An Investigative Exploration and In-depth Analysis of Wi-Fi Networks in Public Environments

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Abstract— *Wireless communication technologies have become ubiquitous, with IEEE 802.11, 3G, and Long Term Evolution (LTE) being prominent examples. Understanding the unique characteristics of each technology is essential for selecting the most suitable option for public Wi-Fi networks. This paper evaluates the performance, security, and cost of 3G, 4G, LTE, and Wi-Fi IEEE 802.11 protocols. Additionally, it conducts a security and vulnerability analysis of these technologies. Compared to 3G, 4G, LTE, and WiMAX, Wi-Fi stands out as a cost-effective solution with high bandwidth, low direct and associated expenses, and minimal power consumption. Consequently, Wi-Fi (802.11 a/b/g/n) emerges as a suitable wireless technology for providing Internet services to cafes, hotspots, and public locations due to its favorable cost-performance ratio.*

Keywords—wireless networks, Wi-Fi, Internet, security.

I. INTRODUCTION

Wireless networking technology, commonly known as Wi-Fi, facilitates communication between computers and devices over a wireless signal [1]. A typical Wi-Fi network comprises three main components: a wired connection to a broadband provider, an access point, and a computer equipped with both wired and wireless connections [2]. Operating within the Industrial, Scientific, and Medical spectrum (ISM band), Wi-Fi offers diverse broadband speeds [3]. Access points, or APs, function as intermediaries for communication between nodes or computers, doubling as wireless Ethernet adapters. The ease of installation and the proliferation of laptops with Wi-Fi capabilities have contributed to the widespread adoption of Wi-Fi technology.

Numerous establishments such as airports, cafes, restaurants, and shopping malls now provide wireless internet access to consumers, reflecting the growing significance of wireless technologies in both business and everyday life, particularly in densely populated areas. Wi-Fi networks offer simplicity in setup and deployment across various settings, including markets, offices, and airports, offering advantages such as flexibility, mobility, ease of use, and cost-effectiveness.

For companies seeking to venture into this industry, understanding the intricacies of wireless technologies, including security, performance, installation, and maintenance costs, is paramount for making informed business decisions based on present and future technology attributes. This thesis aims to examine and compare various wireless network technologies in terms of availability, number of nodes, total cost, end-user cost, vendor cost, range, dependability, and security. Specifically, it delves into comparing Wi-Fi technology for local area networks (IEEE 802.11 a/g) with mobile wireless technologies like 3G, 4G, and LTE, focusing on cost, bandwidth, performance, and implementation aspects.

While Bluetooth, Near Field Communication (NFC), and Radio Frequency Identification (RFID) are not within the scope of this paper, the IEEE 802.11 architecture encompasses nine services classified into Station (STA) services and Distribution (Distribution) services, addressing aspects like authentication, privacy, and data delivery. Stations, including workstations, laptops, and mobile phones, adhere to the IEEE 802.11 specification and possess both MAC and PHY interfaces.

The security of confidential information remains a paramount concern in any wireless network, irrespective of its complexity or purpose. The ongoing research and development in addressing vulnerabilities within wireless networks aim to mitigate emerging threats and crimes associated with evolving technologies in this domain.

II. THE IEEE 802.11 WIRELESS LAN ARCHITECTURE COMPONENTS

The IEEE 802.11 architecture includes nine services that can be classified into two categories: Station (STA) services and Distribution (Distribution) services.

Authentication, de-authentication, privacy, and data delivery are all included in STAs, whereas association, re-association, disassociation, distribution, and integration are all included in distribution services.

Stations are wireless network devices that comply with the IEEE 802.11 specification and have a MAC and PHY interface. Workstations, laptops, and mobile phones are all examples of stations. The features of an 802.11 network adapter or network interface card are implemented in either software or hardware (NIC).

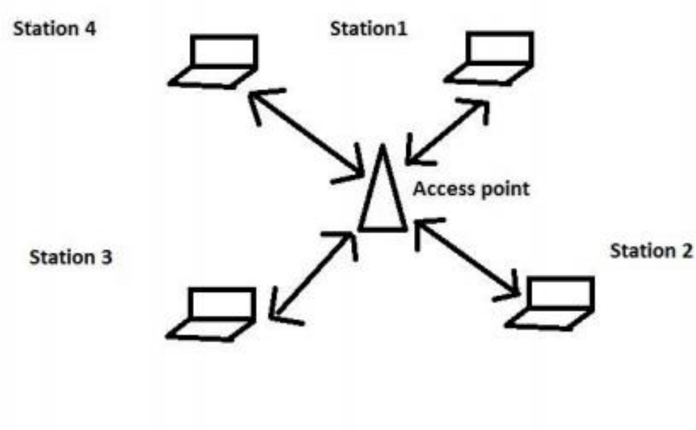

Figure 1: Basic Service Set

The Basic Service Set is depicted in Figure.1, which includes one Access Point and four workstations.

A BSS is made up of a group of Stations that can communicate with each other across an 802.11 wireless local area network. It's also known as a cell.

III. HIGH-RATE WLAN STANDARD

The physical layer and data connection layer, the bottom two tiers of the open system Interconnect (OSI) concept, are the emphasis of the 802.11b standard.

The 802.11b standard distinguishes between FHSS and DSSS transmissions. Both types of spread spectrum employ more bandwidth than a conventional narrowband transmission, but they allow for a stronger signal that is easier to detect by the receiver.

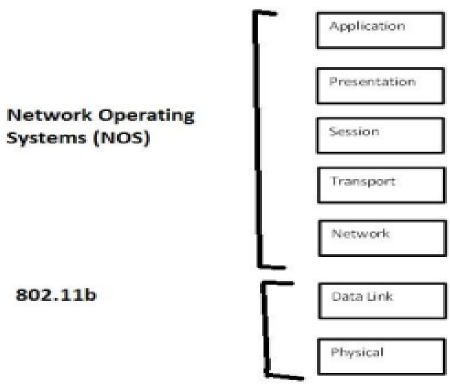

Figure 2.: 802.11b and OSI Model

The IEEE 802.11b standard works on the data connection layer and the physical layer, as shown in Figure 2. Network, transport, session, presentation, and application layers are all covered by the network operating system.

IV. WI-FI AS HOTSPOTS

A hotspot is a device that uses Wi-Fi technology to provide internet access via a router. Free hotspots typically provide free access to a menu or shopping list, as well as payment methods such as PayPal or credit card, or a work public network where authentication and verification functions are disabled.

A wicked individual who sniffs the data received by users on a free hotspot, including deciphering passwords and login names, is referred to as a poisoned hotspot or rogue hotspot.

When using a Wi-Fi hotspot, be sure that all data sent is securely encrypted, and log out when you've finished your job. Always keep in mind that you are not signed into your accounts indefinitely. Pay heed to the browser's warnings and alarms.

HTTP and TLS do not provide complete browsing security. Use a VPN (virtual private network) if possible.

V. IEEE 802.11

Because the globe has become more mobile, and wireless networks allow users to work and travel freely, wireless technologies have become more popular than wired or fixed networks in recent years. The term "Wi-Fi" refers to wireless fidelity, which means that a Wi-Fi-enabled device may connect to a Wireless Local Area Network [2]. At the workplace, hotel, corporate, or university level, wireless LAN is considered as the technology that would provide the most convenient link between current wired networks and portable computing and communication equipment, such as laptop computers and people digital assistants (PDAs). The WLAN has the obvious benefit of reducing the requirement for wiring between multiple buildings. WLAN systems can be used for everything from simple communication between two computers or between a computer and a wired network, all the way up to a large network with many users and a large number of data routes.

The IEEE finalized the first WLAN standard, IEEE 802.11, in mid-1997. This standard specifies a license-free (ISM band) 2.4 GHz operating frequency with 1 and 2 Mbps data speeds using a direct sequence or frequency hopping spread spectrum.

WLAN is addressed by the 802.11 family of standards, which is not a single standard. The IEEE 802.11a standard specifies a WLAN system based on orthogonal frequency division multiplexing (OFDM), which divides an information signal into 52 subcarriers to enable a data transmission rate of up to 54 Mbps and a throughput of more than 24.3 Mbps. The system operates in the license-free (uni band) frequencies of 5.15 to 5.35 GHz and 5.725 to 5.875 GHz.

VI. THIRD GENERATION MOBILE COMMUNICATIONS (3G)

3G stands for third-generation mobile communications and is a widely utilized voice and data transmission standard for mobile phones. NTT DoCoMo in Japan developed 3G, which is based on the Universal Mobile Telecommunications System (UMTS) technology [10]. NTT DoCoMo launched the first pre-commercial 3G network in Japan in 1998, followed by a commercial launch in October 2001.

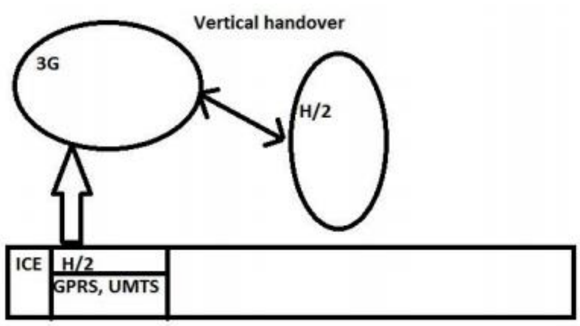

Figure 3. Internetworking of 3G and HiperLAN using multi hop communications

A variation of using 3G systems with or without multihop communication is depicted in Figure 3.

Hiper LAN/2 and IEEE 802.11 (with its central point coordination function) are examples of centrally controlled systems that can be used to create an area-wide local cellular network. Horizontal handover is implemented inside the same system, and vertical handover is implemented by changing the radio interface at the same time as the handover.

3G has capabilities such as high-speed transfer of improved multimedia (voice, videos, data, cellular telephone, web browsing, e-mail, fax, and video conferencing) and roaming capability with operability from any location (vehicles, planes, homes, businesses, and space stations).

VII. FOURTH GENERATION MOBILE COMMUNICATIONS (4G)

Fourth Generation Mobile Communication, or 4G, is a progression of 3G's voice and data transmission communication technology approaches and standards.

The Defense Advanced Research Projects Agency (DARPA) conceptualized the 4G system, which delivers mobile ultra-broadband internet connectivity for mobile devices such as laptops and smartphones. There are two types of 4G networks in use today: mobile WiMAX and Long Term Evolution (LTE).

The goal of 4G development was to incorporate an integrated IP solution, seamless wired and wireless communication, worldwide interconnection, interoperability, and efficient systems with at least 100 MBps data speeds [6]. 4G enables applications like mobile banking, peer-to-peer networking, and internet access (ibid.).

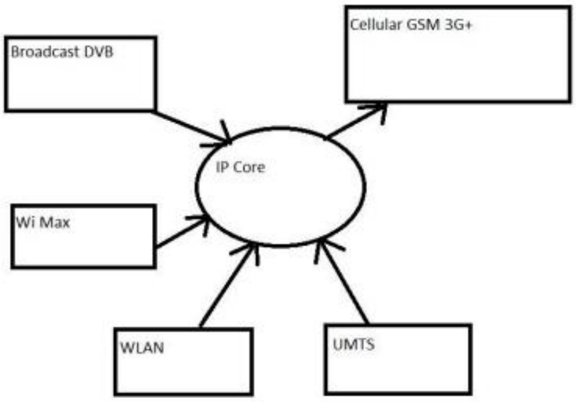

Figure 4: 4G Network

Different networks are connected with IP core in Figure 4, and 4G integrates heterogeneous wireless technologies, obviating the need for new standards for various wireless systems such as Worldwide Interoperability for Microwave Access (Wi Max), wireless local area network (WLAN), Universal Mobile Telecommunication System (UMTS), and General Packet Radio Service (GPRS).

VIII. FIFTH GENERATION MOBILE COMMUNICATIONS (5G)

The fifth generation of mobile communications is referred to as "5G." This technology is being proposed as a standard for mobile telecommunications' next phase (e.g., beyond 4G.) In 5G, data speeds are enhanced beyond 100 Mbps to allow for faster data downloads and streaming.

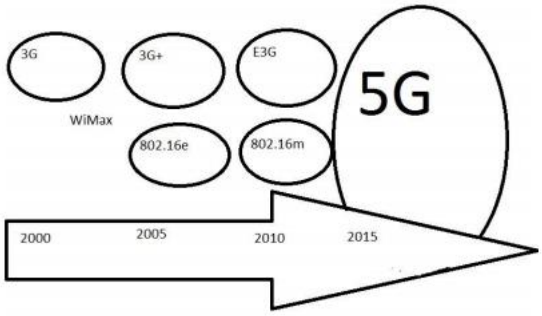

Figure 5: Timeline 3G to 5G

The wireless world wide web will be supported by 5G communication technologies. There are two possible perspectives on 5G technologies: evolutionary and revolutionary. In an evolutionary perspective, 5G technology will provide wireless internet while also allowing for a highly flexible network, however in a revolutionary perspective, 5G technology will be able to interconnect with the rest of the world without any limitations.

8.1 Long Term Evolution (LTE)

LTE (Long Term Evolution) is a relatively recent mobile wireless communication standard. It is a packet-based network with a flat network design. LTE provides fixed, portable, and mobile devices with broadband access.

Increased capacity, reduced network complexity, reduced latency, fast data rate, enhanced coverage, and lower implementation and operational costs are among advantages of LTE technology [8].

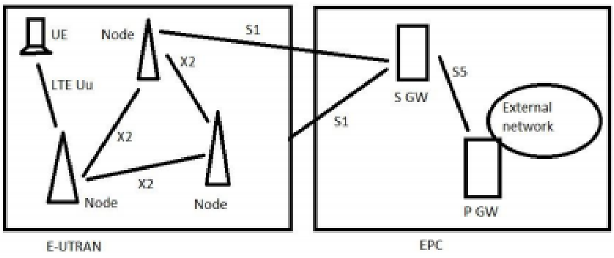

Figure 6: LTE Architecture

A simplified LTE architecture with a server gateway and a packet data network gateway is shown in Figure 6. The s1 interface connects a server gateway to a node. E-UTAN and EPC traffic is supported by the LTE architecture [2].

8.2 Wi Max

Worldwide Interoperability for Microwave Access (WiMAX) is the acronym for Worldwide Interoperability for Microwave Access. The Wi Max development group was established in 1998 with the goal of creating a wireless broadband air interface standard. WiMAX provides a wide range of deployment choices and services. It has a high data rate capability, as well as expandable bandwidth functionality and data rate support. Advanced antenna approaches are also supported by Wi Max.

There are three aspects to the overall network architecture: mobile stations, access service networks, and connectivity service networks.

Business organizations such as virtual private networks (VPNs) and IP connectivity services can benefit from the design.

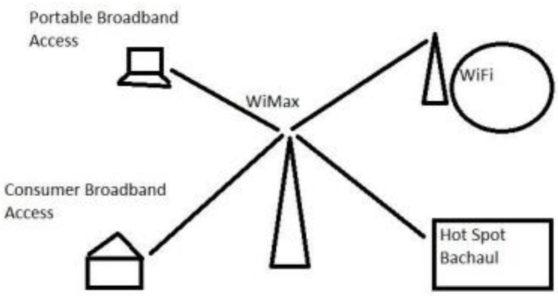

Figure 7: Working of Wi Max as commercial product

Figure 7 shows how WiMAX works with Wi-Fi access points, hotspots, portable broadband access, and consumer broadband access to provide dual polarization, MIMO, and high throughput in the outdoors.

WiMAX, as shown in Figure 8, provides wireless internet broadband connectivity in a radius of several kilometers while also addressing inside installations with reasonable frequency.

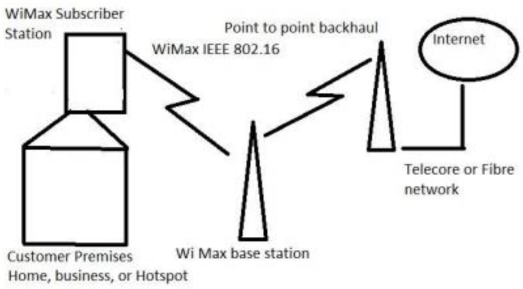

Figure 8: Working of WiMAX with customer premises, Tele core or fiber network.

8.3 Public Networks

Public Wi-Fi networks, which can be wired or wireless, allow Internet access at locations such as airports, coffee shops, and hotels.

There are various public network options, such as using an access point in a lobby, using an access point with authentication, and using access points that allow virtual LANs with SSID, access permission, and security settings.

There is a requirement for more isolation between networks employing access points that support 802.11a and 802.11g frequencies in all of the following ways. The public WLAN operates on the 802.11g frequency, whereas the internal WLAN operates on the 802.11a frequency. This minimizes the likelihood of someone trying to break into the network, but if the visitor has a laptop with a security camera,

This security setting does not operate with a dual-mode radio, thus you must rely on the computer's internal network security.

In practice, public networks are highly fragile and insecure. Anyone can steal passwords in crowded places by shoulder surfing or using a video camera placed near the computer screen and keyboard.

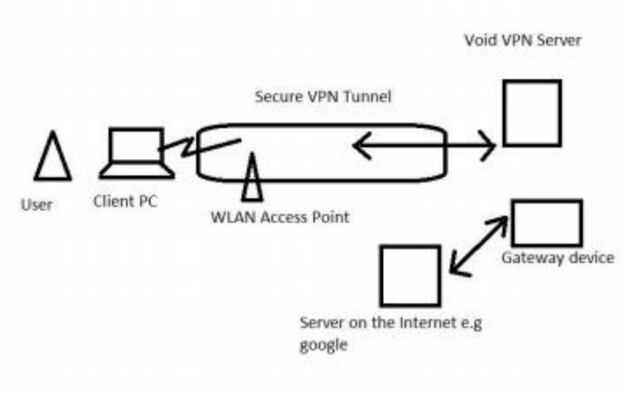

Figure 9: Secure VPN

Figure 9 explains how to use a virtual private network (VPN) to establish a secure network connection across a public network like the internet.

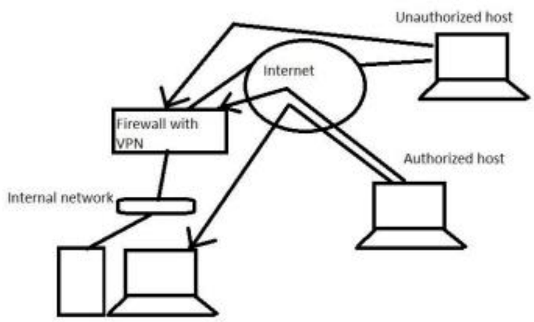

Figure 10: How VPN work shows that how VPN allows user to connect internet with much secure and safer way by encrypting data.

Standards have been set to improve safety. The Payment Card Industry Security Standards Council, for example, produced the Payment Application Data Security Standard (PA-DSS), which is a global security standard (PCI SSC). Vendors must comply with PA-DSS requirements such as protecting card data, keeping a log of payment activities, not storing cardholder data on the internet, encrypting network sensitive traffic, and maintaining instructional documentation.

8.4 Deployment of long distance Wi-Fi:

Network planning, MAC protocol, network administration, power saving, and applications and services are the five phases of long-distance Wi-Fi networks [3]. A long-distance Wi-Fi link requires line-of-sight for sufficient signal strength for reception in network planning. Cost and performance, planning tower location selection, decision on tower height, connection type, antenna type, power transmission, and operating channel are the five phases of network planning.

For channel allocation, the 2.4 GHz band of the 802.11b/g standard is available for license-free outdoor use [3].

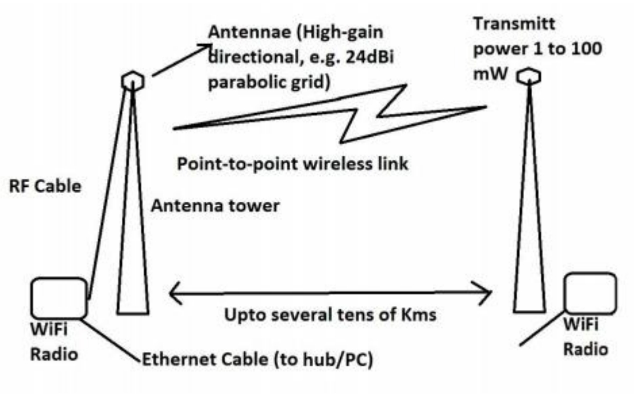

Figure 11: Wi-Fi long distance link [3] shows the point to point wireless link between two antenna towers

Performance, issue identification, and repair are all part of network administration. Configuration collection, signal strength measurement, and error rate measurement are all included [3]. The power saving involves the power conservation settings; for example, a good technique is to turn on only when connectivity is needed [3].

8.5 Security

The security mechanisms suggested by IEEE 802.11 standards (802.11b/802.11i/WPA/WPA2) are mostly supported by Wi-Fi products on the market. The IEEE 802.11 standard specifies basic access control, authentication of networked stations, data secrecy, and data integrity (WEP protocol).

Access control is mostly accomplished through the use of two techniques: SSIDs and/or access control lists (ACLs).

The SSID is a network identifier that is represented by an alphanumeric code that is shared by all access points and stations in the same network. Thus, if the user knows the network's SSID, he or she will be able to connect to it, whether or not their request is accepted. Default settings exist in the manufacturer's suggested solutions, which must be customised by network administrators. Because the access point sends the SSID in clear in beacon frames, which can be easily intercepted, this protection is ineffective.

The second type of access control is ACL, which uses a list of permissions. Each access point does, in fact, keep a list of all approved stations' MAC addresses. Filtering is done by the access point based on the MAC address. In order to add or remove users, each list must be updated on a regular basis, either manually or via specialist software. This defence is also ineffective because recovering the MAC address requires simply passive network listening.

The use of passwords can be added to these two methods. These three forms of defence can be employed in conjunction with one another.

The exchange of pre-shared encryption/decryption keys is required for data confidentiality.

The mechanism for key exchange is not specified by the standard and is left to the manufacturer's discretion. The WEP algorithm is used to encrypt the information. The IEEE 802.11 standard specifies a typical data encryption method.

The decryption algorithm includes generating a

- Decryption key from an IV or received message, as well as a decryption key identifier.
- Obtaining the first message by decrypting the received message with the key
- The integrity of the decrypted message is checked using the ICV algorithm.

Table 1
Key standards for WLAN

Standard	Scope
Wired Industry Forum, Open Air	2.4 GHz frequency-hopping spread-spectrum
IEEE 802.11b	Defines WLAN interoperability among multivendor products, infrared, 2.4 GHz frequency hopping, and 2.4 GHz DSSS
Home Radio Frequency Working Group	SWAP for wireless networking within a home
Bluetooth Consortium	Short-range radio links using 2.4 GHz FHSS.

Beyond Layer 2, 802.11b WLANs offer the same access control (such as network operating system login) and encryption protocols as conventional 802 LANs (such as IP Sec or application-level encryption). These higher-level technologies can be utilised to build end-to-end secure networks that include both wired LAN and WLAN components, with the wireless portion of the network benefiting from the 802.11b feature set's distinctive added protection. The link between different WLAN standards and their scope is shown in Table 1.

The 802.11b feature set provides unique additional security. Table 1 depicts.

The link between different WLAN standards and the breadth of their application.

IX. RESULTS

This section compares the technological properties of Wi-Fi 802.11, 3G, and LTE wireless technologies.

9.1 Wi-Fi and 3G comparison

In terms of coverage, range, upstream and downstream speeds, scalability, and spectral efficiency, Table 2 compares Wi-Fi and 3G technologies.

In comparison to 3G, Wi-Fi technology offers a faster downstream speed, according to the table. Furthermore, Wi-Fi provides faster speeds, is easier to deploy indoors, and has a high spectral efficiency, implying that it provides good low-cost indoor coverage. Although Wi-Fi and 3G are complementary technologies, we must occasionally select one over the other due to price constraints or technological limits.

Table 2
Wi-Fi and 3G comparison.

	WiFi	3G
Range	100m	80Km
Coverage	Indoor	In multiple cities (e.g. 826) in a country
Downstream speed	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	1 Mbit/s
Upstream speed		400kbit/s
Scalability	Fixed 20 MHz channel (13 Non-overlapping channels in 802.11b, 5 in 802.11a)	Traffic growth and increased signal traffic is possible.
Spectral efficiency	2.7 bps/Hz-54MBps in 20 MHz	Max 1.3 (average loaded sector)/Hz per cell or per sector

9.2 Wi-Fi and 4G comparison

In terms of what they offer technically, Wi-Fi and 4G usage in cell phones are vastly different. In the case of Wi-Fi, the signal is sent to the phone via a wireless router or modem, and the range is normally limited to 150 feet. In the case of 4G, you can access the Internet from a nearby cell phone tower at a speed of 6 to 15 Megabytes per second.

In terms of coverage, range, upstream and downstream speeds, scalability, and spectral efficiency, Table 3 compares Wi-Fi (802.11) with 4G technologies. Wi-Fi technology, according to the table, provides faster downstream and upstream speeds than

4G, but it is slower in interior deployments with strong spectral efficiency (37 bits/sec). Tethering speeds are also faster on Wi-Fi than on 4G.

Table 3
Wi-Fi and 4G comparison.

	WiFi	4G
Range	100m	100Km
Coverage	Indoor	In multiple states (e.g. 50).
Downstream speed	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	28 Mbit/s
Upstream speed		22Mbit/s
Scalability	Fixed 20 MHz channel (13 Non-overlapping channels in 802.11b, 5 in 802.11a)	Scalable with Internet, fixed length, voice and other services
Spectral efficiency	2.7 bps/Hz-54MBps in 20 MHz	37 bits/second

9.3 Wi-Fi and LTE comparison

When it comes to data capacity growth, LTE and Wi-Fi access points are viable solutions for users and consumers. In terms of support, quality of service, security, and self-organization (SON), LTE requires fewer cells to deliver much better results than Wi-Fi access points. Table 4 demonstrates that Wi-Fi technology has a similar downstream speed to LTE, although Wi-Fi is only available indoors. In addition, we can see that LTE has a higher upstream speed and spectral efficiency than Wi-Fi.

Table 4
Wi-Fi and LTE comparison

	WiFi	LTE
Range	100m	Cell range 100Km
Coverage	Indoor	Indoor, Outdoor
Downstream speed	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	300 Mbps
Upstream speed		75 Mbps
Scalability	Fixed 20 MHz channel (13 Non-overlapping channels in 802.11b, 5 in 802.11a)	Supports career bandwidth from 1.4 MHz to 20MHz, with GSM, UMTS..
Spectral efficiency	2.7 bps/Hz-54MBps in 20 MHz	16.32 bps/Hz per site

9.4 Wi-Fi and WiMAX comparison

WiMAX 802.16 (Wireless Metro Area Network) technology can serve customers up to 50 kilometers away from the base station, but Wi-Fi 802.11a/b/g (Wireless LAN) has a range of roughly 100 meters. WiMAX is more suited for outside use, whilst Wi-Fi is better suited for inside use. WiMAX is a metro area broadband wireless access (BWA) technology, whereas Wi-Fi is a local network technology that adds mobility to private LANs.

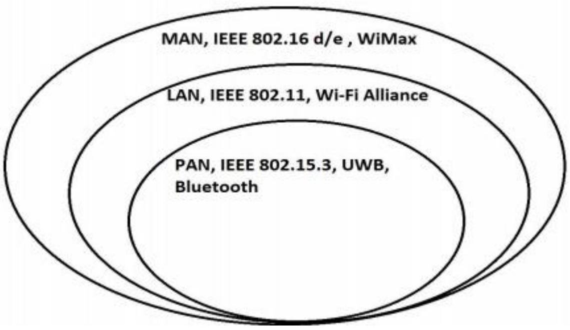

Figure 12: Coverage description of WiMax and Wi-Fi (dBrn Associates, 2004).

Figure 12 depicts Wi-Fi and Wi Max coverage. According to the graph, WiMAX has the best coverage and range, whereas Bluetooth has the worst coverage and range.

In terms of coverage, range, upstream and downstream speeds, scalability, and spectral efficiency, Table 5 compares Wi-Fi and WiMAX technologies. Wi-Fi technology, according to the table, is not as scalable as WiMAX and provides less speed in interior deployment with good spectral efficiency.

Table 4.1.4
Wi-Fi and WiMAX comparison.

	WiFi	WiMax
Range	100m	50KM
Coverage	Indoor	Indoor,
Downstream speed	300 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	Up to 365 Mbps
Upstream speed		Upto 376 Mbps
Scalability	Fixed 20 MHz channel (13 Non-overlapping channels in 802.11b, 5 in 802.11a)	Network expansion, addition of channel, cell splitting, sectorization, polarization modification, and frequency reuse is possible.
Spectral efficiency	2.7 bps/Hz-54MBps in 20 MHz	1.2 to 3.7 bps/Hz per site

X. CONCLUSION

The performance of Wi-Fi standards (IEEE 802.11) in industrial environments was compared to mobile phone radio system standards (3G, 4G, and LTE/5G) in this thesis. In addition, the fundamental technological principles of the IEEE 802.11 family and derivatives have been thoroughly covered in this research.

Wi-Fi is a low-cost technology that meets the needs of customers in terms of market interest. 802.11n appears to be a good future option for commercial use in hotels, hotspots, and cyber cafes because it specifies a 5 GHz frequency with a theoretical maximum speed of 300 Mbps, as well as Multiple Input Multiple output (MIMO), channel bonding, and payload optimization technology. It also offers consistent bandwidth over long distances and covers nearly 1.5 times the distance of previous standards. Our research also reveals that IEEE 802.11 is a low-cost technology when compared to other options on the market.

However, because both Wi-Fi access points and Wi-Fi smartphones are implemented with a variety of Wi-Fi power saving strategies for saving power, the energy consumption of Wi-Fi technology has a considerable impact on the battery of mobile smart-phones.

Finally, we came to the conclusion that, based on our assumptions, gathered data, analysis, observations, and findings, it is possible to provide seamless Wi-Fi internet services to clients in buildings, cafés, hotspots, and other public areas at reasonable technical performance and costs.

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