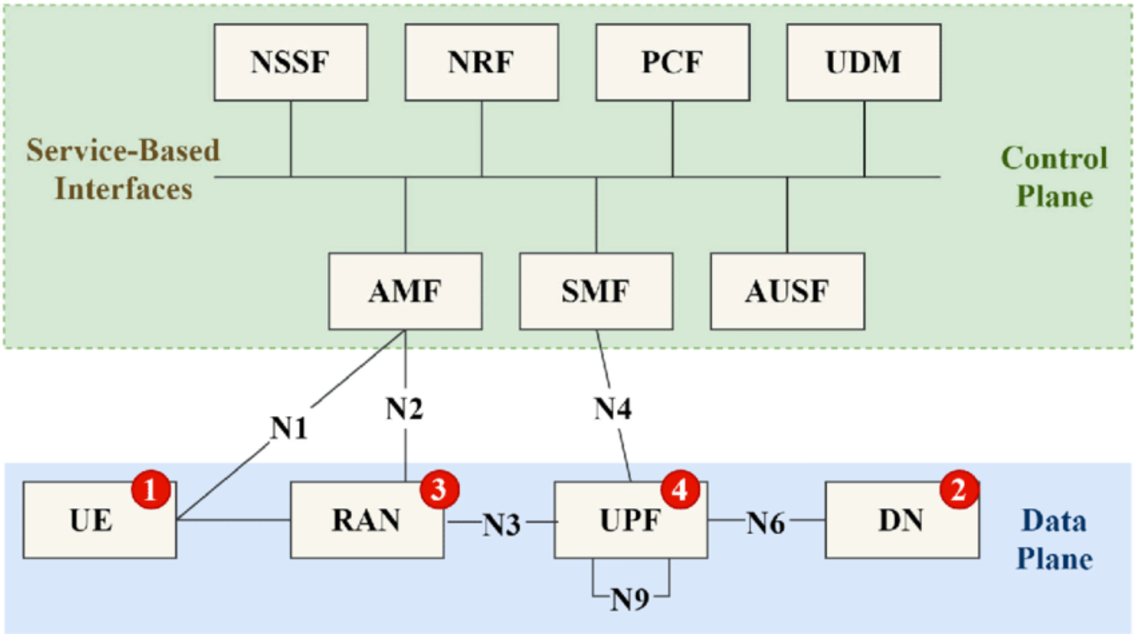

Figure 7: Service-based Architecture [25].

The figure above 4G core network, which evolved in the control plane, decomposed into several microservices that interact via service-based architecture. SBA offers a way to develop and update both standard and innovation-driven functions easily.

3.3.3 Virtualization

Virtualization is the process of decoupling the hardware into the cloud. So that anyone can access the data from anywhere through the cloud. The capability to start the network function in real-time from anywhere is known as 5G network functions virtualization.

3.4 5G Applications

The modern age is the age of technology. Internet usage will increase gradually in this era, and the estimated global growth will increase by a factor of about 4.5 to reach 226EB per month in 2026 since 5G is one of the most wanted inventions in recent years. Almost all enterprises use 5G nowadays. With the use of 5G, life becomes easy and smooth, consumers get what they want in a moment, and virtual life is much more secure than before. 5G helps the health industries as well as farmers to cultivate. IoT is a vital part of technology where 5G makes smart devices reach more people. Below is a figure where it demonstrates how 5G connects the community.

Figure 8: 5G connecting the community [26].

Here are some exciting technical advances which will depend on 5G connectivity described below:

- IoT: IoT (Internet of Things) makes almost everything smart. Everything from the home thermostat to smart city sensors depends on IoT technology. Because of the 5G low latency offer, security, virtualization 5G, and IoT go together with a long way. 5G helps the devices work perfectly, more securely.
- Broadband-Like Mobile Service: By using 5G, people can watch 4K to 8K video instantly without the buffering, and people can feel like they are using the broadband service on mobile. 5G makes the mobile operators offer faster internet connections and networks for the consumers.
- Connectivity for Edge Computing: Cloud computing is among the recent technologies that most companies use. With the move to cloud-native 5G networks, firms can store more data securely, and workers can access the

data from anywhere they want. Enterprises can also save money by moving to cloud computing instead of traditional hardware.

- Food delivery: Using 5G helps enterprises like Starship develop the automatic food delivery robot that started its journey recently in Espoo, Finland. The locations and maps are much more precise than before, which helps the automated robot and driverless cars on the run.
- Entertainment: 5G speed will boost the high-definition live streaming that helps the gamers play, and with the help of ultra-low latency, gaming won't be only for the high computing power devices. [27].

3.4.1 Advantages of 5G

Although 5G was announced in 2020, it still improves. Uses of 5G has many advantages as well as some disadvantages too. The applications of 5G listed in the previous chapter (3.4) are all advantages of 5G. Some other benefits of using 5G are described below:

- 5G helps to monitor the patients by the band provided for the patients where all kinds of import data are stored. It used to be in the market before 5G, but the modern technology makes it secure and more professional.
- By using 5G, the sensors placed in different points and objects in the city reduces accident, helps to drive an autonomous car, and helps build smart cities.
- In the pandemic, most the office runs their business from home. 5G helps to run the office smoothly by providing low latency of the connections, faster speed, and network slicing, helping the connection buffer less.
- Easily compatible with the prior generation.
- It can be used indoors and outdoors, generally over long distances.

3.4.2 Disadvantages of 5G

Since it’s still improving technologically, 5G has some disadvantages also,

- The 5G network coverage is not global yet. It is available in specific locations, but the network coverage is growing fast.
- The use of an unlicensed spectrum makes the 5G security an issue.
- The cost of using 5G is still expensive.
- The 5G accessible devices are expensive, and 5G still did not reach all.

Although 5G has a few disadvantages, it still is the best invention in this era.

4 802.11ax (Wi-Fi 6)

4.1 Wi-Fi 6: A Quick Review

The innovation of networks began with 1G, requires cables to connect, and is costly. People have been thinking about wireless networks for a decade, and finally, in 1999, wireless technology was invented. It is the number one network access method today in the enterprise, at home, and in businesses of all sizes. Wi-Fi uses several bands from the electromagnetic spectrum, commonly using 2.4GHz and 5GHz. Wi-Fi 6, also known as 802.11, is the newer Wi-Fi version. It is based upon the IEEE standards, and that's why it is also called IEEE 802.11 standard. The transmission rate of Wi-Fi 6 is 872 times compare to the first version of Wi-Fi.[28].

	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6	Wi-Fi 6E	Wi-Fi 7 (expected)
Launch date	2007	2013	2019	2021	2024
IEEE standard	802.11n	802.11ac	802.11ax		802.11be
Max data rate	1.2 Gbps	3.5 Gbps	9.6 Gbps		46 Gbps
Bands	2.4 GHz and 5 GHz	5 GHz	2.4 GHz and 5 GHz	6 GHz	1–7.25 GHz (including 2.4 GHz, 5 GHz, 6 GHz bands)
Security	WPA 2	WPA 2	WPA 3		WPA3
Channel size	20, 40 MHz	20, 40, 80, 80+80, 160 MHz	20, 40, 80, 80+80, 160 MHz	20, 40, 80, 80+80, 160 MHz	Up to 320 MHz
Modulation	64-QAM OFDM	256-QAM OFDM	1024-QAM OFDMA		4096-QAM OFDMA (with extensions)
MIMO	4x4 MIMO	4x4 MIMO, DL MU-MIMO	8x8 UL/DL MU-MIMO		16x16 MU-MIMO

Figure 9: Wi-Fi Generations [29].

The figure above shows the improvement of each generation from the previous one, including data rate, bands they use, security, and modulation.

The first Wi-Fi technology was 802.11a, released in 1999, which used a frequency band was 5GHz and with OFDM modulation. After that, in the same year, 802.11b was introduced with DSSS modulation and 11 Mbps throughput. 802.11g was introduced in 2003 and operated in OFDM and bandwidth of 2.4GHZ.

Wi-Fi 4 was launched in 2007 and operated in 64 QAM-OFDM. This Wi-Fi standard made the Wi-Fi even faster and more reliable than previous versions. This version used MIMO, which resulted in a substantial increase in data without the need for more bandwidth or transmitted power.

After Wi-Fi 4, 802.11ac (Wi-Fi 5) was launched in 2013 with higher speeds ranging from 433 Mbps to several Gbps. In Wi-Fi 5, the bands were 5GHz and operated with 256-QAM OFDM. Beamforming technology was introduced in this version of Wi-Fi, where antennae transmitted radio signals. And after the revolution of Wi-Fi 802.11ax, also known as Wi-Fi 6, arrived, which has improvements like 5G. The maximum data rate of this version is up to 9.6Gbps and offers better 2.4GHz and 5Ghz spectrum support. [30].

4.2 Technical Features

The main features of Wi-Fi 6 technology will be discussed in this section. IEEE's project 802 and Wi-Fi Alliance are the two organizations responsible for improving and developing Wi-Fi 6. IEEE enhanced the development of networking standards. The critical effect was the suite of Wi-Fi technologies. And the Wi-Fi Alliance was there to certify and promote different Wi-Fi products. This involves technical factors, such as developing different standards for products such as Wi-Fi mesh networks, as well as governance problems, for example, interacting with policymakers about appropriate spectrum allocations.

Wi-Fi 6 is the first reformation of the Wi-Fi family, enhancing its performance outdoors rather than indoors. Wi-Fi 6 addresses frequency bands between 1GHz to 6GHz. As a result, Wi-Fi 6 may use the unlicensed 2.4GHZ spectrum, unlike

Wi-Fi 5. The following features have been authorized to facilitate dense 802.11 installations. [31].

4.2.1 OFDMA (Orthogonal Frequency Division Multiple Access)

OFDM (Orthogonal Frequency Division Multiplexing) is a modulation method used in the older version of Wi-Fi to increase wireless capacity and efficiency. OFDM can transmit traffic to a single recipient at a time, which causes a lag in the traffic. On the other hand, OFDMA splits traffic into smaller packets to avoid waiting while transmitting data to multiple users simultaneously. [31].

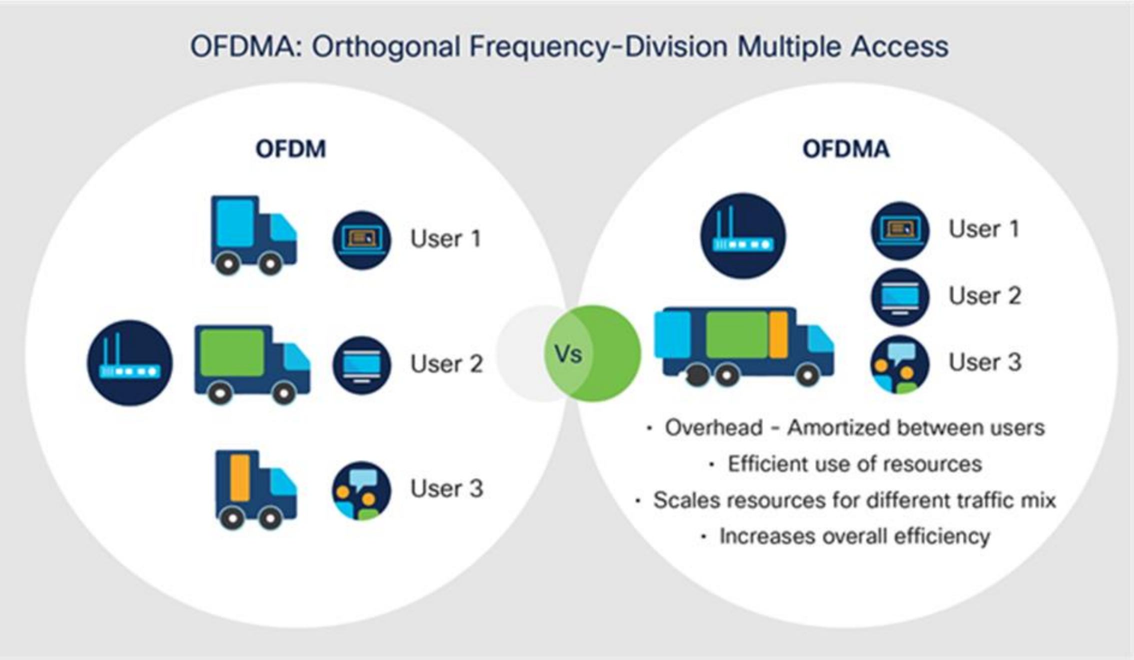

Figure 10: OFDM vs. OFDMA. [32].

The figure above represents the transmitting traffic to the users. OFDM transmits data to a single user, whereas OFDMA can simultaneously send traffic to different users.

An Inverse Fast Fourier Transform, a mathematical procedure, was used in both OFDM and OFDMA to split a channel into subcarriers. The orthogonal subcarriers do not interfere with each other while lacking guard bands. The critical differences between OFDM and OFDMA can be described by taking an example of a 20MHz channel that consists of 64 subcarriers. Out of 64 subcarriers, 52 are used for modulated data, four function as pilot carriers, and eight of the subcarriers serve as guard bands. A more extended OFDM symbol of 12.8 microseconds was introduced by 802.11ax, which is four times longer than the original 3.2 microseconds, making the subcarrier size and spacing decrease from the ordinary one 312.5kHz to 78.125 kHz. The below figure shows the reduction in the subcarrier size and spacing. [31].

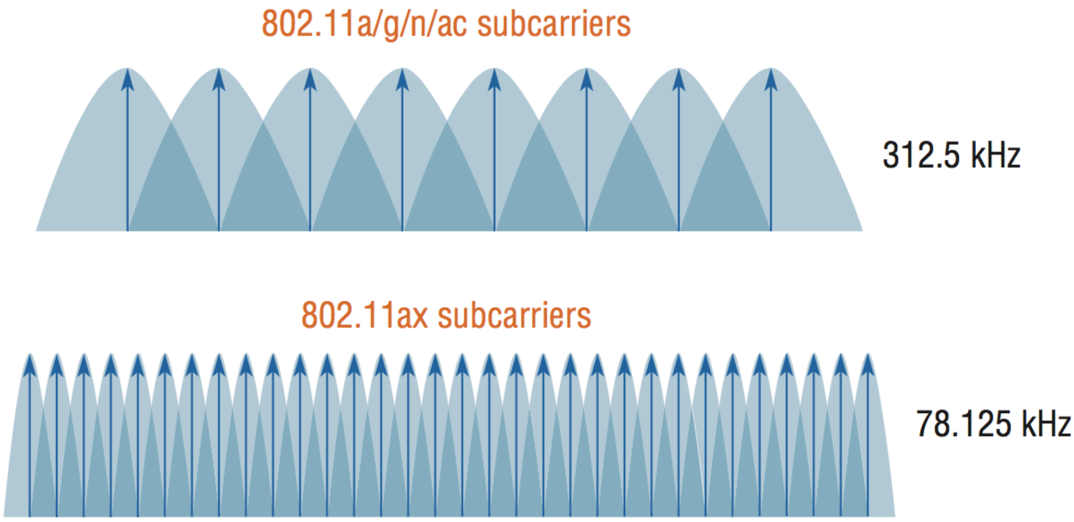

Figure 11: Subcarrier spacing. [33, p 19].

Three types of subcarriers for OFDMA are found:

- Data Subcarriers –modulation and coding schemes are the same as 802.11ac.
- Pilot Subcarriers – used for synchronization purposes between receiver and transmitter.
- Unused Subcarriers – used as guard carriers.[31].

4.2.2 MU-MIMO

MU-MIMO (Multi-user multiple input, multiple output) was introduced with the wave 2 version of 802.11ac wireless standard, a feature used in modern Wi-Fi routers. It enables various wireless devices to communicate with a Wi-Fi network simultaneously.

MU-MIMO is available in both uplink and downlink directions. The APs use numerous spatial streams to broadcast to multiple clients through MIMO, known as downlink multiuser MIMO. It allows up to four clients simultaneously.
And in uplink multiuser, MIMO allows up to eight clients.
There are many benefits to using MU-MIMO. Some of them are listed below:

- Devices can get connected to the network quicker. More devices can serve frequently.
- The devices run with the older version of 802 standards will see upgraded performance and faster speed.
- It enabled smart devices to use the 5GHz band instead of 2.4 GHz.
- Improved latency and power consumption requirements of the client were also increased. [32].

4.2.3 Basic Service Set (BSS) Coloring

Due to overlapping basic service sets (OBSS) and spatial reuse, BSS Coloring is a way of managing medium convention overhead. Only one device may transmit at a time on a given frequency because of Wi-Fi's collision-avoidance mechanism. Before transmitting, the client station checks any other transmissions available on the channel, known as clear channel assessment. If there are any other transmissions available on the channel client station backs off and tries to transmit again later.

6-bit BSS color field at the physical layer and within the management frame was allowed by 802.11ax to reduce the impacts of the co-channel interface. There are a total of 63 BSS color values available. When the traffic is transmitted, the client station checks the color value and backs off if there is a similar color value to complete its transmission first. If there is a different color value, the client station transmits disregard the ongoing communication.

Consider a 2.4GHz channel plan as an example. APs are positioned to minimize the overlap on the same channel; clients in different APs can hear the signals from other APs and need to wait for both cells to clear before transmitting.

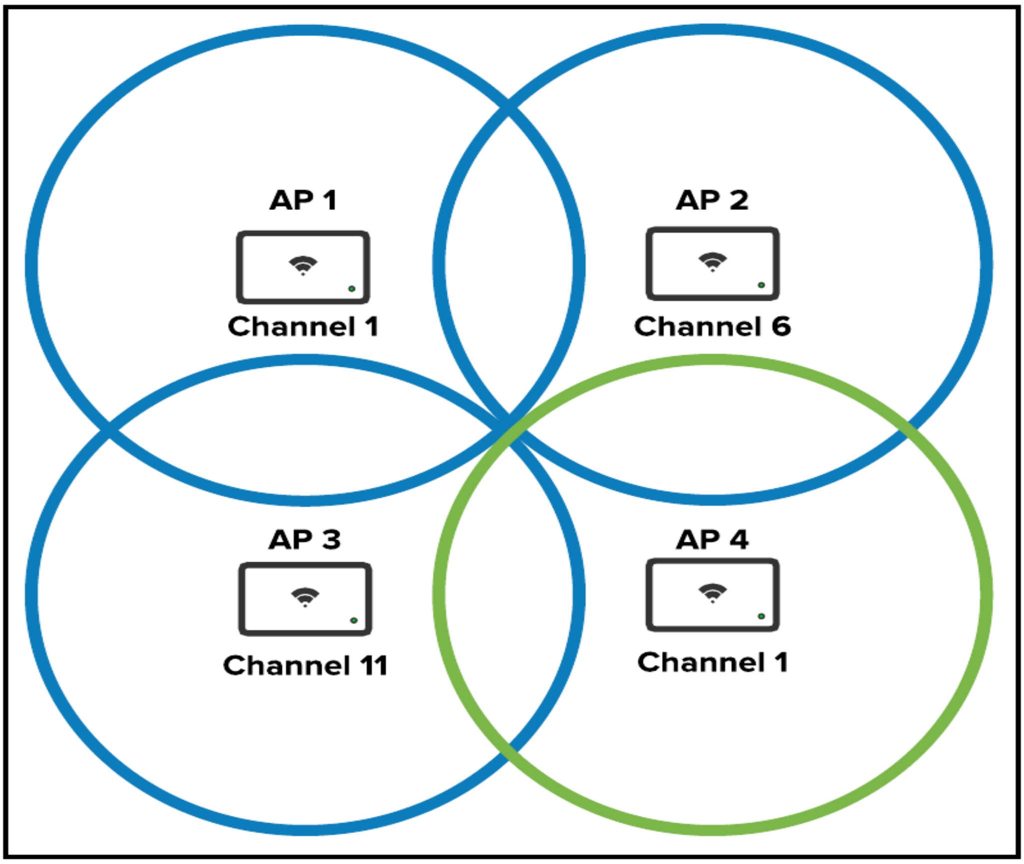

Figure 12: 2.4GHz Channel plan for BSS Coloring [34].

The figure above shows the coloring in the channel, and the color value in AP 4 can have a different color value than other APs to transmit.

Although this 2.4GHz channel plan is for the example, 802.11ax also allows the feature for 5 GHz.

4.2.4 Target Wake Time (TWT)

Target wake time is the power-saving mode. It allows an AP and client to negotiate when and how long it can put the power saving mode on for its wireless radio. The goal of TWT is to minimize the dispute of the traffic between clients by allowing the AP to schedule client stations. It shortens the required amount of time a client station in power saving mode must be awake. [34].

4.3 Advantages of Wi-Fi 6

Although the idea to create Wi-Fi 7 is present in the technology world, there is still scope to improve Wi-Fi 6. There are so many advantages of using Wi-Fi 6. Some of them are described below:

- It provides a faster and more dependable network connection for the consumers and IoT devices.
- The demand for wireless connections is high in enterprises and homes. Compared with the previous version of 802 standards, Wi-Fi 6 handles more data across airways and more active clients per access point.
- The internet speed is four times faster than the previous Wi-Fi standard, providing a seamless consumer experience.
- Wi-Fi 6 supported devices can experience significantly faster speed because of the previous version's 9.6Gbps throughput instead of 3.5 Gbps.
- One of the critical issues with the smart devices was the short battery life. Wi-Fi 6 uses TWT, which makes the battery life of the smart devices longer.
- Wi-Fi 6 helps enterprises connect more devices using OFDMA and BSS. The technologies allow connecting more devices and use the faster internet with reduced co-channel interference and improved transmissions.
- The MU-MIMO uplink and downlink of 802.11ax improves network efficiency by focusing radio energy on specific users. Wi-Fi 6 can provide faster service in crowded areas like airports and shopping malls by using MU-MIMO.
- In a connected world, IoT will expand the number of Wi-Fi devices. The number of devices that may be paired with access points in smart homes and enterprises is increased because of the features of 802.11ax.[35].

These are a few advantages of Wi-Fi 6. There are a lot more advantages in every aspect of the modern world. Hopefully, Wi-Fi 7 will bring much more shortly.

4.4 Disadvantages of Wi-Fi 6

802.11ax was launched in September 2020. Still, the developers are trying to develop the features and the challenges they face. Despite many advantages, Wi-Fi 6 has a few disadvantages too. Some of the disadvantages of Wi-Fi 6 are described below:

- Since the bandwidth is between 2.4GHz and 5GHz, the devices should be able to use Wi-Fi 6. Unfortunately, to get better speed and service, the devices might need to upgrade, which is expensive after the launch of Wi-Fi 6.
- Obstruction between the router and client devices might interrupt the signals as the range is smaller than the 5G network.
- Wi-Fi 6 uses OFDMA, which made the subcarriers narrower at 78.125kHz. Because of that, good phase noise oscillators and linear RF are required.
- Category 6A cables are required for the router to get all the features Wi-Fi 6 offers.[36].

Since it is the updated version of the 802.11 standards, it still needs to develop and solve the challenges. Technology firms are trying to solve the issues to provide better service to the consumers.

5 Comparing 5G and Wi-Fi 6

People, enterprises, and IoT depend on the Internet in this modern technological world. As the demand for the internet increases, network companies like Nokia, Ericsson, and Intel are making the best version of wireless technology to cope with the world. Wi-Fi 6 and 5G are the most updated version of wireless technology. Each has its technical features, business model, cost, etc. Wi-Fi is a type of LAN used for indoor purposes like home or office. But the problem arises when many users are using the same Wi-Fi at a time. Enterprises manage their Wi-Fi heavily to meet the required performance.
On the other hand, 5G is a WAN-type network used indoors and outdoors. The network coverage is usually more extended than Wi-Fi.

This section will compare Wi-Fi 6 and 5G based on technical features, cost, business model, installation, and required skill level.
The functions of Wi-Fi 6 and 5G are complimentary. In terms of user experience, both can deliver gigabit speeds and minimal latency.

5G is a licensed spectrum that makes the consumers pay a certain fee to the service provider. In contrast, Wi-Fi 6 is an unlicensed spectrum that can be utilized by purchasing a compatible device. An access point, router, and switch are enough for a home Wi-Fi network. The most modern router has all the options in a single device like a router, switch, and access point that make the use of Wi-Fi cheaper. Enterprises must pay more to meet their demand depending on how many computers and laptops get connected to a network or how many users use the service. To use 5G, consumers must pay subscription fees to access. Wi-Fi 6 is more accessible and requires almost zero skills, whereas 5G requires installing skills.

5G and Wi-Fi 6 are expected to have a speed of 10 Gbps. However, it depends on many factors, namely the number of connected devices in the network, distance, and obstacles. Deploying Wi-Fi 6 properly will give a greater throughput than 5G. Alternately 5G is provided by the service provider, and they can not change the speed for a single user. Although Wi-Fi has better use for inside and 5G has both inside and outside.

5G offers a gigantic boost in performance, which may help service providers think of broadband connectivity through 5G. Thus, 5G can compete with cable offerings. Although in some cases 5G and wi-fi can go together. For example, one enterprise can use wi-fi 6 for manufacturing operations. At the same time, 5G can offer a comprehensive manufacturing environment, and a modern car can connect to a 5G cellular network during in-vehicle Wi-Fi for users.

To deliver a next-generation experience, Wi-Fi 6 and 5G should work together despite being rivals.[37]

6 Conclusion

This thesis aimed to explain wireless networks, 5G, and Wi-Fi 6, specifically the key features comprising these technological phenomena. It was elaborated that 5G and Wi-Fi 6 are among the most significant technological inventions in recent years. Both developments make the operation of both consumers and enterprises smoother by means of accessible and faster communication. Although both technologies are operational, we can expect their development process to continue.

Lastly, it can be said that both 5G and Wi-fi 6 are for the betterment of the overall technological landscape by offering low latency, faster speed, and increased security. Wi-Fi 6 and 5G have much potential and bring many new companies to start their business. Working together, these technologies can help network innovations succeed and play a significant role in expanding IoT and cloud computing capabilities.

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