International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 08 – Issue 04 || April 2023 || PP. 29-42

Evolution of Cellular Mobile Communication Systems up to the Fifth Generation: An Overview

Nathaniel S. Tarkaa
Department of Electrical and Electronics Engineering, Joseph Sarwuan Tarka University Makurdi, Nigeria

Abstract: The advent of mobile communications greatly revolutionized the way people behaved and related socially and professionally. Once people discovered that it was possible to communicate to one another while in transit, the demand for mobile communications services and systems went on increasing on a very rapid scale. The high quality and reliability of mobile telephony services as we are experiencing it today is a culmination of several technological advancements spanning several generations until the current fifth generation popularly known as 5G. Mobile communications now occupy a very strategic position in almost every aspect of our everyday lives such that people have become more anxious and curious to know about the developments taking place in the industry. Hence, there is the need for communication industry experts and researchers to producecopious literature materials in order to enhance knowledge about every emergent and emerging generation of mobile networks. In this paper, the entire subject matter of cellular communications is discussed starting from its evolution from the first generation to the latest 5G technology. The survey covers a number of important topics including cellular system types, structures and sundry network characteristics while examining and appraising the gradual technological changes that characterized each generation evolution to the next one. The results of the survey are presented in a unique and comprehensible way with diagrams and charts.

Keywords: Frequency Spectrum, Personal Communication Systems, Internet Connectivity, Long Term Evolution, Internet of Things, Network Splicing.

I. INTRODUCTION

The cellular telephone industry has expanded explosively since 1980 and continues to expand rapidly. It is an area of telecommunications that has benefited the whole world. According to the latest data from GSMA Intelligence, there are over five billion mobile phone users in the world today. Mobile cellular communications have moved from first-generation (1G) systems primarily focused on voice communications to third, fourth, and fifth-generation (3G, 4G and 5G) systems dealing with Internet connectivity and multi-media applications [1, 2, 3].Mobile communications now occupy a very strategic position in almost every aspect of our everyday lives such that people have become more anxious and curious to know about the developments taking place in the industry. Hence, there is the need for communication industry experts and researchers to produce copious literature materials in order to enhance knowledge about every emergent and emerging generation of mobile networks.

The earliest radio techniques were based on analog technology and served a few numbers of mobile communities, namely, ocean vessels, aircrafts, police and ambulance dispatching systems. These were the first-generation (1G) cellular radio systems [1]. As far back as 1979, Bell Labs designed and installed a trial cellular mobile system called the Advanced Mobile Phone System (AMPS). This was really the birth of cellular mobile communications in the United States. It used FM radio allocating 30 kHz per voice channel. AMPS set the stage for explosive cellular radio growth and usage. AMPS was designed with an important feature that set it apart from previous mobile radio systems, which is, its interface with the fixed-line Public Switched Telephone Network (PSTN) [1]. It was also based on a organized scheme and unique capability of handover between adjoining cells to take over a call when a user moves from one cell to another when a higher signal level is received by the user [1, 3].

In the late 1980s cellular radio was converted from the bandwidth-wasteful AMPS to a digital technology based on FDMA. More schemes were later developed to further improve on the AMPS technology, namely, a TDMA scheme and a CDMA scheme which were radically different and served to mark the birth of Personal Communication Systems (PCS) [1]. PCS is a term used to describe cellular radio systems that offer multimedia services (i.e., voice, data, video, etc.) at anytime and anywhere as distinct from the first-generation cellular radio system (AMPS) that offered mainly voice services that were location based. Meanwhile, the Europeans came up with a better option, the GSM. The acronym GSM originally stood for the French name Groupe Speciale Mobile, the planning organization that did much of the groundwork for the TDMA cellular system. GSM now stands for Global System for Mobile Communications. GSM is a TDMA scheme which is comparable to the U.S. system called IS-54 [1]. These TDMA systems were narrowband in nature and are often considered to be the second generation (2G) of cellular radio system [1, 2 ,3]. For TDMA technology, there were three prevalent 2G systems: North America TIA/EIA/IS-136, Japanese Personal Digital Cellular (PDC), and European Telecommunications Standards Institute (ETSI) Digital Cellular System 1800 (GSM 1800), a derivative of GSM [2, 3]. GSM systems at 900 MHz, 1800MHz and 1900 MHz (that is, GSM900, GSM1800 and GSM1900) were adopted in many countries including the major parts of Europe, North Africa, the Middle East, many East Asian countries, South America, the United States and Australia [2]. A description of the features of the GSM system serves to highlight some of the characteristics of present-day cellular mobile systems including 5G [1, 2]. A GSM network is composed of several functional entities, whose functions and interfaces are specified. The GSM network can be divided into three broad parts, namely, the Mobile Station (MS), the Base Station Subsystem (BSS) and the Network Subsystem, the main part of which is the Mobile Services Switching Centre (MSC).

Another 2G system based on CDMA (TIA/EIA/IS-95) is a direct sequence (DS) spread spectrum (SS) system in which the entire bandwidth of the carrier channel is made available to each user simultaneously. CDMA is an advanced digital cellular technology, which can offer six to eight times the capacity of analog technologies (AMPS) and up to four times the capacity of digital technologies such as TDMA. CDMA technology constantly evolved to offer customers new and advanced services including internet access. Most importantly, the CDMA network offered operators a smooth migration path to third-generation (3G) mobile systems [1, 2].

GSM networks evolved to 3G wide band multimedia operation through two nonexclusive options as follows:(1) using General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) [also known as 2.5G] in the existing radio spectrum, and in small amounts of new spectrum; or (2) using WCDMA/UMTS in the new 2 GHz bands [2, 3]. GPRS, has been developed for DAMPS (IS-136) [2, 3]. Also, a CDMA high data rate (HDR) called 3G 1X EV-DO, (3G 1X Enhanced Version Data Only) and 1X EV-Data and Voice (DV) systems developed by Qualcomm provides another option for the evolution to 3G from the CDMA technology [2, 3].

To make the transition from 3G to 4G, LTE (Long Term Evolution) was first developed [4, 5, 6]. LTE was developed as an interim step up from 3G to provide more bandwidth than 3G, without achieving the full bandwidth network speed minimum of 100 Mbps specified for 4G [7, 8].4G LTE-A (LTE-Advanced), however, is a specific term that is defined as enabling 100 Mbps [8]. The transmission and receiving capabilities of 4G are powered by MIMO (Multiple Input Multiple Output) and Orthogonal Frequency Division Multiplexing (OFDM) technologies [2, 7, 8]. Both MIMO and OFDM enable more capacity and bandwidth in comparison to 3G [7, 8].

5G is the next evolution of mobile network technology. It offers the promise of increased bandwidth with peak speeds as high as 20 Gbps, which is dramatically more than the 100 Mbps specified by 4G. The 5G rollout involves the use of new carrier technology and antennas, as well as mobile devices that support the new standard [5, 6, 7, 8].

There are several related articles in literature but they are different from the way I have organized and presented my own in this paper. The presentation covers both qualitative and quantitative aspects of all the five generations of cellular mobile communications in a more logical and simplified way as a full journal article.

The rest of the paper is organized as follows: Section 2 discusses the different types of cellular mobile systems. Section 3 is a discussion about frequency management and channel assignment. An overview of wireless access technologies is presented in Section 4. This is followed in Section 5 by a discussion about the evolution of cellular mobile communication networks from the first to the fifth generations. Finally, in Section 6 is the conclusion.

II. TYPES OF CELLULAR MOBILE COMMUNICATION SYSTEMS

2.1 Analog FM Radio System

The different types of mobile communication systems differ primarily in frequency spectrum usage, modulation technique and carrier spacing. As far back as 1979, Bell Labs designed and installed a trial cellular mobile system called the Advanced Mobile Phone Service (AMPS). This was really the birth of cellular mobile radio in the United States and it formed the basis of the analog systems that were later to be developed. The AMPS system used the hexagonal cell structure with a base station in each cell. The cells were clustered into groups of seven cells (i.e., a seven-cell repeat or reuse pattern) [1]. AMPS covered large areas with large-sized cells, and high-traffic-density areas were covered by subdividing the cells [1]. The mobile units were originally installed in a car, truck, or bus [1, 2, 3]. The frequencies for AMPS were 870 to 890 MHz from base to mobile, and 825 to 845 MHz from mobile to base (see Fig. 3). Each radio channel had a pair of one-way channels separated by 45 MHz. The spacing between adjacent channels was 30 kHz. The AMPS system used Frequency Modulation (FM) [1, 2].

The first good-quality mobile telephone systems were put into operation by 1983. These first generation (1G) cellular systems in operation were the analog FM radio systems that allocated a single carrier for each call. Each carrier was frequency modulated by the caller. The carriers were typically spaced at 25kHz intervals (i.e., carrier bandwidth). The overall allocated bandwidth was relatively narrow, and only a few channels (typically 12) were available (see Fig. 2).

2.2 Digital Cellular Radio System

Digital cellular radio systems are often considered to be the second generation (2G). They have three standards: one is the GSM system, which was standardized in Europe but now used worldwide, another is the IS-136 standard, developed in the USA, and a third is IS-95 also developed in the USA. Digital cellular systems and their standards were originally developed for telephony [1, 2]. Digital cellular radio systems are also categorized into narrowband and wideband. A system is defined as narrowband or wideband depending on the bandwidth of the transmission physical channels with which it operates. Narrowband systems support low-bit-rate transmission, whereas wideband systems support high-bit-rate transmission. Digital narrowband cellular systems employ two types of techniques for their operation, FDMA and TDMA. FDMA stands for Frequency Division Multiple Access while TDMA stands for Time Division Multiple Access.

The digital narrowband TDMA systems in North America and Europe developed along similar lines, even though with different features between them [1, 2]. The United States TDMA system was originally called IS-136 (or IS-54), or digital AMPS (DAMPS) and was superseded by the IS-136A upgraded standard [1, 2].This system placed its information on carriers spaced 30 kHz (30 kHz bandwidth). This is the same as the AMPS system and allowed operating companies to gradually replace the analog channels with digital channels to ease base station traffic congestion [1]. Because of its global success, the European-designed system called GSM is usually used as model for digital narrowband and broadband TDMA cellular mobile communications development [1, 2]. The hardware and software architectural elements of the GSM reference model are shown in Fig. 1:

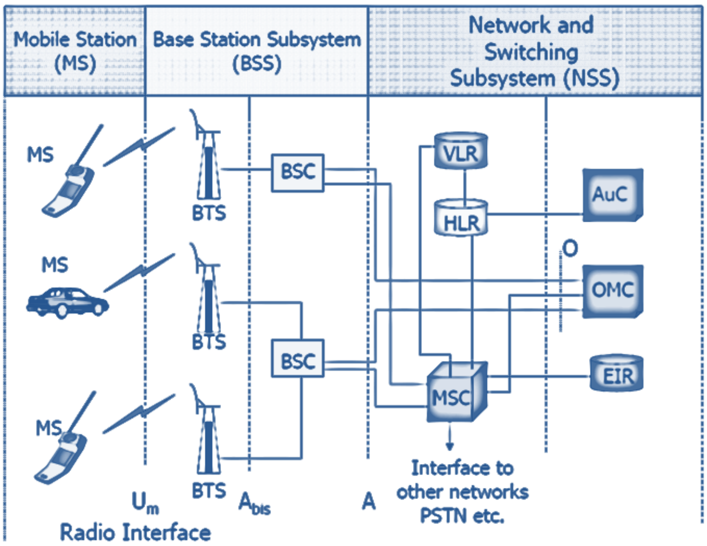

Figure 1: Hardware and software architectural elements of GSM reference model

- A radio network made up of a number of radio cells which are geographical areas served by a fixed transmitter/receiver, known as a cell site or Base Transceiver Station (BTS) or simply Base Station (BS) which make up the Base Station Subsystem (BSS). These cells are used to cover different areas in order to provide the coverage over a wider area than the area of one cell. Cellular mobile networks are inherently asymmetric with a set of fixed main transceivers each serving a set of distributed mobile transceivers (or mobile stations (MS)) which provide services to the network's users.
- A communication link between the BTSs.
- A controller, typically one or more Base Station Controllers or Centralized Base Station Controllers (BSC/CBSC), located within the BSS, to control communication between and to manage the operation and interaction of the BTSs.
- A call controller or switch, for routing calls within the system, called Mobile Services Switching Center (MSC) which together with a number of other components make up the Network and Switching Subsystem (NSS), and

- A link to the land line of Public Switch Telephone System (PSTN) which is usually also provided by the MSC.

One form of digital wideband operation is Code Division Multiple Access (CDMA). In this system, there is a single carrier that is modulated by the speech signals of many users. Instead of allocating each user a different time slot, each is allocated a different modulation code [1, 2, 3]. Mobile users in adjacent cells all use the same frequency band. Frequency reuse is therefore unnecessary. Consequently, each cell can use the full available bandwidth of 12.5 MHz for CDMA operation [1]. The standard for CDMA cellular mobile communications is IS-95 [1, 2, 3]. For CDMA, either frequency hopping (FH) or direct sequence (DS) provides a method for allowing multiple users to occupy the same channel with minimal interference [1, 2]. The IS-95 system uses DS-CDMA. The different types of first and second generations of cellular mobile radio systems in terms of frequency spectrum usage are shown in Fig. 2 [1].

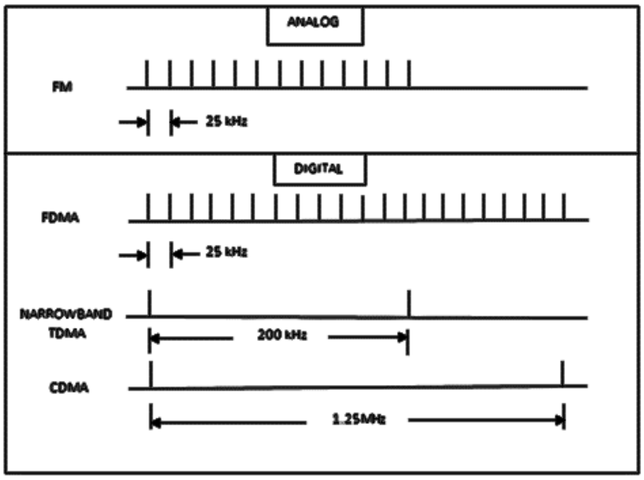

Figure 2: Carrier spacing for 1G and2G cellular radio systems

III. FREQUENCY MANAGEMENT AND CHANNEL ASSIGNMENT

3.1 Introduction

Frequency management refers to allocation of set-up channels and voice channels by regulators, and grouping the voice channels into subsets (done by each operator according to its preference). Channel assignment on the other hand refers to the allocation of specific channels to cell-sites and mobile units. A channel consists of two frequency channel bandwidths, one in the low and one in the high band.

3.2 Cellular A-band and B-band Carriers

The two sets of bandwidths licensed for cellular radio service are known as the A-band and the B-band. A-band carriers are cellular service providers originally termed the non-wire line licensees. These original licensees are companies that provide cellular service and are not associated with any local wire line telephone company. B-band carriers are cellular service providers originally termed the wire line licensees. These licensees are companies that provide cellular service and are associated with the local wire line telephone company in the area where they provide cellular service.

3.3 Frequency Spectrum

A frequency spectrum in mobile communication defines the frequency bands in a particular range allocated to each mobile operator to offer services to their customers. The allocation of the frequency bands requires the mobile network operator to get a license from local regulatory authorities. Cellular coverage is often used in wireless systems such as IS-95 (900 MHz); PCS [1800 MHz (Europe), 1900 MHz (USA)]; DCS (1800 MHz); GSM (900 MHz, 1800 MHz); DECT (2.4 GHz). These wireless systems operate in the 300 – 3000 MHz (UHF) frequency spectrum. The frequency allocations for some of these systems are illustrated in Fig. 3 (a - d). Note that, the PCS band plan, for example, has six frequency allocations, so up to six licenses can be awarded in any given area. There are three 30-MHz and three 10-MHz allocations. The reverse channel or uplink (mobile to base) is 80 MHz above the forward channel or downlink (base to mobile) frequency. Reverse and forward channel allocations are separated by a 20-MHz band, from 1910 to 1930 MHz, which is allocated for unlicensed services like short-range voice communication.

3.4 Channel Spacing

Channel spacing is a term used in radio frequency planning. It describes the frequency difference between adjacent allocations in a frequency plan. Channel spacing means the same thing as bandwidth of the channel. For example, GSM employs a combination of FDMA/TDMA as the method to divide the bandwidth among the users. In this process, the FDMA part divides the frequency of the total 25 MHz bandwidth allocation into 124 carrier frequencies of 200 kHz bandwidth or channel spacing. Each base station is assigned with one or multiples of this frequency and each of this frequency is divided into eight timeslots using the TDMA scheme.

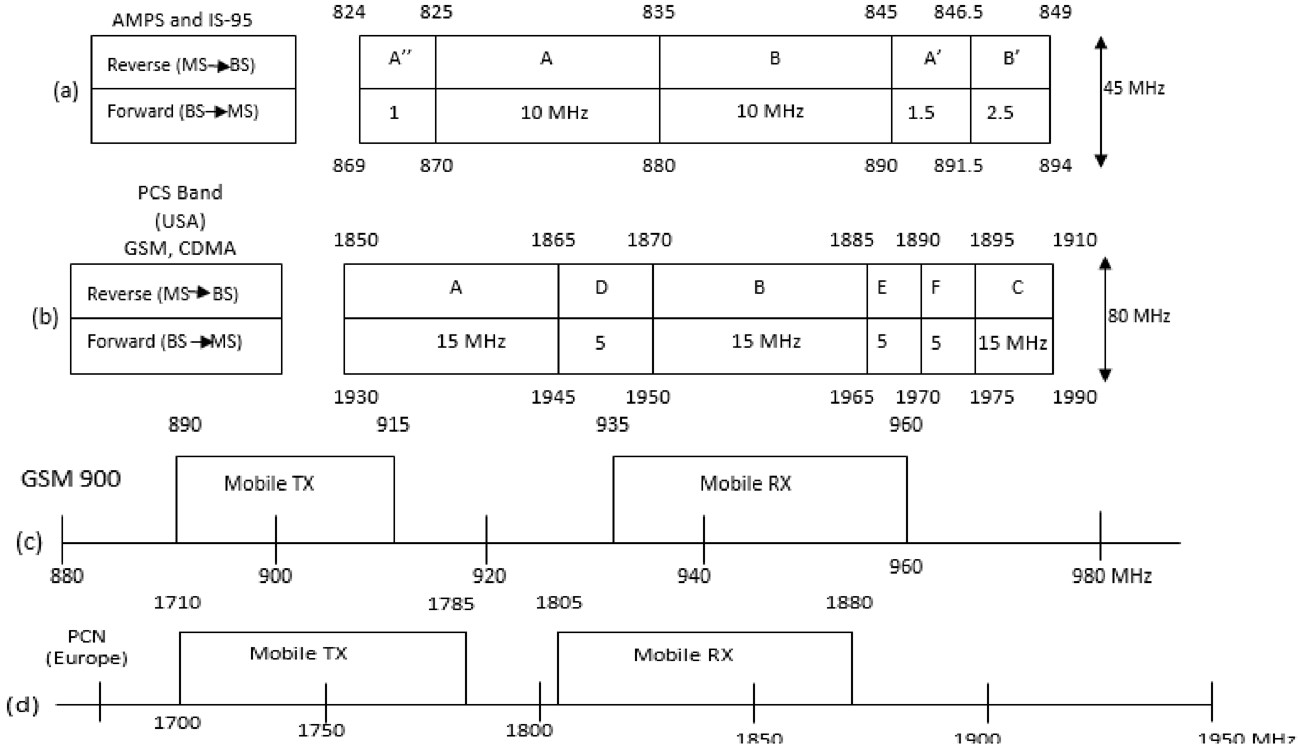

Figure 3: Cellular licensed frequencies

In the cellular band (i.e., AMPS), both operators on A and B have about 12.5 MHz of spectrum in each direction, even though each allocation is unevenly split. The A', B', and A" bands were originally set aside for control functions, but can be used for normal traffic as well.

The frequency bands allocated to GSM are 890 – 915 MHz and 935 – 960 MHz. To allow maximum of users' access, each band is subdivided into 124 carrier frequencies spaced 200 kHz apart, using FDMA techniques.

IV. OVERVIEW OF WIRELESS ACCESS TECHNOLOGIES

4.1 Introduction

As stated earlier, cellular systems divide a geographic region into cells where mobile units in each cell communicate with the cell's base station. The goal in the design of a cellular system is to be able to handle as many calls as possible in a given bandwidth with the specified blocking probability. There are multiple access schemes that are implemented when shared access by many users to a channel is required. Multiple access schemes are designed to maintain robustness and reduce interference effects. Multiple access schemes can be classified as reservation-based multiple access and random multiple access [2]. If data traffic is continuous and a small transmission delay is required (for example in voice communication) reservation based multiple access is used. The family of reservation-based multiple access includes Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). In many wireless systems for voice communication, the control channel is based on random multiple access and the communication channel is based on FDMA, TDMA, or CDMA. A brief discussion of the access technologies for cellular mobile communication networks is outlined below [1, 2] and depicted in Figs. 4 and 5.

(i) Frequency Division Multiple Access (FDMA): 1G,
(ii) Time Division Multiple Access (TDMA): 2G and
(iii) Code Division Multiple Access (CDMA): 3G
(iv) Orthogonal Frequency Division Multiplexing (OFDMA): 4G and 5G

4.2 Frequency Division Multiple Access (FDMA):

FDMA simply means splitting up an available frequency band into a specific number of channels, and the bandwidth of each channel depends on the type of information signals to be transmitted. One pair of channels is used in full duplex operation. Information to be transmitted is superimposed on a carrier at the channel center frequency. The information can be a composite of several information signals, which are multiplexed prior to being superimposed on the carrier, or a single information signal can be placed on the carrier. FDMA access scheme is used in 1G networks.

4.3 Time Division Multiple Access (TDMA):

TDMA uses only one frequency band, and many channels are created by transmitting information for each channel in allocated time slots. This mechanism creates the illusion that many users are accessing the radio system simultaneously. In reality, the time sequencing means only one user is occupying the system at any time. In a TDMA mobile radio system, each base station is allocated a 25 or 30 KHz channel, and users share this same channel on a time-allotted basis. The maximum number of users of each channel depends on how many bits per second are required to digitize the voice of each user. TDMA is used in 2G networks.

4.4 Code Division Multiple Access (CDMA):

The objective of CDMA is to allow many users to occupy the same frequency band without interfering with each other. Each user is assigned a unique orthogonal code. In a CDMA system, all signals from all users will be received by each user. Each receiver is designed to listen to and recognize only one specific sequence. Having locked into this sequence, the signal can be dispread, so the message stands out above the other signals (which appear as noise in comparison). Interference thus becomes a limiting factor, because as more users occupy the same frequency band, the noise level rises to a point where dispreading does not provide an adequate S/N. CDMA is used in 3G networks.

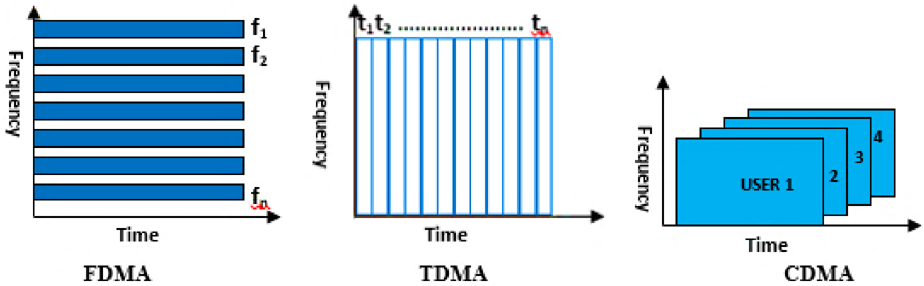

Figure 4: Wireless Access Technologies

4.5 Orthogonal Frequency Division Multiplexing (OFDM)

In data communications and networking, orthogonal frequency-division multiplexing (OFDM) is a method of digital data modulation whereby a single stream of data is divided into several separate sub-streams for transmission via multiple channels (see Fig. 5) [9].OFDM is a specialized FDM having the property that, the sub-streams, in which the main signal is divided, are orthogonal to each other [9]. Orthogonal signals are signals that are perpendicular to each other. A main property of orthogonal signals is that they do not interfere with each other.

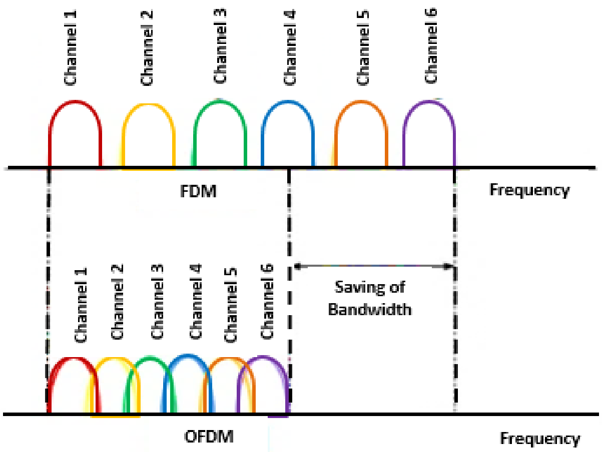

Figure 5: Saving of bandwidth by OFDM

When any signal is modulated by the sender, its sidebands spread out either side. A receiver can successfully demodulate the data only if it receives the whole signal. In case of FDM, guard bands are inserted so that interference between the signals, resulting in cross-talks, does not occur. However, since orthogonal signals are used in OFDM, no interference occurs between the signals even if their sidebands overlap. So, guard bands can be removed, thus saving bandwidth [9]. The criteria that need to be maintained is that the carrier spacing should be equal to the reciprocal of the symbol period. In order that OFDM works, there should be very accurate synchronization between the communicating nodes. If frequency deviation occurs in the sub-streams, they will not be orthogonal any more, and interference will occur between the signals.

V. EVOLUTION OF CELLULAR MOBILE COMMUNICATION NETWORKS

5.1 First and Second Generation (1G and 2G) Cellular Systems

The first public cellular telephone system (first-generation, 1G), called Advanced Mobile Phone System (AMPS), was introduced in 1979 in the United States. During the early 1980s, several incompatible cellular systems (TACS, NMT, C450, etc.) were introduced in Western Europe. The deployment of these incompatible systems resulted in the mobile phones also being incompatible, and roaming between the many countries of Europe was not possible. The first-generation systems were designed for voice applications. Analog frequency modulation (FM) technology was used for radio transmission [1, 2, 3].

In 1982, the main governing body of the European post telegraph and telephone (PTT), set up a committee known as Groupe Special Mobile (GSM), under the auspices of its Committee on Harmonization, to define a mobile system that could be used across western Europe in the 1990s [1, 2]. The work on GSM (renamed Global System for Mobile Communications) started by allocation of necessary duplex radio frequency bands in the 900 MHz region and selecting the radio technologies for the air interface. The GSM architecture is an open architecture which provides maximum independence between network elements [2]. This approach favoured an evolutionary growth path to the next generations.

GSM 900 and its later derivatives, GSM1800 and GSM1900 (i.e., GSM system at 900 MHz, at 1800 MHz and at1900 MHz) were adopted in many countries, including the major parts of Europe, North Africa, the Middle East, many East Asian countries, Australia, South American countries, North America and the United States to provide additional capacity and enable higher subscriber densities [2]. This globalization positioned GSM and its derivatives as one of the leading contenders for offering digital cellular and Personal Communications Services (PCS) worldwide. A PCS system offers multimedia services (i.e., voice, data, video, etc.) at anytime and anywhere. GSM 900, GSM 1800, and GSM 1900 are second-generation (2G) systems and belong to the GSM family. Two digital technologies, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) emerged as clear choices for the newer PCS systems. TDMA is a narrowband technology in which communication channels on a carrier frequency are apportioned by time slots. For TDMA technology, there are three prevalent 2G systems: North America TIA/EIA/IS-136, Japanese Personal Digital Cellular (PDC), and European Telecommunications Standards Institute (ETSI) Digital Cellular System 1800 (GSM 1800), a derivative of GSM. Another 2G system based on CDMA (TIA/EIA/IS-95) is a direct sequence (DS) spread spectrum (SS) system in which the entire bandwidth of the carrier channel is made available to each user simultaneously [2].

CDMA is an advanced digital cellular technology, which can offer six to eight times the capacity of analog technologies (AMPS) and up to four times the capacity of TDMA. The speech quality provided by CDMA systems is far superior to any other digital cellular system, particularly in difficult RF environments such as dense urban areas and mountainous regions. In both initial deployment and long-term operation, CDMA provides the most cost-effective solution for cellular operators. Most importantly, the CDMA network offered operators a smooth migration path to third-generation (3G) mobile systems [2].CDMA is a widely used digital wireless technology that has a worldwide subscriber base. The major markets for CDMA technology are North America, Latin America, and Asia, in particular Japan and Korea.

5.2 Evolution of Cellular Communications from 1G to 3G

Mobile systems have seen a change of generation, from first to second to third in about every ten years (see Fig. 6). At the introduction of 1G services, the mobile device was large in size, and would only fit in the trunk of a car [1]. All analog components such as the power amplifier, synthesizer, and shared antenna equipment were bulky [1]. 1G systems were intended to provide voice service and low rate (about 9.6 kbps) circuit-switched data services. Miniaturization of mobile devices progressed before the introduction of 2G services (1990) to the point where the size of mobile phones fell below 200 cubic centimeters [1]. The first-generation handsets provided poor voice quality, low talk-time, and low standby time. The 1G systems used Frequency Division Multiple Access (FDMA) technology and analog frequency modulation [1, 2].

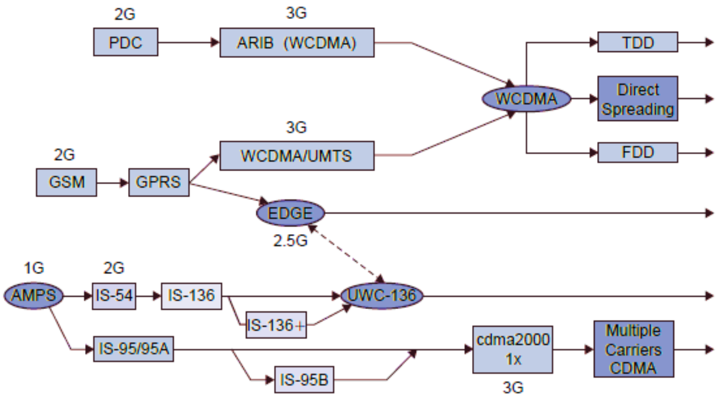

Figure 6: Cellular networks evolution from 1G to 3G [2]

The 2G systems based on TDMA and CDMA technologies were primarily designed to improve voice quality and support low-rate data services (16–32 kbps) and also introduce security (encryption) [1, 2].

The focus of the third-generation (3G) mobile systems has been on the economy of network and radio transmission design to provide PCS services, taking into account the limitations imposed by the finite amount of radio spectrum available. The combination of Internet access, web browsing, and the whole range of mobile multimedia capability is the major driver for development of higher data speed technologies. CDMA was the selected approach for 3G systems by the ETSI, Association of Radio Industries and Business (ARIB)- Japan and Telecommunications Industry Association (TIA) [2]. In Europe and Japan, Wideband CDMA (WCDMA/UMTS was selected. UTMS stands for Universal Mobile Telecommunication Services.

The use of CDMA technology began in the United States with the development of the IS-95 standard in 1990. The IS-95 standard has evolved to other frequency bands (IS-95A), to provide better voice services and applications and toIS-95B to provide higher data rates (up to 115.2 kbps) for data services [2]. To further improve the voice service capability and provide even higher data rates for packet and circuit switched data services, the industry developed the cdma2000 standard in 2000. A CDMA high data rate (CDMA-HDR) system was developed by Qualcomm called 3G 1X EV-DO, (3G 1X Enhanced Version Data Only) system design which improved the system throughput [2]. 3G 1X EV-DO can transmit data in burst rates as high as 2.4 Mbps with 0.5 to 1 Mbps realistic downlink rates for individual users. The uplink design is similar to that in cdma2000. Also, the 3G1X EV-Data and Voice (DV) standard was finalized by the TIA [2]. 3G 1X EV-DV achieved peak data transmission throughput of 3.09 Mbps in the downlink. As an alternative, Time Division-Synchronous CDMA (TD-SCDMA) was developed by Siemens and the Chinese government. TD-SCDMA uses adaptive modulation of up to quadrature phase shift keying (QPSK) and 8-PSK, as well as turbo coding to obtain downlink data throughput of up to 2 Mbps. TD-SCDMA uses a1.6 MHz time-division duplex (TDD) carrier whereas cdma2000 uses a 2 x 1.25 MHz frequency-division duplex (FDD) carrier (2.5 MHz total). TDD allows TD-SCDMA to use the least amount of spectrum of any 3G technologies. Fig. 7 shows a 3G-WCDMA/UMTS architecture [11].

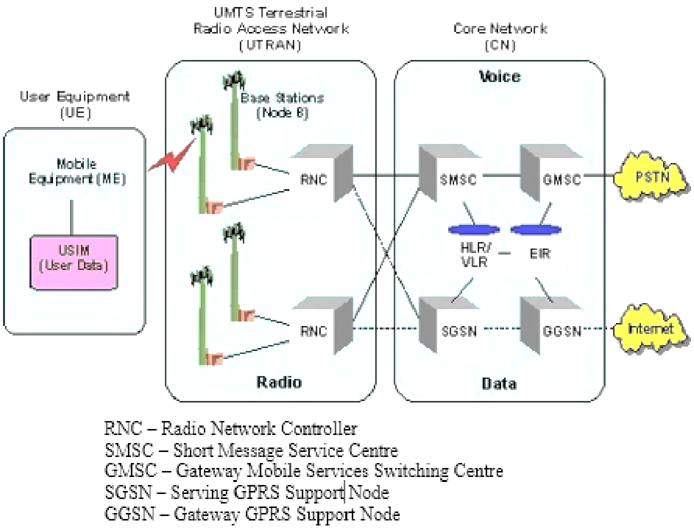

Figure 7: 3G-WCDMA/UMTS Network Architecture

GSM operators have used two nonexclusive options for evolving their networks to 3G wide band multimedia operation: (1) General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) in the existing radio spectrum, and in small amounts of new spectrum; or (2) WCDMA/UMTS in the new 2 GHz bands (see Fig. 8) [2]. The significance of EDGE (also referred to as 2.5G system) for GSM operators is that it increases data rates up to 384 kbps and potentially even higher in good quality radio environments that are using GSM spectrum and carrier structures more efficiently. EDGE both complements and is an alternative to WCDMA coverage. EDGE also has the effect of unifying the GSM, DAMPS, and WCDMA services through the use of dual-mode terminals. Dual-mode EDGE/ UMTS mobile terminals allows full roaming and handover from one system to the other, with mapping of services between the two systems [2]. Fig. 8 depicts an integrated 2G-GSM/3G-UTMS architecture [12].

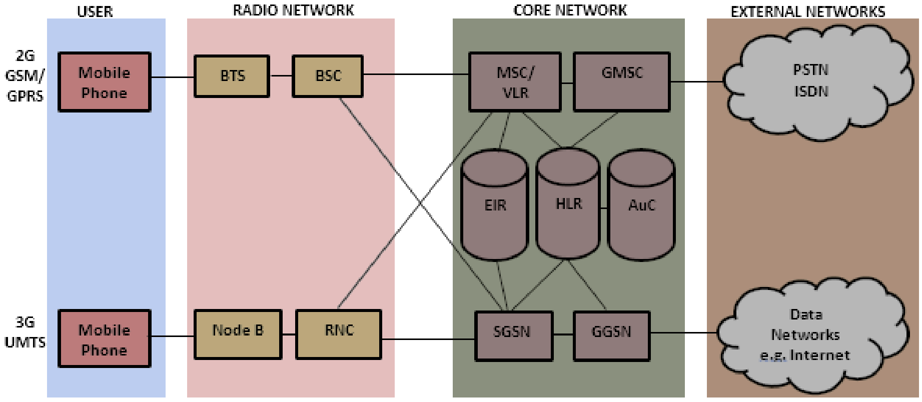

Figure 8: An integrated 2G/3G architecture

5.3 Fourth Generation (4G) Systems

The 4G wireless cellular standard was defined by the International Telecommunication Union (ITU) and specifies the key characteristics of the standard, including transmission technology and data speeds [2, 4, 8]. Each generation of wireless cellular technology has introduced increased bandwidth speeds and network capacity. 4G users get speeds of up to 100 Mbps, while 3G only promised a peak speed of 14 Mbps [8]. With 4G download speeds, mobile users can stream high-definition video and audio. 4G also enables wireless broadband, which provides a way for users to get internet connectivity without the need for a fixed, wired connection from an internet service provider (ISP).

In 2008, no mobile network or cellular carrier was able to achieve the 100 Mbps speed that 4G specified, though there were competing approaches, including Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX), which aimed to bridge the gap between 3G and 4G [8].Sprint was among the principal backers of WiMAX, while Verizon pushed for LTE. A key difference between WiMAX and LTE is that WiMAX did not make use of OFDM, which became a foundational element of all 4G deployments over time [8]. By 2011, Sprint changed course and began to support LTE across its network, and WiMAX began to disappear [8].LTE was originally developed to make the transition for carriers easier from 3G to 4G. It was indeed a "long-term evolution" for mobile networks when 4G came out in 2008 [8] as the evolution took many years. LTE provided more bandwidth than 3G, without achieving the full bandwidth network speed minimum specification of 100 [8].LTE has steadily increased in speed and performance since 2011, with the 4G LTE-Advanced (LTE-A) technology providing cellular networks with the full 100 Mbps of network performance defined by the original IMT-Advanced specification [8].

The transmission and receiving capabilities of 4G are powered by Multiple Input Multiple Output (MIMO)and Orthogonal Frequency Division Multiplexing (OFDM) technologies [2, 4, 8]. Both MIMO and OFDM enable more capacity and bandwidth in comparison to 3G. OFDM provides more speed than the primary technologies that powered 3G, which include TDMA and CDMA technology [8]. With MIMO, 4G reduces network congestion in comparison to 3G, because more users can be supported. 4G is also an all-IP-based standard for both voice and data, different from 3G, which only uses IP for data [9], while enabling voice with a circuit-switched network. As an all-IP network, 4G is more efficient for mobile network providers to operate and optimize than managing different network technologies for voice and data. Fig. 9 shows the 4G LTE architecture:

- **E-UTRAN** means Evolved-UMTS Terrestrial Radio Access Network. It is the air interface in an LTE cellular network. E-UTRAN uses the OFDMA modulation method for the downlink and SC-FDMA for the uplink.

- **EPC** stands for Evolved Packet Core. It is a framework for providing converged voice and data on a 4G LTE network.
- **MME** means Mobility Management Entity. The MME manages User Equipment (UE) access network and mobility, as well as establishing the bearer path for UEs.
- **HSS** means Home Subscriber Server. HSS is the master user database that supports IP Multimedia Subsystems (IMS) network entities that handle calls and sessions.

5.4 Fifth Generation (5G) Systems

The development and rollout of 4G's successor, 5G, is a multiyear process. As was the case with each prior generation, it takes multiple years to roll out a new generation of technology. The 5G rollout involves the use of new carrier technology and antennas, as well as mobile devices that support the new standard [7, 8, 10]. 5G with its next generation network architecture has the potential to support thousands of applications in both the consumer and industrial segments.

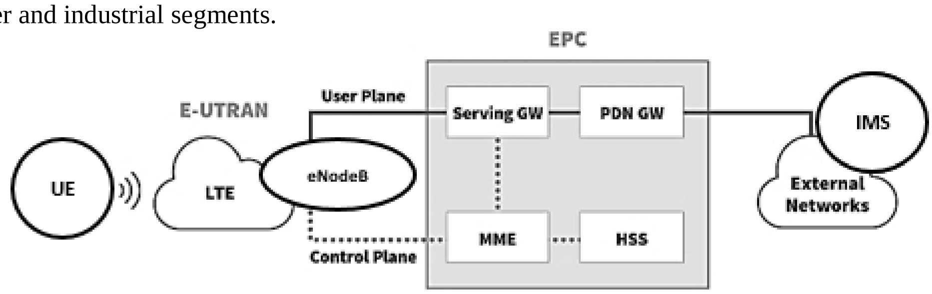

Figure 9: 4G LTE Network Architecture

The possibilities for 5G seem almost limitless as speed and throughput are exponentially higher than current networks. These capabilities will enable applications across vertical markets such as manufacturing, healthcare, and transportation, where 5G will play a major role in everything from advanced manufacturing automation to fully autonomous vehicles [4, 5, 6, 7, 8, 9].

5G has received enormous amount of attention and hype. While the potential is enormous, it is important to know that the industry is still in its early stages of adoption [7]. The process of deploying the 5G network started many years ago and involved building out the new infrastructure, most of which is funded by the major carriers. Full 5G deployment will take time, rolling out in major cities long before it can reach less populated areas [7].

5.4.1 5G Network Architecture

The standards behind 5G network architecture were developed by the 3rd Generation Partnership Project (3GPP), the organization that develops international standards for all mobile communications [7, 10]. The International Telecommunications Union (ITU) and its partners define the requirements and timeline for mobile communication systems, defining a new generation approximately every decade. The 3GPP develops specifications for those requirements in a series of releases.

The 5G network architecture presents significant advances beyond 4G LTE technology, which comes on the heels of 3G and 2G. It’s important to note that 5G is not a direct replacement for 4G - it’s a complementary technology [7, 10]. With the two working in tandem, you should get good or at least decent speeds on your mobile device wherever you are. Carriers continue to upgrade 4G networks, and both download speeds and latency are still improving. The 5G network architecture improves vastly upon past architectures. Large cell-dense networks enable massive leaps in performance. In summary, 5G offers three principal advantages [7].

- Faster data transmission, up to multi-Gigabit/s speeds.
- Greater capacity, fueling a massive amount of Internet of Things (IoT) devices per square kilometer.
- Lower latency, down to single-digit milliseconds, which is critically important in applications such as connected vehicles in Intelligent Transportation System (ITS) applications and autonomous vehicles, where instantaneous response is necessary.

The 5G network architecture diagram showing the key components of the 5G System also known as 5GS is depicted in Fig. 10 [7, 10]. The 5GS is composed of the 5G core network, which enables the advanced functionality of 5G network, 5G Access Network (5G-AN) and User Equipment (EU). The 5G core uses a cloud-aligned service-based architecture (SBA) to support authentication, security, session management and aggregation of traffic from connected devices, all of which require the complex interconnection of network functions as shown in the 5G core diagram.

5.4.2 5G Planning and Design

The design considerations for a 5G network architecture that support highly demanding applications are complex [7]. There is no-size-fits all approach. 5G architecture must support low, mid and high-band spectrum, from licensed, shared and private sources, to deliver the full 5G vision. For this reason, 5G is architected to run on radio frequencies ranging from sub-1GHz to extremely high frequencies, called millimeter wave (or mmWave) as illustrated in Fig. 11. The lower the frequency, the further the signal can travel and the higher the frequency, the more data it can carry. There are three frequency bands at the core of 5G networks [7] as follows:

- 5G high-band (mmWave) delivers the highest frequencies of 5G. These range from 24 GHz to approximately 100 GHz. Because high frequencies cannot easily move through obstacles, high-band 5G is short-range by nature. Thus, mmWave coverage is limited and requires more cellular infrastructure.
- 5G mid-band operates in the 2 – 6 GHz range and provides a capacity layer for urban and suburban areas. This frequency band has peak rates in the hundreds of Mbps.
- 5G low-band operates below 2 GHz and provides a broad coverage. This band uses spectrum that is available and in use today for 4G LTE, essentially providing an LTE/5G architecture for 5G devices that are ready now.

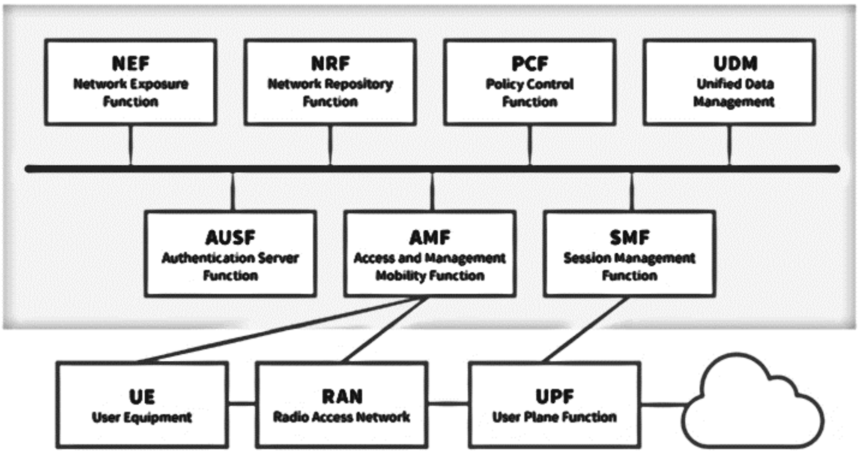

Figure 10: 5G Network Architecture

In addition to spectrum availability and application requirements for distance/bandwidth considerations, operators must consider the power requirements of 5G, as the typical 5G base station design demands over twice the amount of power of a 4G base station [7].

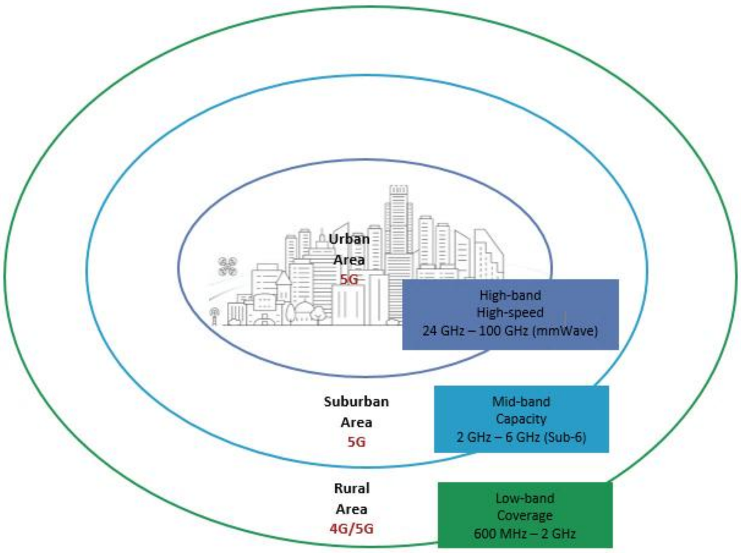

Figure 11: High frequency spectrum usage in 5G Networks

For 5G to deliver its full vision, the network infrastructure needs to evolve as well [7, 10]. Fig. 12 illustrates the evolution of the network over time. The earliest uses of 5G technology will not be exclusively 5G but will appear in applications where connectivity is shared with existing 4G LTE in what is called nonstandalone (NSA) mode [7, 11]. When operating in this mode, a device will first connect to the 4G LTE network, and if 5G is available, the device will be able to use it for additional bandwidth. For example, a device connecting in 5G NSA mode could get 200 Mbps of downlink speed over 4G LTE and another 600 Mbps over 5G at the same time, for an aggregate speed of 800 Mbps [7]. As more and more 5G infrastructure goes online over the next several years, it will evolve to enable 5G-only stand-alone mode (SA). This will bring the low latency and ability to connect with massive numbers of IoT devices that are among the primary advantages of 5G [7].

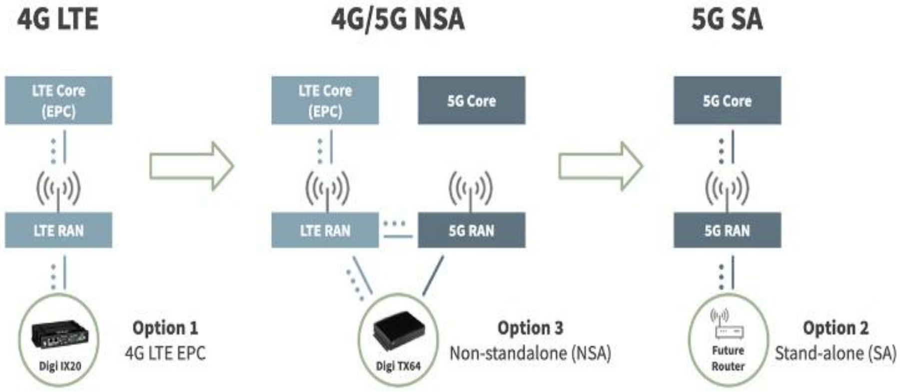

Figure 12: Evolution of 5G network infrastructure over time

5G core networks can be customized through network slicing (see Fig. 13) [7, 11]. Network slicing allows the operator to have multiple logical "slices" of functionality optimized for specific applications, all operating on a single physical core within the 5G network infrastructure. A 5G operator may offer one slice that is optimized for high bandwidth applications, another slice that is more optimized for low latency, and a third one that is optimized for a massive number of IoT devices. Depending on this optimization, some of the 5G core functions may not be available at all. For example, if only the servicing of IoT devices is required, it would not be necessary to include the voice function that is necessary for mobile phones. And because not every slice must have exactly the same capabilities, the available computing power is used more efficiently [7].

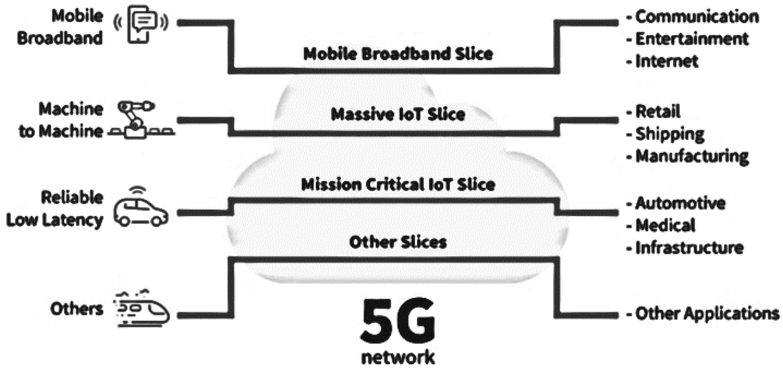

Figure 13: 5G Network slicing

5.4.3 Power Transmission

The power output of a small 5G cell is usually less than 1 watt, compared to 120 Watts of a massive MIMO tower. In comparison, a typical 2G, 3G, or 4G antenna has a transmission power of 20 Watts [13]. 5G in the 24 GHz range or above uses higher frequencies than 4G and as a result, some 5G signals are not capable of travelling long distances unlike 4G or lower frequency 5G signals (sub 6GHz) [14]. This requires placing 5G base stations every few hundred meters in order to use higher frequency. Also, these 5G higher frequency signals cannot penetrate solid objects easily, such as cars, trees, walls, because of the nature of these higher frequency electromagnetic waves. So, 5G cells for higher frequencies, are deliberately designed to be as inconspicuous as possible, having a small power output of less than 1 Watt per cell, which finds applications in places like restaurants and shopping malls [14]. The 4G or lower frequency 5G signals on the other hand are placed at longer distances apart, accounting for the massive MIMO cell power output of 120 Watts. This is essentially the same as the 5 GHz WLAN [13].

Like any other wireless radio communication system, 5G base stations have to comply with radio frequency electromagnetic field (EMF) exposure limits, such as those specified by the International Commission on Non-Ionizing Radiation Protection (ICNRP) [15]. EMF measurements surveys of 5G base stations have been conducted in some countries and typical exposure levels in areas accessible by the general public were found to be thousands of times below the approved limits and similar to those of other existing mobile technologies (2G, 3G, and 4G) [15], so the issue of 5G transmission being dangerous to health does not arise.

5.4.4 Summary of 5G Evolution

Every generation of wireless cellular communication takes approximately a decade to mature. The switch from one generation to the next is mainly driven by the operators need to reuse or repurpose the limited amount of available spectrum. Each new generation has more spectral efficiency, which makes it possible to transmit data faster and more effectively over the network.

The first generation of wireless communications,1G, started back in the 1980s with analog technology. This was followed quickly by 2G, the first network generation to use digital technology. The growth of 1G and 2G was initially driven by the market for mobile handsets. 2G also offered data communications but at very low speeds. The next generation, 3G, began operations in the early 2000s. The growth of 3G was driven by handsets again, but was the first technology to offer data speeds in the 1Mbps range, suitable for a variety of new applications both on smartphones and for the emerging IoT ecosystem. The current generation of wireless technology, 4G LTE, began operations in 2010. It is important to note that 4G LTE has a long life ahead; it is a very successful and mature technology and is expected to be in wide use for at least another decade. 4G LTE and 5G networks will coexist over the next decade, as applications begin to migrate and then 5G networks and applications will eventually supersede 4G LTE. Tables 1 and 2 show the evolution of wireless cellular networks from 1G to 5G [2, 4]. Table 1 lists the general details while Table 2 shows the long term of the evolution by number of years [4].

Table 1: Network technology migration paths and their associated data rates

Technology/System	Generation	Carrier width (MHz)	Duplexing	Multiplexing	Modulation	Maximum data rates	End user data rates
AMPS, NMT, C240, TACS	1G	0.03	FDD	FDMA	FM	9.6kbps	4.8-9.6kbps
GSM, IS-54/IS-136 (DAMPS) IS-95A	2G	0.20 0.03	FDD FDD	TDMA TDMA CDMA	GMSK QPSK	9.6-14.4kbps1 4.4kbps	about 12kbps about 10kbps
GPRS	2.5	0.20	FDD	TDMA	GMSK	up to 115.2kbps (8 channels)	10-56kbps
EDGE	2.5	0.20	FDD	TDMA	GMSK, 8-PSK	384kbps	about 200kbps
WCDMA	3G	5.00	FDD	CDMA	QPSK	2Mbps (stationary); 384kbps (mobile0	50kbps uplink; 150-200kbps downlink
Cdma2000	3G	1.25	FDD	CDMA	QPSK	153kbps	90-130kbps
3G 1X EV-DO	3G	1.25	FDD	TD-CDMA	QPSK, 8-PSK 16-QAM	2.4 Mbps	700 kbps
3G 1X EV-DV	3G	1.25	FDD	TD-CDMA	QPSK, 8-PSK 16-QAM	3-5 Mbps	>1Mbps
TD-SCDMA	3G	1.60	FDD	TD-CDMA	QPSK, 8-PSK	2Mbps	1.333 Mbps
	4G/4G LTE	100-800	FDD/TDD	OFDM	QPSK, QAM,	200 Mbps	15-50 Mbps
	5G	1000-24000	FDD/TDD	OFDM	16QA, 64QAM, 256QAM	10 Gbps	> 50 Mbps

Table 2: Depiction of Long-Term Evolution

Generation	Year	Latency	Services
1G	1980s	>1000 ms	Voice calls
2G	1990s	630 ms	Voice calls, short messages (SMS) and roaming
3G	2000s	212 ms	Introduced some mobile Internet experience
4G	2010s	60-100 ms	Brought fast Internet experience
5G	2020s	<1 ms	Brings super-fast Internet for Internet of things (IoT) applications

VI. CONCLUSION

In this paper, an attempt has been made to present an overview of cellular mobile communications in a very concise and understandable way. Various related literatures were surveyed. It became clear that each generation of cellular networks is a culmination of the previous technological developments taking place in the field. For example, the fifth generation (5G) is the culmination of 1G to 4G. 1G evolved, driven primarily by the demand for mobile phones which was closely followed by 2G also for the same reason and in addition to improve efficiency. The evolution of 3G was primarily driven by the need to extend the use of mobile phones to data communications rather than voice communications alone - this contributed significantly in ubiquitous mobile communications everywhere and anywhere, often referred to as PCS and IoT. Hence the fourth generation (4G) of cellular networks were tailored towards enhancement of the capacity and capabilities already achieved with 3G in the areas of speed, spectrum efficiency and latency. An advanced version of 4G known as 4G LTE currently trending is a successful and mature technology that will remain in use for the next decade. The fifth generation (5G) of wireless cellular networks is a burgeoning technology that has been designed to extend the capabilities of 4G LTE to the climactic level of PCS and IoT communications.

Great effort was made to fetch only among the most salient points from the vast literature surveyed. Closer attention was given mostly to technological changes involved with each generation, for example, FDMA for 1G, TDMA for 2G, CDMA for 3G, and MIMO/OFDMA for 4G and 5G; plus a few other relevant information about cellular networks. More details were however provided for 5G because of the generality of curiosity about the new technology. It was found that 5G is just a state-of the-art technology. The major differences between it and the previous generations are the extra-high frequency bands, low transmitter powers and complexity of equipment. The main aim of this paper is to present the topic in different style for better understanding and it is believed it will make an interesting reading.

REFERENCES

[1]. Robert G. Winch, *Telecommunication transmission systems* (McGraw-Hill, 1998).
[2]. Vijay K. Garg, *Wireless communications and networking* (San Francisco: Morgan Kaufmann Publishers, 2007).
[3]. Roger L. Freeman, *Fundamentals of Telecommunications, Second Edition*(Hoboken, NJ; John Wiley & Sons, 2005).
[4]. Thales, “4G LTE Explained (Long Term Evolution)-Updated”, www.thalesgrop.com/en/markets/digital, 12/01/2022.
[5]. Mark Jansen and Paula Beaton, Digital Trends Media Group, 5G vs 4G: “How does the newest network improve on the last?”, www.digitaltrends.com/mobile/5G-vs-4G, April 22, 2022.
[6]. Twi Limited, “What is 5G Technology and how does it work?”, www.twi-global.com/technical-knowledge/faqs/What-is-5G, copyright, 2022.
[7]. Harald Remmert, CTO, Cellular Solutions, Digi International, “What is 5G Network Architecture?”, www.digi.com/blog/post/5g-network-arch, March 19,202021.
[8]. Sean Michael Kerner, Search Mobile Computing, “4G (fourth-generation wireless)”, www.techtarget.com/searchmobilecomputing/definition/4G
[9]. Tutorials point, “Orthogonal Frequency Division Multiplexing (OFDM)”, www.tutorialspoint.com/orthogonal-frequency-division-multiplexing-ofdm, 07/10/2019.
[10]. 3GPP, Technical Specification Group Services and System Aspects; “Release 15 Description; Summary of Rel-15 Work Items”, www.3gpp.org, 2019.
[11]. CDMA, www.idonghuntistory.com, Accessed 22/10/2022.
[12]. Modern Wireless Systems, www.telephoneworld.org, Accessed, 22/10/2022.
[13]. Kurt Behnke, “Is this anything to worry about? 5G Health Issues Explained”, www.grandmetric.com, 26/03/2019.
[14]. Volodymyr Bezverkhniy, “Are the Energy Waves needed in 5G Technology Dangerous to Humans?”, www.quora.com, accessed 24/10/2022.
[15]. Md Sajid Ali Khan, “Downlink Transmit Power in NR (5G) (Passive Vs Active Antenna Power Calculations)”, www.linkedin.com, Dec 15, 2020.