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Evolution of Mobile Cellular Network Communication Infrastructure: A Literature Perusal

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ABSTRACT

Abstract— Nigerian government is faced with the problem of reconciling access to education with quality in the face of the explosive population of school age children and youths, against the backdrop of inadequate educational facilities and infrastructure. The nation's tertiary institutions can hardly accommodate up to 30% of the population of prospective candidates into tertiary institutions in Nigeria. This puts high pressure on the admission process. Thus manual methods of credentials evaluation to determine eligible candidates in the various courses of study, becomes cumbersome and error prone. More often than not, evaluation and selection processes are compromised as a result of personal interest, subjectivity in judgment, fatigue or graft. Consequently, some candidates are enrolled into courses where the fall short of entry requirements. Following established principles for software architecture designs, this study seeks to present a suitable architecture that can be used to design data structures and program components that are required to build a computer-based system for determining the eligibility of candidates seeking admission into tertiary institutions in Nigeria. It presents the structure and properties of the components that constitute the system, and the interrelationships that occur among all the architectural components of the system. This framework presents standards and procedures which systems developers can adopt to develop generic application for credentials evaluation and eligibility clearance for prospective candidates into Nigerian tertiary institutions.

Keywords: Candidates' eligibility, credentials screening, prospective students, admissions, tertiary education.

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1. BACKGROUND TO THE STUDY

The technologies powering wireless communication infrastructure continues to evolve at a blitzing speed, and the driving factors for this evolution is not far-fetched. First, wireless communication technologies enables the extension of communication and its attendant services to distant and vast areas with very little equipment on the ground in comparison with wired technologies. Second, in this contemporary information age, there is a consistent growth in the demand for information services on the go, and to accommodate these demands, innovations in bandwidths carrying capacities and security have been receiving immense attention.

In this study, an evaluation of wireless networking technologies from the perspective of the generations that have been witnessed, their enabling technologies, the services provided and supported by each generation, their security concerns and some myths about the state-of-the-art fifth generation is presented.

2. HISTORICAL PERSPECTIVE

Attempts and efforts at wireless communication or information (signal) transmission is intricately linked to the evolution of human civilization. Anecdotal sources show that in ancient times, primitive communication systems, which can be categorized as wireless (smoke signals, flashing mirrors, flags, fires, etc.) were in use. It is reported that the ancient Greeks utilized a communication system comprising of a collection of observation stations on hilltops, with each station visible to its neighboring one (Majid, 2018).

In modern day concept, this parallels the line of site requirement of some wireless connection technologies. Upon receiving a message from a neighboring station, the station personnel repeated the message in order to relay it to the next neighboring station. This again depicts the concept of the use of repeaters or active hubs for signal boosting in the modern times. Using this system, messages were exchanged between pairs of stations far apart from one another. Such systems were also employed by other civilizations (Kachhavay, 2014).

However, from a technological perspective, it is more logical to link the origin of wireless networks, with the first radio transmission which took place in 1895, a few years after the invention of the telephone, which incidentally happen to be the enabler of wireless communications. In the first radio-based wireless transmission demonstration, Guglielmo Marconi relayed a message between the Isle of Wight and a tugboat 18 miles away. And six years later, Marconi successfully transmitted a radio signal across the Atlantic Ocean from Cornwall to Newfoundland and in 1902 the first bidirectional communication across the Atlantic Ocean was successfully achieved. Marconi's pioneering radio-based transmission continued to evolve, thus inspiring the official documented origins of radio-based telephony of 1915, involving a conversation between ships (Hugh, 2016).

3. PUBLIC MOBILE TELEPHONY

3.1 Mobile Telephone System

In 1946, the first public mobile telephone system, known as Mobile Telephone System (MTS), was introduced in 25 cities in the United States. By today's standards, the approach adopted in achieving mobility fell short of the requirements due to technological limitations. The mobile transceivers of MTS were very big and were carried around by vehicles. Thus, what was available then was actually car-based mobile telephony (Bhalla, 2010). MTS was an analogue system, which processed voice information as continuous waveform that was then used to modulate/demodulate the Radio Frequency (RF) carrier.

The system was half-duplex, and at material points in time, the user could either speak or listen. And to switch between these two modes, users had to push a specific button on the terminal (Nicopolitidis, 2004). Major limitations of MTS were the manual switching of calls and the fact that a very limited number of channels were available, was a major snag. In most cases, the system provided support for three channels, meaning that only three voice calls could be served at the same time in a specific area.

3.2 Improved Mobile Telephone System

An enhancement to the technology behind MTS, gave birth to Improved Mobile Telephone System (IMTS) which came into operation in the 1960s. The enhancement provided support for automatic call switching, communication channel partition to 23 channels (spectrum) and full-duplex communication, thus eliminating the intermediation role of the operator in a call and the need for the push-to-talk button by the users of the system (Nicopolitidis, 2004).

IMTS had variegated shortcomings associated with inefficient spectrum usage and destructive signal interference caused by electromagnetic flux emanating from the Base Transceiver Stations (BTS). These shortcomings resulted in the problem of limited capacity which made the system impractical. The solution to this problem was found around the 1950s and 1960s by researchers at AT&T/Bell Laboratories, who introduced the use of the cellular concept, which eventually brought about a revolution in mobile telephony a few decades later. It is interesting to note that this revolution has allowed the possibility to provide telephony services to millions of users across the globe to this day, with over 100 million wireless customers in the United States alone (Nicopolitidis, 2004). The successive improvements and enhancements to this cellular concept is what has incrementally gave birth to the various generations of the existing and ensuing mobile networks.

4. EARLY CELLULAR TELEPHONY SYSTEMS

The early cellular telephony systems which can rightly be classified under the first generation of cellular systems (1G systems) debuted in the late 1960s and, due to regulatory delays, their deployment commenced in the early 1980s. These systems were descendants of MTS/IMTS because they were based on their enabling analog systems. The first service trial of 1G system was in Chicago in 1978, while the first commercial use of this innovation which at this time was dubbed Advanced Mobile Phone System (AMPS), was 1982 where it offered only voice transmission. Variations of this AMPS emerged in other parts of the world under different names and descriptions such as Total Access Communication System (TACS) in the United Kingdom, Italy, Spain, Austria, Ireland; MCS-L1 in Japan and Nordic Mobile Telephony (NMT) in several other countries. AMPS is still popular in the United States but analog systems are rarely used elsewhere nowadays. AMPS standards utilize frequency modulation (FM) for speech and perform handover decisions for a mobile at the BSs based on the power received at the BSs near the mobile. The available spectrum within each cell is partitioned into a number of channels and each call is assigned a dedicated pair of channels. Communication within the wired part of the system, which also connects with the Packet Switched Telephone Network (PSTN), uses a packet-switched network (Franzen, 2001).

4.1 Digital Cellular Telephony

Analog cellular systems were the first step for the mobile telephony industry. Despite their significant success, they had a number of disadvantages that limited their performance. These disadvantages were alleviated by the second generation of cellular systems (2G systems) which represent data in digital form by passing voice signals through an Analog to Digital (A/D) converter and using the resulting bitstream to modulate an RF carrier. At the receiver, the reverse procedure was performed (Franzen, 2001). Compared to analog systems, digital systems had a number of advantages, covering (Nicopolitidis, 2004):

i. Privacy and Security: Digitized traffic can easily be encrypted in order to provide privacy and security. Encrypted signals cannot be intercepted and overheard by unauthorized parties easily. Powerful encryption is not possible in analog systems, which most of the time transmit data without any protection, making it easy for conversations and network signaling to be easily intercepted. This was the significant problem in 1G systems which resulted in eavesdroppers picking up user's identification numbers and using them illegally to make calls.

ii. Minimal Interference: Analog data representation made 1G systems susceptible to interference, leading to a highly variable quality of voice calls. In digital systems, it is possible to apply error detection and error correction techniques to the voice bitstream. These techniques made the transmitted signal more robust, since the receiver can detect and correct bit errors. These techniques lead to clear signals which in turn translated into better call qualities. Furthermore, digital data was amenable to compression which increases the efficiency of spectrum use.
iii. Radio Frequency (RF) Sharing: In analog systems, each RF carrier is dedicated to a single user, regardless of whether the user is active (speaking) or not (idle within the call). In digital systems, each RF carrier is shared by more than one user, either by using different time slots or different codes per user. Slots or codes are assigned to users only when they have traffic (either voice or data) to send.

4.2 Cordless Phones (Mobile Phones)
Cordless telephones first appeared in the 1970s and since then have experienced a significant growth. They were originally designed to provide mobility within small coverage areas, such as homes and offices. Cordless telephones comprise a portable handset, which communicates with a BS connected to the Public Switched Telephone Network (PSTN). Thus, cordless telephones primarily aim to replace the cord of conventional telephones with a wireless link. Early cordless telephones were analog.

This fact resulted in poor call quality, since handsets were subject to interference. This situation changed with the introduction of the first generation of digital cordless telephones, which offer voice quality equal to that of wired phones (Majid, 2018). Although the first generation of digital cordless telephones were very successful, it lacked a number of useful features, such as the ability for a handset to be used outside of a home or office. This feature was provided by the second generation of digital cordless telephones. These are also known as telepoint systems and allow users to use their cordless handsets in places such as train stations, busy streets, etc.

The advantages of telepoint over cellular phones were significant in areas where cellular BSs could not be reached (such as subway stations). If a number of appropriate telepoint BSs were installed in these places, a cordless phone within range of such a BS could register with the telepoint service provider and be used to make a call. However, the telepoint system was not without problems. One such problem was the fact that telepoint users could only place and not receive calls.

A second problem was that roaming between telepoint BSs was not supported and consequently users needed to remain in range of a single telepoint BS until their call was complete. Telepoint systems were deployed in the United Kingdom where they failed commercially (Churi, 2012). Nevertheless, in the mid- 1990s, they fared better in Asian countries due to the fact that they could also be used for other services (such as dial-up in Japan). However, due to the rising competition by the more advanced cellular systems, telepoint is nowadays a declining business (Nicopolitidis, 2004).

5. EVOLUTION OF PUBLIC MOBILE TELEPHONY GENERATIONS

Figure 1 depicts a graphical view of the cellular network technologies till date.

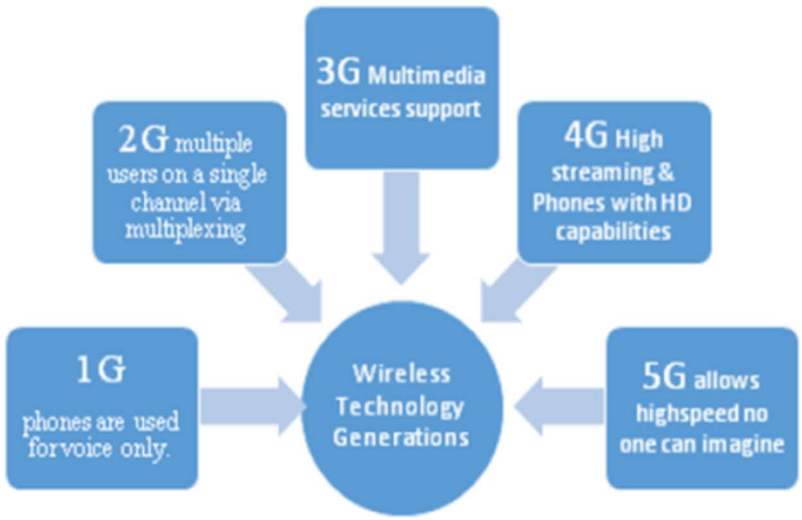

Figure 1: Cellular Network Infrastructure Generations (Majid, 2018)

5.1 First Generation (1G)

In 1946, the first public mobile telephone system, known as Mobile Telephone System (MTS), was introduced in 25 cities in the United States. Due to technological limitations in that era, the mobile transceivers of MTS were very big and could only be carried by vehicles (Nicopolitidis, 2004). And because MTS was an analog system, it processed voice information as a continuous waveform, which was in turn used to modulate/demodulate the Radio Frequency (RF) carrier. MTS had half-duplex capability which meant that the users could either speak or listen in the course of conversations, and to switch between the two modes, the users had to push a specific button on the terminal (Nicopolitidis, 2004).

The era of cellular telephony by today's standards began with 1G systems in the 1980's. The major difference between 1G systems and its preceding MTS/IMTS was the use of the cellular concept in 1G, which permitted simultaneous use of the network by multiple users. This revolution marked the beginning of the series of innovations that is still on and evolving very rapidly. 1G systems used Frequency Division Multiple Access (FDMA) to increase its carriage capacity. FDMA technique partitions the frequency available for wireless communication into many channels, with each channel capable of carrying a data signal (Ganesh, 2014). 1G operated within the frequencies of 800 – 900 MHz, had a channel capacity of 30 KHz and a speed of up to 2.4kbps. It was a circuit switched network based on analog system and circuit switched network. It had three major limitations. The first is that it can only be used to manage calls within a country. That is, it does not support international roaming. The second problem is that it is insecure, while the third is its poor voice quality with very low spectrum efficiency (Majid, 2018; Arshad, 2019). The size of the mobile units (mobile phone) at the time was very big and were not really portable. The attempts to address these drawbacks was behind the technologies and innovations that gave birth to the 2G systems (Vora, 2015; Pandya, 2015; and Mousa, 2012).

1G systems may be viewed as obsolete, but a significant number of people still use analog cellular phones and analog cellular infrastructure is still found throughout North America and other parts of the world. In the wireless industry, 1G often refers only to analog cellular technology because it was the only system implemented based on popular standards such as AMPS or NMT. However, it can be generalized to include other types of wireless services and products (Pahlavan, 2005). The analog cordless telephone, which appeared in the market in the 1980s, can be considered as a 1G cordless telephone product. Paging services, which were deployed at around the same time as analog cellular systems and cordless telephones, can be referred to as 1G mobile data services providing one-way transmission of short data messages. Figure 2 shows the technological standards behind 1G.

Figure 2: Technology Standards in 1G (Arshad, 2019)

While the first commercial 1G system was developed in the United States, (AMPS), to offer only voice transmission services, some European countries, had several systems based on 1G technologies. These according to (Nicopolitidis, 2004).include:

i. Total Access Communications System (TACS) in the United Kingdom, Italy, Spain, Austria and Ireland
ii. Nordic Mobile Telephone (NMT) in several countries
iii. C-450 in Germany and Portugal
iv. Radiocom 2000 in France
v. Radio Telephone Mobile System (RTMS) in Italy.

The most popular systems were TACS and NMT, which together accounted for over 50% of analog cellular subscribers in 1995. And few years down the line, Japan first analog cellular system (Nippon Telephone and Telegraph (NTT) system) began operation in the Tokyo metropolitan area in 1979.

5.2 Second Generation (2G)

The quest for cellular services that the analog networks could not provide, the growing demand for wide-area wireless data services, and the need to address some drawbacks inherent in 1G systems, spurred 2G systems which were designed to support a complete set of standards (Pahlavan, 2005). 2G emerged in the late 1980's and it was based on GSM (Global System for Mobile Communication) which solved the problem of channel security by providing support for encryption. The other core objectives behind 2G systems design was the supports for multimedia services like Text, Pictures, SMS, e-mails etc.

Although security, speed, and voice quality were improved in 2G but there were still a lot to be done, and researchers had to work acidulously to formulate better techniques for providing better services (Pandya, 2015).

2G systems are completely digital and thus has the following advantages over 1G systems (Nicopolitidis, 2004):

i. Enhanced Security and Privacy: Digitized traffic can be easily encrypted to provide privacy and security. Encrypted signals cannot be easily intercepted or eavesdropped by unauthorized parties. By contrast, reliable encryption is not possible in analog systems, which most of the time transmit data without any protection.

ii. Reliable Information Quality and better Use of Channel Capacity:. In digital systems, it is possible to apply error detection and error correction techniques to the user traffic. Using these techniques, the receiving system can detect and correct bit errors, thus enhancing transmission reliability. This feature also leads to signals with little or no corruption, which translates into (a) better voice call qualities, (b) higher speeds for data applications, and (c) efficient spectrum use, since fewer retransmissions are bound to occur when error correction and error detection techniques are used. Digital data can be compressed, further increasing the efficiency of spectrum usage. This increased efficiency enables 2G systems to support more users per base station per MHz of spectrum than 1G systems, thus allowing operators to provide service in high-density areas more economically.

iii. Sharing of Radio Frequency (RF): In analog systems, each RF carrier is dedicated to a single user, regardless of whether the user is active (speaking) or not (idle within the call). In digital systems each RF carrier is shared by more than one user, either by using different time slots or different codes per user. Slots or codes are assigned to users only when they have traffic (either voice or data) to send.

5.2.1 Enabling Technologies for 2G Systems

The movement from analog to digital systems was made possible due to the development of techniques for low-rate digital speech coding and the continuous increase in the device density of integrated circuits. While 1G systems, employ FDMA for user separation, 2G systems allow the use of Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) as well (Mousa, 2012).

i. Time Division Multiplexing (TDMA) is the technology behind a wide range of second-generation cellular systems such as GSM, IS-54 and DECT. TDMA divides a band into several time slots and the resulting structure is known as the TDMA frame. Each active node is assigned as a slot or slots for transmission of its traffic. Nodes are notified of the slot number that has been assigned to them, so they know how much to wait within the TDMA frame before transmission (Pandya, 2015). Uplink and downlink channels in TDMA can either occur in different frequency bands (FDD-TDMA) or time-multiplexed in the same band (TDD-TDMA). The latter technique has the advantage of easy trading uplink to downlink bandwidth for supporting asymmetrical traffic patterns (Nicopolitidis, 2004). TDMA is essentially a half-duplex technique, because for a pair of communicating nodes, at a specific time, only one of the nodes can transmit. But as a consequence of slot duration which is so small, an illusion of two-way communication is created. This short slot duration, however, imposes strict synchronization problems in TDMA systems for distant nodes as propagation delay can cause a node to miss its turn. In order to protect inter-slot interference due to different propagation paths to mobiles being assigned adjacent slots, TDMA systems use guard intervals in the time domain to ensure proper operation (Nicopolitidis, 2004). In order to accommodate various nodes inside the same cellular network, FDMA divides the available spectrum into sub bands each of which are used by one or more users. Each user is allocated a dedicated channel (sub band), different in frequency from the channels allocated to other users. When the number of users is small relative to the number of channels, this allocation can be static, however, for many users' dynamic channel allocation schemes are necessary.

In cellular systems, channel allocations typically occur in pairs. Thus, for each active mobile user, two channels are allocated, one for the traffic from the user to the Base Station (BS) and one for the traffic from the BS to the user (Osseiran, 2016). The frequency of the first channel is known as the uplink (or reverse link) and that of the second channel is known as the downlink (or forward link). For an uplink/downlink pair, uplink channels typically operate on a lower frequency than the downlink one in an effort to preserve energy at the mobile nodes. This is because higher frequencies suffer greater attenuation than lower frequencies and consequently demand increased transmission power to compensate for the loss. By using low frequency channels for the uplink, mobile nodes can operate at lower power levels and thus preserve energy. Due to the fact that pairs of uplink/downlink channels are allocated by regulation agencies, most of the time they are of the same bandwidth. This fact makes FDMA relatively inefficient since in most systems the traffic on the downlink is much heavier than that in the uplink. Thus, the bandwidth of the uplink channel is not fully used (Mavromoustakis, 2016).

ii. Code Division Multiplexing (CDMA): Instead of sharing the available bandwidth either in frequency or time, CDMA places all nodes in the same bandwidth at the same time. The transmissions of various users are separated through a unique code that has been assigned to each user. All nodes are assigned a specific n-bit code. The value of parameter n is known as the system's chip rate (Vora, 2015). The various codes assigned to nodes are orthogonal to one another meaning that the normalized inner product of the vector representations of any pair of codes equals zero. Furthermore, the normalized inner product of the vector representation of any code with itself and the 1s complement of itself equals 1 and 21, respectively. Nodes can transmit simultaneously using their code and this code is used to extract the user's traffic at the receiver. Obviously, the receiver knows the codes of each user in order to perform the decoding. The use of TDMA or CDMA in cellular systems offers a number of advantages. These are (Nicopolitidis, 2004):
   i. Natural integration with the evolving digital wireline network.
   ii. Flexibility for mixed voice/data communication and the support of new services.
   iii. Potential for further capacity increases as reduced rate speech coders are introduced.
   iv. Reduced RF transmit power (which obviously translates into increasing battery life in handsets).
   v. Reduced system complexity (mobile-assisted handoffs, fewer radio transceivers).

5.2.2 **Personal Digital Cellular (PDC)** Standard

Personal Digital Cellular (PDC) was a 2G mobile telecommunications standard used exclusively in Japan which was phased out in favor of 3G technologies like Wide Code Division Multiple Access (W-CDMA) and CDMA2000 (Docomo, 2012). 2G used the Bandwidth of 30 to 200 KHz with data rate of 64kbps (Majid, 2018). And with the rapid growth of these services, consumer base rose remarkably and there was further quest for more data services, thus leading to the need to improve channel capacity and security. Innovations aimed at achieving these emerging needs resulted in the emergent of intermediate generations of 2.5G and 2.75G which enhanced data rates using the technologies of GPRS (General Packed Radio Service), CDMA (Code Division Multiple Access), EDGE (Enhanced Data rates for GSM Evolution) (Vora, 2015). Data rates were increased from 64kbps in 2G to 144kpbs and 180kbps in 2.5G and 2.75G respectively, providing users with a higher data download/upload speed which made it possible to download multimedia contents in various formats. Figure 3 depicts the technologies behind 2G.

Figure 3: Technology Standards in 2G (Arshad, 2019)

5.3 Third Generation (3G)

The inability for 2G to handle complexities incidental to some multimedia data like videos, temporary absence of network coverage in some specific area, and weak digital signals, spurred studies that culminated in the emergence of 3G (Majid, 2018; Vora, 2015; Pandya, 2015). The motivation for developing 3G technologies was based in part, on the need to develop international standard that compassed 2G technologies and at the same time provide reliable support for mobile data services. The 3G systems were expected to improve voice quality, expand network capacity, and increase the data rates of wireless data services. The primary standard for 3G systems was referred to as International Mobile Telecommunications (IMT) (Pahlavan, 2005). 3G was developed to improve voice services, data throughput, high Quality of Service (QoS) and information security (Jaiswal, 2014). 3G mainly targeted increased data rates, and it achieved this objective by using packet switching technique and wide band wireless network which provided global access and more clarity.

This collection of technologies were dubbed the Universal Mobile Telecommunication System (UMTS) in Europe and Code Division Multiple Access 2000 (CDMA2000) in America (Majid, 2018). 3G Operated at the frequency range of 2100MHz and had bandwidth of 15-20MHz for high speed internet. It provided speed of around 125kbps to 2Mbps for faster downloading, and it supported clear and continuous voice and video calling (Majid, 2018). 3G systems also provided support for three-dimensional (3D) gaming, mobile television, multimedia messaging systems, live contents streaming, sending/receiving large e-mails etc. Some major characteristics of 3G are: digital broadband, high speed internet and high QoS for better voice quality over the air interface (Singh, 2016).

Third generation mobile and wireless networks meets the demand of future services, while offering global mobile multimedia communication capabilities in a seamless and efficient manner (Patil, 2014). Regardless of their location, users are able to use a single device to enjoy a wide variety of applications (Andria, 2015). Improvements to 3G lead to the development of 3.5G which was six times faster than UMTS and had data rate in-between 5-30Mbps. It was based on techniques of like wide code division multiple access (W-CDMA), wireless local area network (WLAN), and High Speed Download Packet Access (HSDPA). 3G consumed more power than 2G and also network plans were expensive compared to 2G (Vora, 2015). Two key variants of 3G technology were 3.5G High Speed Download Packet Access (HSDPA) which enhance the data speed of downlink data transmission at speeds ranging from 8Mbps to 10Mbps and 3.75G High Speed Uplink Packet Access (HSUPA) which improves the uplink speed up to 5.8 Mbps with decreasing delay between the up and downlinks (Arshad, 2019). Figure 4 depicts some of the technology standards behind 3G

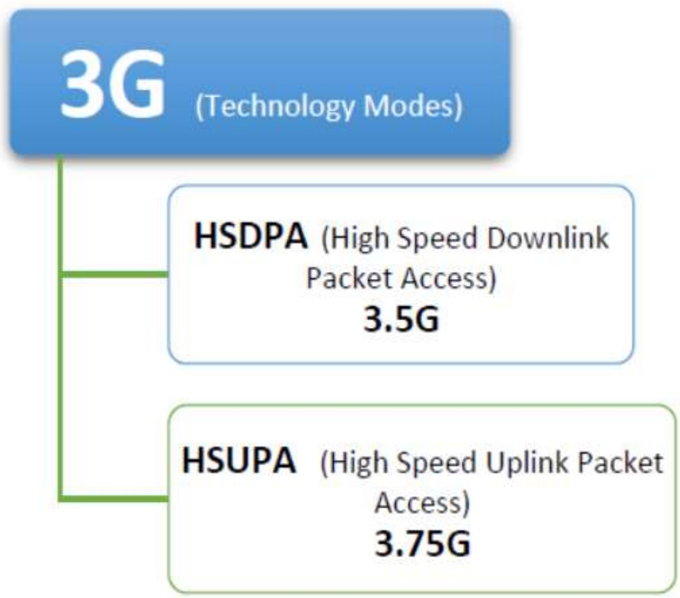

Figure 4: Technology Standards for 3G (Arshad, 2019)

5.3.1 Third Generation Service Classes and Applications

3G provides some of the following services (Nicopolitidis, 2004):

iii. Voice and Audio: Different quality levels for voice communication is offered, with higher qualities having higher costs. The capacity required is provided by 3G with substantial support for good quality voice calls.

iv. Wireless Messaging: Current 2G systems support rather primitive means of messaging (e.g. the SMS message comprises a maximum of 160 characters). 3G wireless messaging allow cellular subscribers to use their terminals to read and respond to incoming emails, open and process e-mail attachments, and handle terminal-to terminal messages. Depending on the desired speed of message transfer, the capacity demanded by this service class can vary, however, speeds around 28.8 kbps is more than sufficient.

v. Switched Data: This service class includes support for faxing and dial-up access to corporate LANs or the Internet. As far as file transfer is concerned, speeds like those of today's fast modems (56 kbps) are required in order to shorten the time a user spends on-line and thus the associated cost of file transfers.

vi. Medium Multimedia: This is arguably the most popular service class introduced by 3G, which enabled web browsing through 3G terminals, an application already proving very popular. This service class offers asymmetric traffic support in web sessions, as the traffic from the network to the terminal (downlink or forward-link traffic) is always much higher than the traffic in the reverse link (uplink or reverse-link traffic). This service class also supports asymmetric multimedia applications such as high-quality audio and video on demand, by offering speeds of up to the maximum (2 Mbps) at the downlink, and around 20 kbps for the uplink.
vii. High Multimedia: This service class is used for high-speed Internet access and high-quality video and audio on-demand services. It supports asymmetric traffic offering of the highest possible bit rates in the downlink and in the uplink.
viii. Interactive High Multimedia: This service class supports high-quality interactive applications requiring the maximum speeds possible

3G networks also enabled a wide range of end-user applications that are completely new and mobile. Some of these 3G applications are (Mousa, 2012).

i. Multimedia Applications: Examples of these class of applications are video telephony and videoconferencing systems. The increased capacity offered by 3G systems enabled the use of these applications in a cost-efficient manner. Users are able to participate in virtual meetings and conferences through their 3G terminals. In addition, they are able to use audio/visual transport applications that deliver multimedia content, such as HD-quality music and TV-quality video feeds, from service platforms and the Internet.
ii. Mobile Commerce Applications: Mobile commerce (m-commerce) is a subset of electronic commerce (e-commerce). As most people keep their handsets with them at all times, they are able to make on-line purchases and reservations upon demand without having to be in front of an interconnected personal computer. Thus increased capacity provided by 3G systems have offered efficient support for massive use of m-commerce applications.
iii. Multimedia Messaging Applications: These applications handles transport and processing of multimedia-enhanced messages. Users are able to use their 3G terminals to send and receive voice mails and notifications, video feed software applications and multimedia data files. Having a single mailbox on the same terminal for these messages has greatly increased time efficiency for the end user.
iv. Broadcasting Applications: Such applications typically use asymmetric distribution infrastructures combining high capacities in the downlink with low capacities in the uplink. Multimedia news broadcasting, interactive games and location-based information services, such as flight information in airports are examples of such applications.
v. Geolocation-based Applications: Geolocation technology determines the geographical location of a mobile user. There are two types of geolocation techniques, one based on the handset and the other on the network. The first uses the global positioning system (GPS) system to determine user location while in the second, the replicas of the signals from the same handset at different base stations are combined in order to determine user location. Some obvious applications employing geolocation technology include mobile map service and identification of user location for emergency calls.

5.3.2 Some other Enabling Technologies for 3G Systems

The requirements for high data rates and efficient support for multimedia services underlie the design of 3G networks. And one approach that was adopted for reliable results was to twerk the modulation and multiple access scheme to be much more spectrally efficient and flexible to provide for greater immunity against severe selective frequency fading of broader signal bandwidths using multiple antenna technologies that germane to achieving high spectral efficiency.
For seamless connection and services integration an IP based scalable network design was the primary base for 3G network architectures which employed a collection of schemes to address sundry issues. Some of these schemes as presented by Kim (2008) are:

i. Modulation and Multiple Access Scheme: to check severe multipath fading, in conventional single-carrier modulation schemes, a different modulation schemes was adopted for 3G networks. And this scheme was the Orthogonal Frequency Division Multiplexing (OFDM) which is a robust scheme against severe multipath fading (Prasad, 2000). In OFDM, the entire signal bandwidth is divided into a number of narrow bands or orthogonal subcarriers, and the signal is transmitted in the narrow bands in parallel. Various methods of combining OFDM with multiple access concepts such as code-division multiple access (CDMA) and/or time-division multiple access (TDMA), as well as multicarrier CDMA (MC-CDMA) and frequency hopping OFDMA (FH-OFDMA) arose in a the quest to add to achieve high performance in the ever evolving mobile network technologies (Majid, 2018).
ii. Intelligent Antennas: intelligent antennas provide increased capacity to terminal-base station links. Consequently, antennas design such as the steered-beam and the switched-beam approaches. Mavromoustakis (2016), were products of studies aimed at enhancing 3G networks. The steered approach uses the antenna elements to construct narrow transmission beams that are directed at designated mobile device to follow it as it moves. The switched-beam approach on the other hand, tries to increase the SIR at the mobile receiver by switching transmission to the appropriate antenna element as the mobile moves.
iii. Multiuser Detection Systems: this was used to reduce co-channel interference between users in the same cell. The procedure is based on the detection of the strongest signal, subtract it from the aggregate received signal before trying to detect the second (weaker) signal. Once the second signal has been detected, subtracting it from the aggregate received signal often leads to a better estimate of the first signal. And the iteration of this process improves user detection. Many variants of this technique which either detect users one by one, or all of them together exists (Bhalla, 2010).
iv. Multiple Antenna Techniques: it is an establish fact that using multiple antennas at both transmitter and receiver, dramatically increase channel capacity while the total transmit power remains constant (Kim, 2008). The multiple antenna channel forms independent information paths or spatial multiplexing channels, with capacity increases linearly with the number of spatial multiplexing paths formed. However, in outdoor environment, that requires line of sight (LOS), the channels tend to be highly correlated, and the import of this is that this scheme may not achieve the high data rate expected, and another drawback this technique is high sensitivity to channel estimation errors (Vora, 2015).

5.4 Fourth Generation (4g)

In 2010, 4G cellular technology was launched with several important changes to its predecessors. It incorporated an enhanced capacity of up to 40 MHz and had its peak speed requirement set at 100 Mbps during handoff stages from one cell to another (Karthika, 2016) Long Term Evolution (LTE) presented a classic example of 4G, offering a download speed of up to 100Mbps. 4G provided additional service over and above what was offered by 3G, such as Multi-Media Newspaper, TV programming with more clarity, High Quality live streaming, HDTV, location-based services, video chatting, Digital Video Broadcasting (DVB), expanded multimedia services and seamless browsing with high speed.

Among others, 4G offered battery efficiency by making for low cost power consumption per bit, improved QoS (Quality of Service), had ultra-low latency of about 50 milliseconds and making it possible to download High definition movie in a small amount of time (Pandya, 2015). 4G also made it possible to develop and deploy mobile WiMAX for nomadic and mobile applications (Kanani, 2014)

5.4.1 Some Services and Applications Supported by 4G

i. Tele-presence. These are real-time virtual reality services that offer virtual meetings, an evolution of today's teleconferencing applications. The conference attendants, although in different places, will have the illusion of participating in a conference in the very same room. This class of applications uses full stimulation of all senses to provide users with the illusion of actually being in a specific place. The concept of a virtual meeting is one of the major applications in 4G.
ii. Information Access. This class of systems allows instantaneous access to large volumes of data such as large video and audio files. They offer the highest data rates possible, with a traffic pattern that is asymmetrical, with 50/1 ratios or more characterizing the downlink/uplink data rate ratio.
iii. Inter-machine Communication. This service classes offers devices the ability to communicate with one another either for maintenance or for intelligence purposes. An example application of this type is car engine equipment that contains wireless interfaces enabling parts to contact the respective vendors when malfunctions occur.
iv. Intelligent Shopping. This services categories helps users to access information regarding prices and products offered by shops they visit. Upon entering a shop, the user's terminals will automatically tune to the shop's service providers and display information regarding the products sold by the shop.
v. Security. Secure services protect the privacy of users' personal information.
vi. Location-based Services. 4G systems have the ability to determine the location of users with a high level of accuracy. For example, if a person with a health problem calls an ambulance from his handset but is unable to report his location to the operator, his position can be determined with high accuracy by querying the user's handset for its location.

5.4.2 Enabling Technologies for 4G Systems

i. Orthogonal Frequency-Division Multiplexing (OFDM): is a frequency division multiplexing (FDM) scheme that uses a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub carriers are used to carry data. This data is then divided into several parallel data streams or channels for each sub-carrier (Iqbal, 2012). Under this scheme, each sub carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) (Kupta, 2005).
ii. **Multiple Input and Multiple Output (MIMO)**: In MIMO, the system exploits the fact that the received signal from one transmit antenna can be quite different than the received signal from a second antenna. This scheme is mostly used in indoor or dense metropolitan areas where there are many reflections and multipaths between transmitter and receiver. In this case, a different signal can be transmitted from each antenna at the same frequency and still be recovered at the receiver by signal processing. Reusing frequency in this way is known as Re-use 1, where the same frequency is used for different signals at the same time (Churi, 2012). A variant of this scheme is the beamforming scheme where an attempt to form a coherent construction of the multiple transmitters at the receiver is done (Browne, 2005). This scheme yields a higher signal-to-noise ratio (SNR) at the receiver, and can provide higher bandwidth or longer reach for the same transmitted power. Rather than exploiting the different air interface responses between antennas, beamforming modifies the signal to unify the signal. Therefore, beamforming does not reuse frequency in the same way as MIMO. Another variant involves dividing the frequency into separate bands for separate cells, in a scheme called Re-use 3.

This comes from the common practice of dividing wireless cell sites into three distinct sectors (Iqbal, 2012; Singh, 2016).

iii. **LS Codes**: LS codes are used in LAS-CDMA to spread the transmitted signal. These codes are used to create multiple code divided transmission channels and have Inter-Symbol Interference (ISI) and Multiple Access Interference (MAI) rejection properties. LS codes are defined according to a tree structure where each LS code is made up of a C component and an S component (Iqbal, 2012). These components are complementarily orthogonal, the sum of their auto correlation functions does not have side lobes and the sum of their cross-correlation function is null within the IFW (Li, 2003)

iv. **Software Defined Radio:** Software-defined Radio (SDR), sometimes shortened to software radio (SR), refers to wireless communication in which the transmitter modulation is generated or defined by a computer, and the receiver uses a computer to recover the signal intelligence. To select the desired modulation type, the proper programs must be run by microcomputers that control the transmitter and receiver (Bhalla, 2010). The ultimate goal of SDR technology is to provide a single radio transceiver capable of playing the roles of cordless telephone, cell phone, wireless fax, wireless e-mail system, pager, wireless videoconferencing unit, wireless Web browser, Global Positioning System (GPS) unit, and other functions still in the realm of science fiction, operable from any location on the surface of the earth, and perhaps in space as well (Pandya, 2015). Figure 4 shows some technological standards underlying 4G networks.

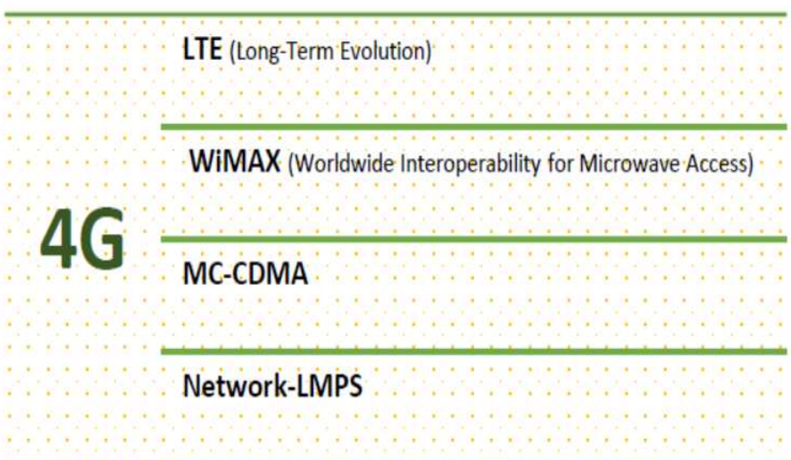

Figure 5: Technology Standards in 4G (Arshad, 2019)

5.5 Fifth Generation (5G)

The upcoming mobile cellular technology is 5G, which has already been launch in this current year, 2020 by Huawei. 5G is an emerging technology that is being awaited to achieve emerging concepts such as smart cities, self-driving cars, three dimensional virtual reality settings, advanced robotics etc. 5G technology requirements specifies transmission speed of about 10 Gbps to support mobile cloud services and virtual reality environment with ultra-HD audio / video applications (Pandya, 2015). It is also required to support bi-directional large bandwidth with data rates of up to 300GHz for ubiquitous connectivity, and the core network infrastructure must be based on the internet and the cloud. All these required standards are to be integrated with different IP networks to achieve an all 5G network interface (5G-NI) switching types (Arshad, 2019). 5G is already been projected as World Wide Wireless Web (WWWW), which will be a real wireless network where access to the internet with have no limits, barriers and restrictions (Majid, 2018).

5.5.1 Enabling Technologies and Schemes for 5G Systems

i. **Massive Multiple Inputs and Outputs (MIMO)**: These are systems equipped with large transmitters and/or receivers that are either co-located or distributed in different applications to significantly enhance both spectral efficiency and energy efficiency (Rusek, 2013). In these systems, the effects of noise and fast fading vanish, and intra-cell interference is mitigated using simple linear precoding and detection methods. By properly using multiuser MIMO (MU-MIMO) in massive MIMO systems, the medium access control (MAC) layer design is simplified by avoiding complicated scheduling algorithms (Kumar, 2015). In this technique, the channel response of each terminal is estimated by the base station, in a concept of referred to as spatial multiplexing which is the major thrust of massive MIMO. In another variation of channel management concept dubbed multi-point MIMO, the channel resources are spatially shared by users rather than an orthogonal use like in point to point MIMO (Majid, 2018). With resources amenable to spatial sharing, the resulting interference are automatically eliminated using precoders and decoders. MIMO makes it possible to achieve phased coherent signals from all antennas at the base station, and this trend provides for an energy efficient, robust, secure, and spectrum efficient system (Fizza, 2016; Shinde, 2016; Larsson, 2014). (Marzetta, 2011). The technologies and schemes underlying massive MIMO systems is the thrust of the force behind 5G wireless communication networks.

ii. **Spatial Modulation (SM)**: Spatial modulation is a novel MIMO technique used for low-complexity implementation of MIMO systems to avoid degrading system performance (Renzo, 2014). Instead of simultaneously transmitting multiple data streams from the available antennas, SM encodes part of the data to be transmitted onto the spatial position of each transmit antenna in the antenna array. Thus, the antenna array plays the role of a second (in addition to the usual signal constellation diagram) constellation diagram (the so-called spatial constellation diagram), which can be used to increase the data rate (spatial multiplexing) with respect to single-antenna wireless systems. Only one transmit antenna is active at any time, while other antennas are idle (Fizza, 2016).

iii. **Beam Division Multiple Access (BDMA)**: BDMA is a technique independent of time and frequency resources. In BDMA the base station allocates separate beam to each mobile station. This is done by dividing antenna beam according to location of mobile station. Here different beams of distinct patterns are formed using phase array antenna (Majid, 2018).

iv. **Millimeter (mm)-wave Signals**: 5G systems will need to provide significant improvement in cell capacity to accommodate the rapidly increasing traffic demands. Although 5G will introduce an array of new technologies that enable networks and devices to make better use of scarce spectrum resources, this will not be sufficient to keep pace with the mobile data requirement increase, which is expected to reach levels of gigabits per second (Fizza, 2016). This could only be realized with much more spectrum than the spectrum currently available to IMT systems through the International Telecommunications Union's (ITU) process. Due to the high fragmentation of existing spectrum in different regions of the world and due to the long time required for the spectrum reframing, contiguous and broader frequency bands at higher frequencies is a promising way forward (Shinde, 2016). Terrestrial wireless systems have largely restricted their operation to the relatively slim range of microwave frequencies that extends from several hundred MHz to a few GHz and corresponds to wavelengths in the range of a few centimeters up to about a meter (Wani, 2018). Due to the limited range of mm-wave signals, 5G systems will include a large number of pico-cells (100 to 200m radius), each using high directional antennas for improved range and spatial separation. Combining tremendously increased bandwidths with spatial multiplexing gains from the high dimensional multiple antenna transmissions, mm-wave systems offer the possibility of phenomenal capacity gains compared to current commercial networks.

v. **Cognitive Radio (CR) Networks:** The CR network is an innovative software defined radio technique considered to be one of the promising technologies to improve the utilization of the congested RF spectrum (Rusek, 2013). Adopting CR is motivated by the fact that a large portion of the radio spectrum is underutilized most of the time. In CR networks, a secondary system can share spectrum bands with the licensed primary system, either on an interference- free basis or on an interference-tolerant basis (Rusek, 2013). The CR network should be aware of the surrounding radio environment and regulate its transmission accordingly. In interference-free CR networks, CR users are allowed to borrow spectrum resources only when licensed users do not use them. A key to enabling interference - free CR networks is figuring out how to detect the spectrum holes (white space) that spread out in wideband frequency spectrums. (Kumar, 2015).

vi. **Mobile Femtocell (**MFemtocell**):** The MFemtocell is a new concept that has been proposed recently to be a potential candidate technology in next generation intelligent transportation systems (Kachhavay, 2014). It combines the mobile relay concept (moving network) with femtocell technology. An MFemtocell is a small cell that can move around and dynamically change its connection to an operator's core network. It can be deployed on public transport buses, trains, and even private cars to enhance service quality to users within vehicles. Deployment of MFemtocells can potentially benefit cellular networks. First, MFemtocells can improve the spectral efficiency of the entire network (Kachhavay, 2014).

vii. **Dense Heterogeneous Network**: 5G cellular network are multi-tier heterogeneous network consisting of macro cells along with a large number of low power (e.g., small cells, relays, remote radio heads (RRHs)), and the provisioning for P2P (such as D2D and M2M) communication (Wani, 2018). The deployments of heterogeneous nodes in 5G systems will significantly result in higher subscriber and equipment's density than today's conventional single- tier (e.g., macrocell) networks (Shinde, 2016) . The heterogeneity of different classes of BSs (e.g., macrocells and small cells) provides flexible coverage areas and improves spectral efficiency. By reducing the size of the cell, the area spectral efficiency is increased through higher spectrum reuse (Arshad, 2019). Additionally, the coverage can be improved by deploying small cells indoors (such as home, office buildings, public vehicles, etc.). Wireless P2P communication (e.g., D2D/M2M communication among UE and autonomous sensors/actuators) underlying cellular architecture can significantly increase the overall spectrum and energy efficiency of the network. In addition, the network controlled P2P communications in 5G systems will allow other nodes (such as relay or M2M gateway), rather than the macrocell BS, to control the communications among P2P nodes. Given that the inter-tier and intra-tier interferences are well managed, the adoption of multiple tiers in the cellular network architecture will provide better performance in terms of coverage, capacity, spectral efficiency, and power consumption (Fizza, 2016). Figure 6 depicts some of the technological standards in 5G networks.

Figure 6: Technology Standards in 5G (Arshad, 2019)

Table 1 presents a glance of the evolution of cellular network technologies from 1G to %G.

Table 1: A Glance at the Requirements and Standards behind Cellular Network Generations.

Generation	**1G**	**2G**	**3G**	**4G**	**5G**
Requirements	No official Requirements Analog technology	No official Requirements Digital Technology	ITU"s IMT-2000 required 144 kbps mobile, 384 kbps pedestrian, 2 Mbps indoors	ITU"s IMT Advanced requirements include ability to operate in up to 40 MHz radio channels and with very high spectral Efficiency.	at least 1 GB/s or more data rates to support ultra-high definition video and virtual reality, applications, 10 GB/s data rates to support mobile cloud service
Data Bandwidth	1.9 kbps	14..4 kbps to 384 kbps	2 Mbps	2 Mbps to 1 Gbps	1Gbps & Higher (as demand)
Core Network	PSTN	PSTN Packet Network	Packet network	All IP Network	Flatter IP Network & 5G Network Interfacing(5G-NI)
Service	Analog voice	Digital voice Higher capacity, packetized data	Integrated high quality audio, video and data	Dynamic information access, wear-able devices, HD streaming; global roaming;	Dynamic information access, wear-able devices, HD streaming; any demand of users; upcoming all technologies; global roaming smoothly;

Generation	1G	2G	3G	4G	5G
Standards/Enabling Technology	NMT, AMPS, Hicap, CDPD, TACS, ETACS, PTT,	GSM, GPRS, EDGE ETC.	HSDPA, HSUPA, WCDMA, CDMA 2000	All access convergence including: LTE, WiMAX, OFMDA, MC-CDMA Network-LMPS	WWWW, CDMA, BDMA
Multiple Access	FDMA	TDMA CDMA	CDMA	CDMA	CDMA & BDMA
Inception/Deployment	1970-84	1990	2000	2010	2020
Switching	Circuit	Circuit Packet	Circuit Packet	Packet	All Packet

6. MYTHS AND RECENT HEALTH CONCERNS ABOUT MODERN CELLULAR NETWORKS

In his monograph (Kostoff, 2019) agrees that the concerns about the potential adverse health effects from 4G and 5G cellular infrastructures are real. In this section, this review attempts to illuminate the bases for this concern, with the view to show if the concern is real or mythological. The latest cellular technology (5G) that have reignited this concern, introduced millimeter waves for the first time into the evolving usable spectrum in addition to microwaves that have been in use for older cellular technologies, right from the 2G through to the 4G. Given the limited reach caused by the introduction of this mm-wave into the stack, the resulting 5G infrastructure will require cell antennas every 100 to 200 meters to function properly. It is strongly believed that this increased concentration of antennas and other devices will expose many more people to, not only, millimeter wave radiation, but to that which was inherent in the concentration of antennas that was accentuated by 4G.

And to compound the myth and the real concerns, 5G introduced novel concepts (such as active antennas capable of beam-forming; phased arrays; massive multiple inputs and outputs (MIMO)) which pose unique challenges for measuring exposures (Moskowitz, 2019). The high point of the 5G myth emanated from its linking to the corona virus pandemic, a claim which to a large extent may have been politically motivated. The brute fact is that exposure to high levels of RF radiation could potentially cause tissue damage, but the levels at which this could occur, and the length of time required for noticeable damage are intense areas of ongoing research.

Government health agencies, academics and sundry groups from around the world have devoted resources to studying the effect of RF radiation on humans to determine safe levels of exposure. t is however pertinent to raise the awareness that exposure to harmful radiation is not limited to the cellular networks only, but right from picking up, or placing our mobile devices, especially smartphones, nearby. This is instructive because when most persons pick up their wireless device, they do not have the slightest thought to the radiation that it emits. Devices that run on wireless technology release radiofrequency (RF) energy.

7. CONCLUSION

Wireless cellular network infrastructure will continue to evolve because the requirements for broader bandwidth, high performance and stiff competition will not abate, and consequently, innovation has all the required impetus, financial and technical support to keep it evolving. Attempts to improve on what have been achieved is especially now much more easier owing to advances in networking itself, which has made information and knowledge sharing common place, and the collaborations and synergies arising therefrom has tremendously aided innovation across the overall information world. And because the contemporary information world is premised on network infrastructure, of which mobile cellular networks are key, the spate of innovation in this domain therefore is highly expected.

In this study we have perused the literature on the evolution of these mobile cellular networks, and have highlighted there basis requirements, enabling technologies, bandwidth capacities, services provided/supported and their timelines. The study also made a mention of some health concerns, and attempted to separate the myths from the actual concerns

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