

# EXHIBIT J

# A Review on the Evolution of Cellular Technologies

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**Abstract**— This paper deal with the comparative analysis of cellular technologies from 1<sup>st</sup> generation (1G) to 5<sup>th</sup> generation (5G). Nowadays 3G offers high data rates, improved communication links by restraining the noise interference and provides multimedia services in addition to video calling and quality of service (QoS). Similarly, 4G systems provide better services. In addition to HD video calling, high dates throughput, better QoS, streaming online gaming services are the key features. Now the cellular technology enters in 5<sup>th</sup> generation (5G) which is typically based on 4G network. Hence, 5G cellular infrastructure eager to design for users to offer FHD video calling, fast and reliable communication services, IOT, advancement in online secure banking etc.

In this paper, the goal is to address technology standards, data rates and frequencies to express the evolution of mobile cellular technologies and their progression over the years.

**Keywords**— GSM, Mobile cellular communication, data rates, frequency, IOT, 3G, 4G and 5G

## I. INTRODUCTION

Wireless communication was introduced first ~ 1895 by sending the Morse code with the help of EM waves using Radiotelegraphy. In modern wireless communication the way of transmitting and receiving the signal used similar phenomenon of EM wave transmission. Wireless transmission is evolving over the period of time, then radio telephones and mobile network called cellular networks. There is been an exponential growth in the field of wireless communication over the years [1].

First generation (1G) of mobile cellular technology was launched in 1980's called NMT (Nordic Mobile Telephone), provides services like voice. In next generation (2G) of mobile systems were digital, introduced ~ 1990's called the GSM (Global System for Mobile communication). 2G provides more services e.g. voice, SMS (Short Messaging Service) and MMS (Multimedia Messaging Service) etc [2]. Other variant of 2G technologies were GPRS (General Packet Radio Service), which is used to access WAP/internet services to the customers [3]. Third generation (3G) of mobile communication systems were introduced ~ 2000's to provide the faster services of voice, SMS, MMS, Video calling and internet services etc. There is been an

exponential growth in term of data bandwidth and throughput from which the customer services improve [4]. Today Fourth generation (4G) system exist which was launched first in 2010. It has more advancement as compared to previous generations. The major advancement in 4G over 3G and other technologies is its higher bandwidth (BW) and data throughput [3]. Now Fifth generation (5G) communication system promises the real wireless network experience, would provide and support the WWW (Wireless World Wide Web). It is based on CDMA (Code Division Multiple Access) and BDMA (Beam Division Multiple Access) technology standards with the switching type of all IP network. Hence it which supports the core network for internet. It would also to support additional features e.g. Ultra HD video streaming, Online gaming services, Mobile full HD TV, reliable and secure online banking transaction, telemedicine, holographic communication etc. [5-6].

## II. EVOLUTION OF CELLULAR TECHNOLOGIES

Progression of mobile generations from 1G - 5G improves the user experience with communication systems. The network for 5G will be expected to launch in 2020, which is to address the current and future needs of the wireless communication systems. Progression in the cellular technology over the years are shown in figure 1.



Figure 1 Progression of cellular technologies over the years

### A. First Generation (1G)

1G was introduced in the beginnings of 1980's based on analog system having circuit switched network. 1G mobile system was used only for voice operations by using a technique called FDMA (Frequency Division Multiple Access). Operating frequencies was ~ 800 – 900 MHz and channel capacity were limited to 30 KHz. It had limited capacity, poor reception, deprived performance of battery and background noise interference etc. As merit, it has simple infrastructure and

required less network elements for the development. Technologies standards used in 1G [7] are illustrated in figure 2.

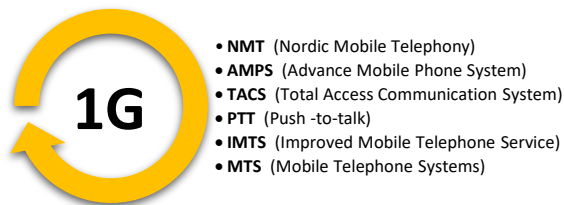


Figure 2 Technology standards in 1G

**B. Second Generation (2G)**

2G cellular technology took a big leap towards the progression in wireless cellular technology when launched in 1990’s and was based on digital system technology. In early stages of 2G, a limited data services were introduced commercially. GSM was the first 2G network, providing services like voice and data together.

The advancement in GSM technology is GPRS which is also known as 2.5G in which the data speed was enhanced upto 150 Kbps. After 2.5G, technology was introduced under the umbrella of 2G known as EDGE (Enhanced Data rate for GSM Evolution). Typically, it has ~ 2.75G, which is the upgradation in GPRS with maximum data rate ~ 384 Kbps [10]. Technologies under 2G are shown in figure 3.

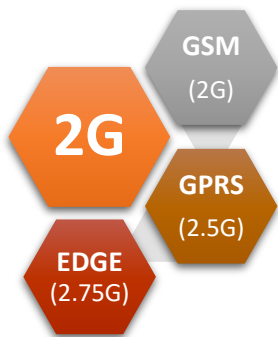


Figure 3 Different technologies under 2G

In 2G, circuit switched network is used for voice and packet for data to transmit and receive the data from source to destination. Noise interference and voice quality was also improved in 2G. Digital encryption was first introduced in 2G to secure data transmission [11].

**C. Third Generation (3G)**

Characteristically 3G was developed to improve voice services, data throughput, high QoS (Quality of Service) and information security [8]. 3G cellular technology was introduced

in 2000 by ITU (International Telecommunication Union) called IMT-2000. In 3G, 144 Kbps data rate for mobile user, 384 Kbps for pedestrian user and 2 Mbps for indoor users was achieved successfully [9]. Technologies standards used in 3G are demonstrated in figure 4.

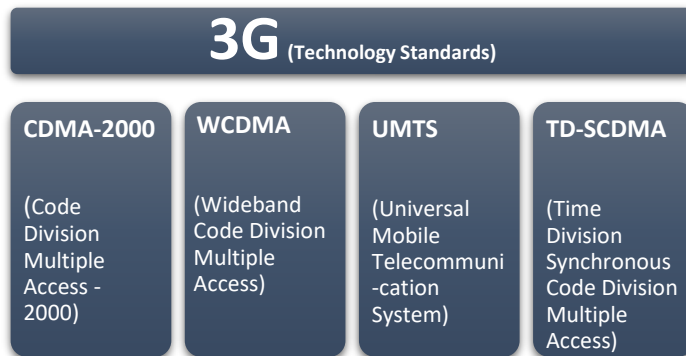


Figure 4 Technology standards under 3G

Packet switching is used in 3G for voice and data communication except the air interface. Some major characteristics of 3G are: digital broadband, high speed internet and high QoS for better voice quality over the air interface because of its equipment design to cater the noise interference problem, which is been a major issue with its predecessor [12].

Digital integrity and data security are upgraded in 3G mobile cellular technology. Similarly broadband internet service, data speed improved radically from 144 Kbps to 2Mbps. Services such as voice, SMS, MMS, video, High speed data, video conferencing were introduced adequately.

Two key variants of 3G technology are 3.5G (HSDPA) which enhance the data speed of downlink data transmission ranging speed from 8Mbps to 10Mbps downlink and 3.75G (HSUPA) which improves the uplink speed upto 5.8 Mbps with decreasing the delay in between the up and downlink. In figure 5 variants of 3G technology are illustrated.

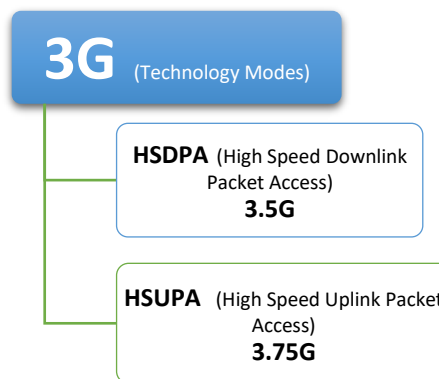


Figure 5 Technology modes of 3G

There are some apprehensions in 3G cellular technology like increase in power consumption reduces the battery life of a device by making it less dependable.

#### D. Fourth Generation (4G)

In 2010, 4G cellular technology was launched with several important changes to its predecessors like ITU-IMT incorporate the capacity upto 40 MHz and sets its peak speed requirement of 100 Mbps during handoff stages from one cell to another [13]. Technologies under 4G are exhibited in figure 6.

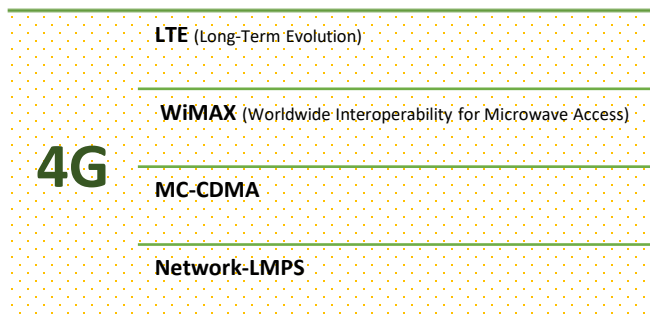


Figure 6 Technology standards under 4G

The key developments in 4G over its predecessors are: switching type and its core network i.e. all IP network is used as switching type and core network is internet (3G used packet network, 2G used PSTN). Features like high speed and real time data streaming vicissitudes the defiance of 4G to next level. With the ultra-broadband internet service, data speed ranges from 100 Mbps – 1.0Gbps. High speed handoff, MIMO technology and Global mobility are some of the foremost accomplishment of 4G over its previous generation.

4G user can relish the following service: - HD voice, SMS, MMS, mobile TV, wearable devices, HD streaming, Global roaming, gaming services etc.

#### E. Fifth Generation (5G)

The upcoming mobile cellular technology is 5G, which will be going to launch in 2020. 5G is an emerging technology that interest in research and development sector, which will transform the mindset of a user about slow wireless cellular technology. 5G cellular technology promptly states the requirements that at least 1.0 Gbps or more to deliver which supports virtual reality environment with ultra-HD audio / video applications along with 10 Gbps data speed to support mobile cloud service [14].

5G mobile cellular technology is based on several technology standards, delineated in figure 7.

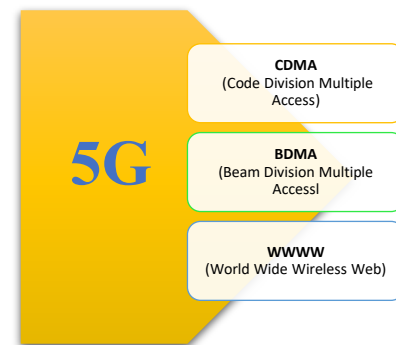


Figure 7 Technology standards under 5G

It will support bi-directional large bandwidth with data rates  $\geq 1.0$  Gbps with the proposed spectrum 3 to 300GHz through ubiquitous connectivity. The core network infrastructure will be based on internet and cloud computing. In 5G, cloud computing platform will be implemented with its maximum functionality. Management of previous technologies would become easy under the umbrella of cloud computing management solutions. All IP network and 5G network interfacing (5G-NI) would be used as switching type.

The main leap towards the success of 5G is related to energy efficiency and high data rate. Therefore, battery life of 5G devices are going to improve as compared its predecessors. With the massive MIMO technology, the transmission and reception can be improved further. There are also some issues yet to be addressed are; the infrastructure laying cost, security and privacy concern of a user that needs to design new policies and guidelines before execution of 5G.

Some 5G targeted application areas are: -

- Cloud computing
- Online gaming services
- Telemedicine
- Virtual reality
- Wearable wireless devices
- Holographic communication
- Ultra-high definition streaming
- Global roaming
- Gaming services
- Realtime full high definition video calling

### III. RELATIVE ANALYSIS OF CELLULAR TECHNOLOGIES

Generally, it is observed that mobile generations are proportional and depends upon data rates, bandwidth and operating frequency of cellular technologies, elaborated in equation (i).

$$\text{Mobile Generations} = R \propto Bw \propto f \dots \dots \dots (i)$$

Where,

- R = Data rate
- Bw = Bandwidth
- f = Frequency

Relative analysis of cellular technologies upto 5G is elaborated in figure 8. It is evidently observed that radical development towards the improvement and enhancement of the mobile cellular technologies are shown, where selective RF parameters are chosen for discussion.

Technology standards, Data rates and frequency are selected over the course of time because they are considered as the core of any cellular technology and without these parameters, advancement in mobile generations cannot be judged.

High-end applications demand high data rate and more bandwidth to run applications without any agitations and provides error-free environment to enhance the user experience.

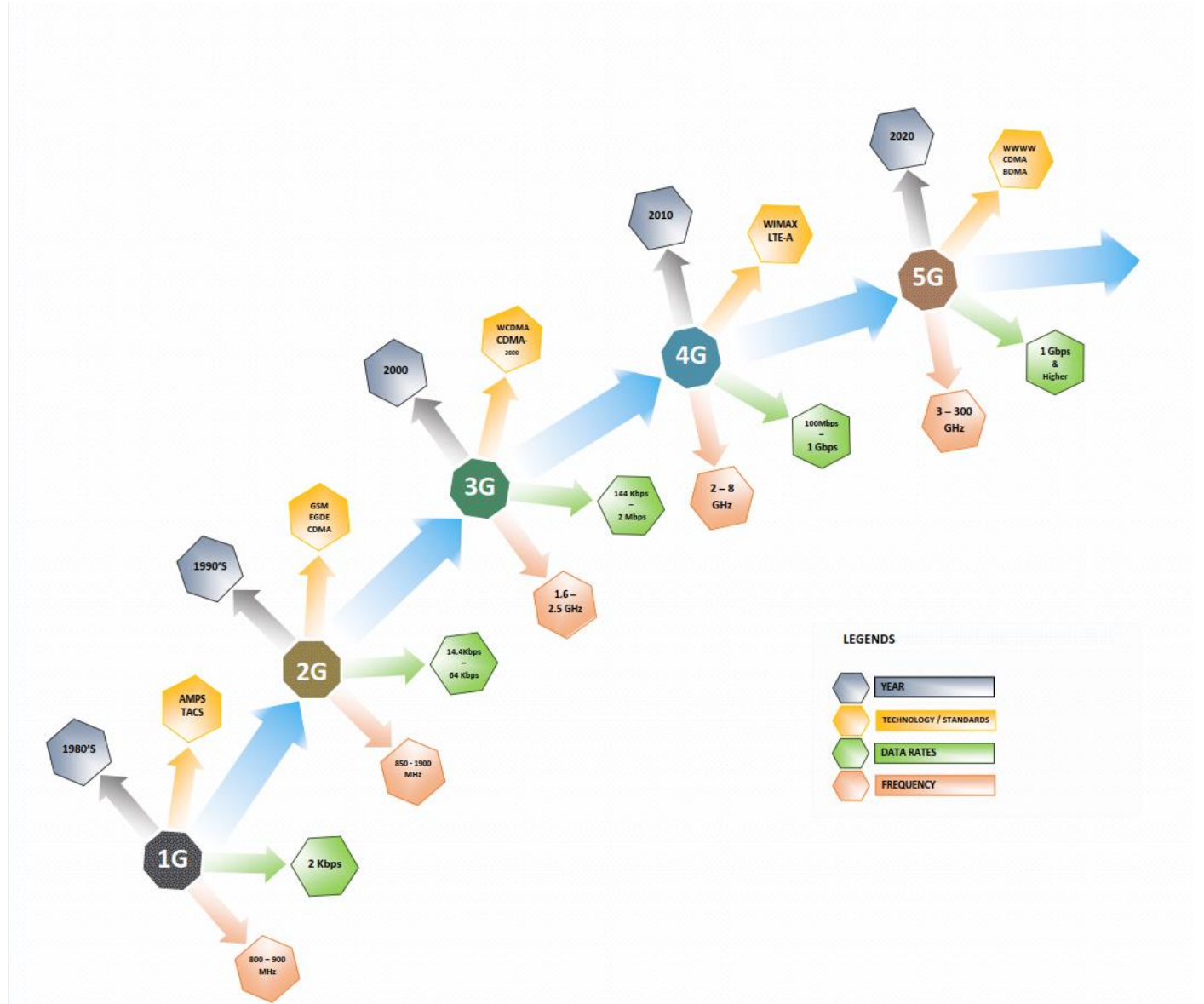


Figure 8 Mobile Generations with reverence to years, Technology Standards, Data Rates and their Frequencies

#### IV. CONCLUSION

In earlier stages of wireless communication technology, the demands of user were limited, as time goes by the needs of a user encourage professionals to design and develop the new technology to meet the requirements of customers. 1G

introduced the analog communication, followed by 2G in which the analog signals convert into the digital signal, results better communication (jitter free). After that 3G provides the internet to users and opens up a new dimension towards the speed

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