Recent Trends in Next Generation Cellular Mobile Network - 5G and beyond (6G)

Dr. P. C. Jain, LF-IAFI
Ex-Professor, EE Dept., School of Engg., Shiv Nadar University, G. Noida (UP)-201314
premchandjn@gmail.com

Abstract --**The evolution of the cellular networks standards have changed the market perception of the technology. The progression in mobile network standards played a crucial role in shaping the way one can communicate and access. The first generation (1G) focused on analog voice communication in AMPS (Advanced Mobile Phone System) Standard. The transition from analog to digital communication offered improved efficiency and additional features in 2G digital cellular phones which included GSM and CDMA standards. 3G cellular network marked as a significant advancement by enhancing data transmission capabilities, enabling better connectivity, and supporting digital data access on the Internet. As technology continued to evolve, subsequent generations such as 4G and beyond have further transformed the landscape, enabling faster data rates, increased connectivity, and the widespread adoption of advanced mobile applications and services. In 3G and fourth generation (4G), packet switched network was provided instead of circuit switched infrastructure. OFDMA alongwith MIMO antenna systems were used in the 4G-LTE. The goal of 4G was to provide speed of 300Mbps by using 20MHz channel bandwidth).**

The LTE upgraded to LTE-Advance which used additional spectrum using carrier aggregation (CA) and enhanced MIMO to provide 1Gbps data rate. The next LTE-A Pro (4.5G) permitted more number of CA making speed to 3Gbps data rates. The fifth generation features ultra-reliable low latency communication, massive machine type communication besides of course, enhanced mobile broadband. The 5G provides 20Gbps peak data rate and 1mS latency using mm Wave frequency spectrum. 5G mission is to connect everyone and everything at any time. The sixth generation (6G) means more bits, more spectrum, more reliability. To cover extended reality (XR) including augmented reality AR/VR (Virtual Reality), 6G may deliver around 1Tera bps (Tbps) and 100uS latency, which may be possible by using beyond 300GHz to 3THz referred as sub-mm wave spectrum. Non-terrestrial network (NTN) link using LEO (lower Earth Orbit) satellites will boost in-flight and onboard ships network connection speeds including rural broadband communication. The 6G will need integration of terrestrial, airborne, and satellite network in to a single wireless system.

Keywords: 4G, 5G, 6G, mm wave, Non-terrestrial, LEO

I. INTRODUCTION

IN the short span of 20-30 years, the mobile network industry revolutionized the world. The rapid progression from 1G to 4G and beyond has not only improved communication but also opened up a new possibilities for variety of services and applications. The 1G standard mobile phones were widely used in 1980s. The 1G used analog FM with FDMA in AMPS US standard. The 2G mobile phones changed to digital format and text messaging were featured in early 1990s. The 2G used digital voice with digital modulation and TDMA/CDMA. The 2G included GSM, CDMA and a few other standards. The introduction of 3G in year 2000 brought a notable shift towards digital data access, paving the way for more advanced mobile services. Users experienced better connectivity, higher download speeds, besides improved network reliability, and significant improvement in cellular networks. As technology continued to evolve, subsequent generations such as 4G and beyond have further transformed the landscape, enabling faster data rates, increased connectivity, and adoption of advanced mobile applications such music downloads, web browsing alongwith video streaming [1].

4G and beyond are IP-based heterogeneous networks, featuring ability to use any network at anytime and anywhere. This implies users in different locations and economic classes can use from any service provider, multiple services at the same time. 4G enhances the Quality of Service and reduces cost of resources. It enable global mobility and service portability. With this the service providers are not limited to a single system.

II. 4G-LONG TERM EVOLUTION (LTE)

The 4G is a full IP technology with download speeds up to 100Mb/s and uploads to 50Mb/s. The 4G-LTE is based on OFDMA in down link and MIMO antenna systems [2]. The LTE supports MIMO operation by using multiple antennas in both BS (Base Station) and cell phone to improve spectral usage efficiency and increase in coverage. For special multiplexing in down link, LTE supports Single user (SU) -MIMO with up to 4 streams of transmission as well as Multi-user(MU)-MIMO where the BS sends to different users, different data streams using same frequency resource. The LTE up-link uses Single carrier (SC)-OFDMA to minimize PAPR (Peak to average power ratio) [3]. In LTE transmit channel bandwidth can be chosen between 1.4MHz and 20MHz depending on spectrum availability. Latency can be as low as 10-20ms, useful for applications like online gaming, voice and video. The LTE supports down link peak data rate of 170Mb/s with 2X2

MIMO and 320Mb/s with 4X4 MIMO, and uplink 50Mbps using 20MHz BW.

a) LTE-Advanced: LTE continued to be upgraded to LTE-A (Advanced) and LTE-A Pro that provides high data rates. LTE-A supporting intelligent node and adaptive resource allocation that extends both range and capacity of the network via data rates proportional to the signal quality besides mitigating signal interference between cells. Interestingly, it utilizes wide BW (20 to 100MHz) through the use of carrier aggregation [4]. The carrier aggregation enables carriers to send and receive data over an aggregated data pipeline to increase data rates alongith lower latency. The CA allows operators to combine up to five 20MHz channels contiguous or non-contiguous in to one channel to boost data rate to 1Gbps. The LTE-A also includes advanced down link intra-cell coordinated multi-Point (CoMP) transmission, and heterogeneous networks with emphasis to relays. The downlink uses spatial multiplexing using up to 8x8 MIMO whereas the uplink uses 4x4 MIMO. The MIMO improves reliability in transmitting high data rates in fading channels. The LTE-A supports down link peak data rate up to 1Gbps and uplink 500Mbps using 8x8 MIMO, 20+20MHz BW, and 64-QAM both in down link and up link.

b) LTE-A Pro: LTE-A Pro [5] accommodates license assisted access (LSA) and LTE-WLAN Aggregation (LWA) that combines together LTE spectrum and unlicensed 5GHz spectrum used in Wi-Fi IEEE802.11ac/ax (WiFi-5/6). It also provided IoT/M2M (Machine-to-Machine) connectivity with lesser BW for low data rates and power savings. It also offered feature of a device-to-device (D2D) communication which allows handset owner talk directly to other rather than through a cell site. The LTE-A Pro permits maximum to 32 CA to obtain very high data rates. The LTE-A Pro supports data rates of 3Gbps down link and 1.5Gbps in uplink using 100+100MHz BW.

c) Cellular IoT

The IoT (Internet of Things) meant a network of physical devices with embedded sensors. Any object with embedded sensors and an IP address can become an IoT device. The IoT devices collect and share data with other IoT devices on the network and also with the central servers. Such platform supports billions of devices which includes low BW, small packet size. Such IoT devices polls data after every few sec. The 4G cellular networks can support IoT applications, especially those requiring longer-range connectivity but the limitations include high power consumption [6] and potential cost issues for applications with large data transmission needs. Low-bandwidth-data applications requiring very low data rates to be exchanged over the Internet such as smart homes, offices, and buildings to adjust thermostats, lock doors or turn lights on/off from the remote locations using smart phone applications. However, IoT in industry and infrastructure use cases such as smart metering, smart cities, smart agriculture, or asset management requires low bit data rates (50kbps per IoT device), relatively long ranges (10kms or more) with reliability, and 10 to 15 years long battery life. The LTE-M (Machine) and Narrow band (NB)-IoT are emerging cellular IoT technologies designed for Low Power Wide Area (LPWA). The LPWA use cases include applications with low data rates, longer ranges, and extended battery life. Examples include smart cities, smart agriculture, and asset management. The low cost of both connectivity and hardware will drive remote monitoring in key verticals as above.

i) LTE-M: This is a versatile LPWA technology. LTE-M is a stripped-down version of Long-Term Evolution. It is designed to support smart cities, high data rates, and mobility for IoT applications. It utilizes a narrower bandwidth of 1.4MHz instead of the 20MHz bandwidth used in standard LTE. The reduction in bandwidth to 1.4MHz reduces FFT size leads to a 28% cost reduction. It leads to a second generation LTE chip built for IoT [7]. The power consumption is lowered due to the processing of fewer OFDM subcarriers at the RF level. The cost will also reduce by ~25% because of RF transceiver design. This results in an overall average cost saving of 39%, and a 50% reduction in modem complexity compared to LTE. It provides downlink and uplink peak data rates of 1Mbps using a 1.4MHz bandwidth. It features deep penetration in buildings and basements make it suitable for various IoT applications. The low latency is a key advantage, facilitating real-time communication. The maximum uplink power transmitted by devices is 23dBm and downlink power is 46dBm with a low latency of 10-15 milliseconds. It implements Power Saving Mode (PSM), allowing devices to conserve power. To summarize, the LTE-M addresses the specific needs of IoT applications by providing a cost-effective, power-efficient, and versatile connectivity solution. Its capabilities, including extended range, low latency, and support for voice functionality, make it well-suited for diverse use cases, particularly in the automotive sector and other IoT applications.

ii) NB-IoT: The Narrow Band IoT operates in the LTE band [8] and uses direct sequence spread spectrum (DSSS) instead of OFDM. It obviates the need for gateways, allowing sensor data to be directly transmitted to main server. However, Voice over LTE is not supported and lacks mobility features. However, these limitations are balanced by its advantages in cost and power efficiency. The NB-IoT is cost-effective and has lower power requirements compared to LTE-M. The maximum transmitted power is 20dBm over a 200kHz bandwidth. The NB-IoT reduces the complexity by 75%. It supports downlink and uplink peak data rates of around 250kbps. The latency ranges from 1.6 to 10 seconds. It operates in a licensed band, providing high security and eliminating interference issues. It supports massive IoT connections, with the ability to handle 50k-100k connections per cell site. With an average daily transmission of 200 bytes, NB-IoT can achieve a battery life of up to 10 years. To summarize, the NB-IoT is a compelling option for specific IoT applications, particularly those that prioritize cost efficiency, low power consumption, and scalability. Its use of a licensed band ensures secure and interference-free communication, making it suitable for various projects, especially in the context of smart cities. The ongoing evolution of NB-IoT standards further enhances its capabilities and addresses certain limitations.

III. FIFTH GENERATION (5G)

Fifth generation (5G) is the latest generation of mobile connectivity technology that offers very high speeds, increased capacity, lower latency, and greater network flexibility. The 5G enables vast amount of data to travel faster than ever by using higher frequency bands. The 5G uses 3.5GHz mid-band for high coverage and high capacity (10Gbps) in urban areas. 5G speeds will further increase by another order of magnitude once base station (BS) starts supporting high-band (>20GHz) millimeter (mm) wave frequency to support very high data rate (20Gbps) with ultra low latency (time taken by RF signal from base station to user mobile phone). The 5G also allows thousands of mobile devices in a small area to be connected simultaneously, whilst using less energy per bit of data (less power consumption in the devices). 5G technology connects everything everywhere to create increased profitability by enabling extraordinary business opportunities and increased automation. It is necessary to educate mobile operators that there is more business to be done other than just selling SIM cards. Mobile operators have to understand that there is a platform for both public network and non-public network (NPN) that is private network. Private 5G network is important for the manufacturing industry to implement meta-verse applications to achieve drastic improvements in the overall productivity. The 5G will achieve mainly three goals [9] as shown in Fig. 1.

a) Enhanced Mobile Broadband (eMBB): The eMBB is extension of LTE capability providing high throughput (10-20Gbps) and low latency (1ms) for ultra HD video streaming, AR/VR, flash up/download, and high density environments like airports/stadia. Fixed wireless access (FWA) can provide viable alternative to wire line fiber broadband network. As our hunger for data continues to grow (70% of the time live video streaming and online games grown significantly in popularity), and new use cases come to the forefront, one has to be ready to meet those data needs. It is to be note that BW is shared by all users on a cell tower at BS. If you are streaming video at sports stadium airport or with dense population, you experience a choppy download and poor viewing experience due to buffering. With 5G, one can achieve theoretically download a 40GB 4k resolution ultra-HD video movie in less than a minute.

b) Ultra Reliable Low latency Communication (uRLLC): It also referred as mission critical communication requiring low latency, high reliability. It supports industrial automation, drone control, tele-medicine, remote surgery, and autonomous vehicles. This is necessary to control the autonomous cars and high precision mission critical industrial devices in real time communication for potentially life saving functions.

c) Massive Machine Type Communication (mMTC): The mMTC extends LTE-IoT using LTE-M and NB-IoT stripped down version of LTE discussed above to support large number of IoT devices with lower cost, lower throughput, enhanced coverage, and long battery life (10 years). The IoT is poised to support 125 billion devices by 2030. The massive MTC or massive IoT will work at low data rates per device but very high connection densities. It focuses on providing connectivity to a large number of IoT devices in 5G (1 million devices per sq. km) without any constraints of high data rates and low latency. For example, a smart factory needs communication with a

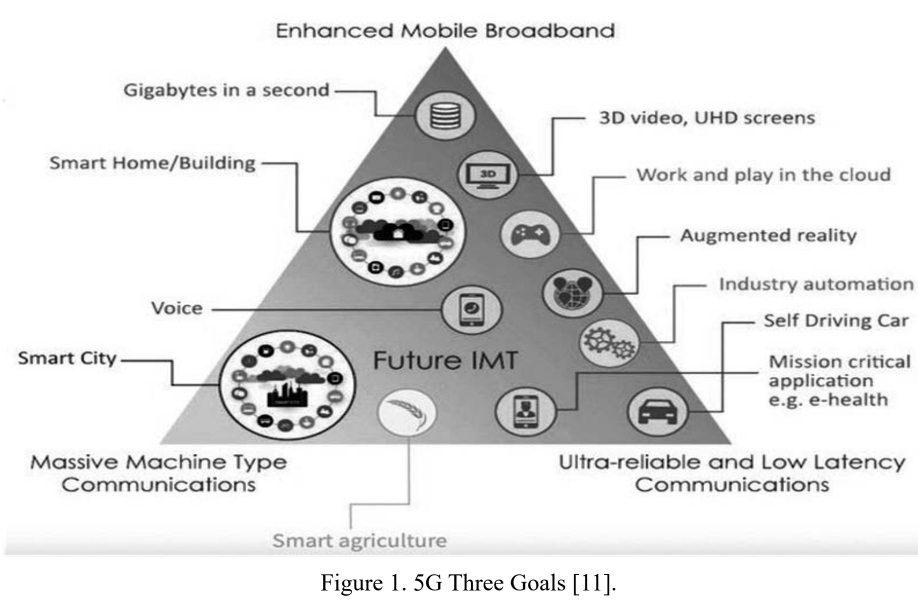

Figure 1. 5G Three Goals [11].

massive number of devices and machines simultaneously. In agriculture, the large number of environmental sensors collect the data in remote locations, however, they need to send only a few bits every day or even every week with modest latency.

d) 5G-NR (New Radio): 5G-NR phase-I non stand alone (NSA) used 4G-LTE core network together with 5G next generation radio (gNB) in sub-6GHz band. The Stand alone (SA) allows 5G-gNB to act as a master node using 5G core and without relying on 4G-LTE core network control. The 5G-NR supports macro cells and small cells, which is significantly challenging task compared to LTE. The gNB uses mm wave frequency band to achieve higher data rate with around 200m short range through multiple beam formation using antenna arrays which compensates higher path losses at above frequency bands. The MIMO at gNB transmits multiple data streams to multiple antennas and the mobile phone receiver receives and combines them to recover the data. With this the revised Shannon's formula becomes

$$C = M.B.\text{Log}_2[1+N(\text{SNR})/M]$$

where M is the number of transmit antennas and N is the number of receive antennas. It creates highly directional beams that can be redirected to specific location or device (Fig. 2).

The Sub-6GHz band uses 32 to 64 antenna array elements, while mmWave frequency band ranges from 64 to 128 antenna array elements[10]. The 6GHz sub-band allows a massive 64T64R MIMO configuration.

The 6GHz sub-band has better in-building penetration. The small cells provides large density in short ranges at mm wave frequency band compensating the limitation of diffraction, path loss and penetration. The 5G-NR consists of a flexible slot based frame work, advanced channel coding (LDPC), scalable OFDM, massive MIMO, mm wave spectrum. The 5G infrastructure and handsets entails substantial increase in cost. The 5G networks require a much higher density of base stations (BS) sites, with more than 100 BS sites per square kilometer. Earlier, Mobile network used integrated cell sites where radio, hardware, software were proprietary of single manufacturer. Today above task is carried by more than one company. The user equipment (UE) from multiple suppliers creates more competitive market, and network operators have more flexibility in managing their network and upgrade to the latest technology. Open(O)-RAN will provide flexibility, and cost efficiency compared to the fixed function RAN equipment [11]. Support is required for wide range of applications with vary dissimilar needs.

As compare to 4G, the 5G aims to provide significantly higher data rates (>10Gbps), lower latency (~1ms), and higher efficiency. The goal is to support one million devices/km^2 with 99.99% reliability besides battery life of 10 years for IoT devices.

The 5G Rel. 15 emphasizes eMBB, and Rel. 16 emphasize uRLLC and mMTC. The evolution of 5G began in Rel. 16 which addresses cellular vehicle-to-everything (C-V2X), device-to-device (D2D) proximity services, integrated access and backhaul (IAB), and IoT relays. The communication

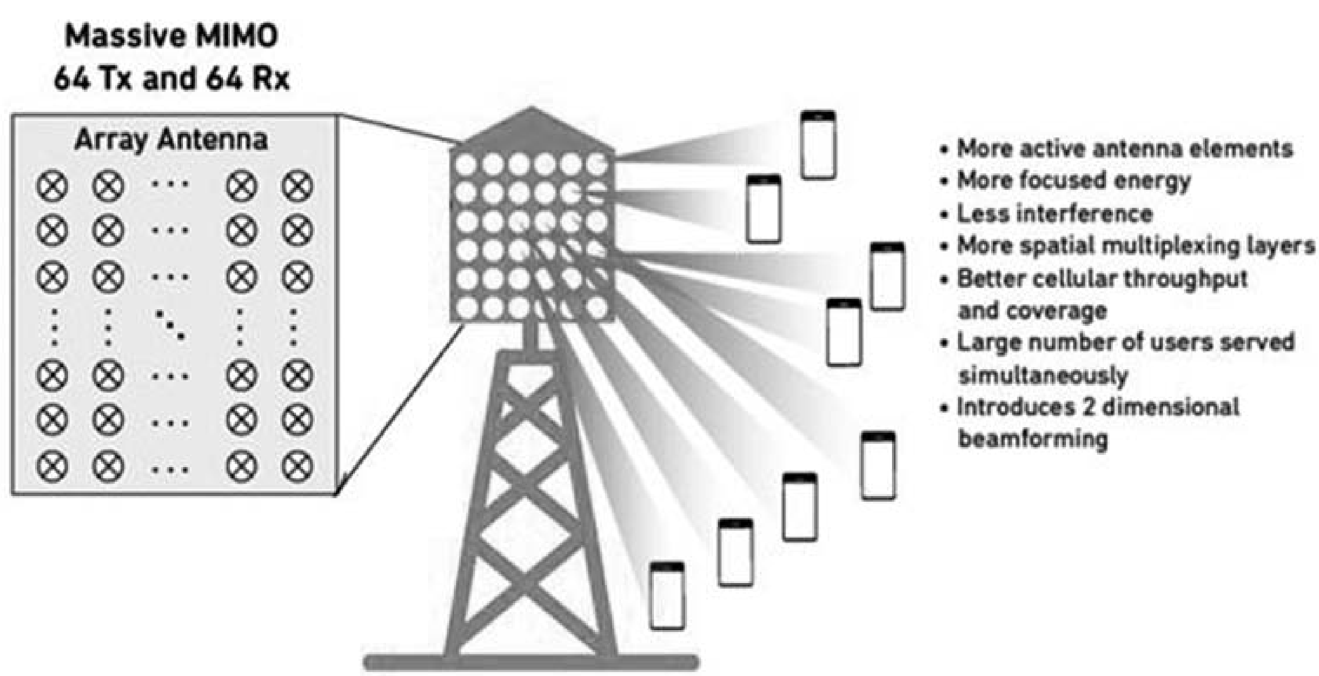

Figure 2. 3D Beam forming [9].

between cars, between infrastructure and cars will make driving safer and more efficient. The 5G will support intelligent transport applications such as connected trucks, connected bus stops, parking information, and fleet monitoring. Another feature is to tap the unlicensed band (5GHz) to provide licensed assisted access (LAA). The Industrial IoT (IIoT) will power wirelessly connected factory of future. The Industry has gone first through mechanization, second through electrification, third through digitization, and now 5G connectivity referred as Industry 4.0. The Rel. 17 will support 52 to 71GHz mm wave frequency bands including unlicensed band (60GHz) for multi-cast, broadcast, and non-terrestrial networks (NTN) using satellites.

IV. SIXTH GENERATION (6G)

The 6G will fully connect the physical, digital, and human world and manage the opportunities and challenges of growth and sustainability. The 6G will work towards a more holistic, immersive communication and networks to reach a variety of performance targets, and to reduce costs, maintenance, overheads, and service times. The 6G means more bits, more spectrum, more reliability [12]. The 6G aims for peak data rates of 1Tbps, user average data rates of 1Gbps, and latency less than100µs. The number of connected devices will support 1 crore devices/km^2. The mobile devices will include AR, VR and hologram devices. To cover Extended Reality (XR) along with AR/VR, 6G must deliver around 1Tera bps (Tbps) data rates [13]. In XR, tracking, control, localization, and computing are inherent features. The Holograms are next generation media technology that displays gestures and facial expression in real time, and it needs 16 Gpixel (picture elements) resolution and requires 1Tbps throughput.

Other possible applications include fast download contents from server to mobile devices. The whole content on DVD can be transferred in a fraction of sec. To achieve such a speed 6G frequency band will be beyond 300GHz to 3THz referred as sub-mm wave spectrum which is above microwave and mm wave frequency band [14]. The path loss at THz can be reduced by utilizing ultra-massive MIMO (array of 1024 antenna elements) which results in very focused beams similar to laser beams. This will neither scatter nor diffract the path. A meta material will be required. It does not require separate antenna array with phase shifters [15].

The evolution of 6G is expected to go beyond enhancing communication performance and extend its utilization by integrating sensing and artificial intelligence (AI) with communication. This integration suggests a more comprehensive approach to communication, incorporating advanced sensing capabilities and AI-driven functionalities (Fig. 3).

This scenario is designed to cover specialized use cases with more stringent requirements on reliability and latency. It covers smart industries with extended new applications such as full automation, industrial control and operations, drone operations, remote medical surgery, robotic interaction, etc.

Massive communication (extends mMTC) [16]. Applications include agriculture, environmental monitoring, health, smart cities, transportation, logistics, energy, infrastructure, etc.

Ubiquitous connectivity provides access to the Internet in rural areas. It is expected to extend the current broadband and IoT services into rural, remote, and sparsely populated areas, connecting the unconnected areas at an affordable cost. The terrestrial network can not achieve ubiquitous, high quality, high reliability services at any time and anywhere. It is necessary to integrate terrestrial network with non-terrestrial network (NTN) to achieve world wide connectivity [17]. It brings space-air-ground-sea coverage via a seamless access to satellite link and terrestrial network with optical backhaul. The satellite communication provides broadband to home and communities in remote locations as well as connectivity for maritime, and airplanes. The low earth orbit (LEO) satellite extends the satellite broadband capacity and offers lower latency compared to GEO and MEO satellites. The optical link for inter-satellite communication, flat panel antennas for cheaper satellite, higher capacity data transfer, and better connectivity are on the move. The very low earth orbit (VLEO) satellite (300km) will reduce size, power consumption, latency, RF signal path loss, and forms a smaller beam diameter projected on the ground. It supports data rate of several Gbps consuming only a few watts of power.

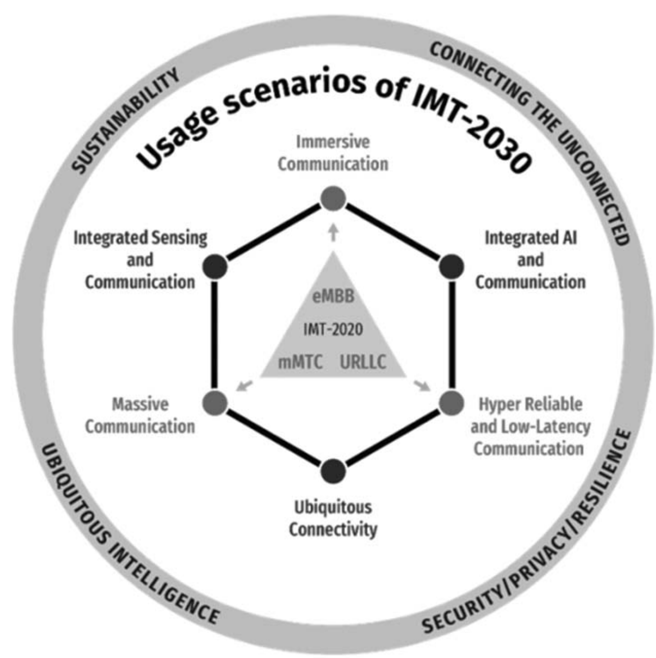

Fig. 3. 6G Wheel shaped diagram [8].

Integration of AI with communication in 6G is expected to support distributed computation and AI-powered applications.

The four overarching aspects shown in Fig.3 are highlighted in 6G development which includes connecting the unconnected, security/privacy/resilience, ubiquitous intelligence, and sustainability. Connecting the unconnected aims to extend connectivity to previously unconnected regions and population. The security/privacy/resilience emphasizes the importance of robust security measures, privacy protection, and network resilience. The ubiquitous intelligence envisages intelligence being embedded across the network, supporting diverse use cases and applications. The sustainability aspects of 6G includes specific goals such as energy efficiency (in bits/Joule), low power consumption, reduction of greenhouse gas emission, and adherence to a circular economy model. The focus on sustainability and the overarching aspects reflects a commitment to addressing broader societal and environmental challenges. The UN sustainable development goals (SDG) promote global health and quality of life. In 6G it is expected to reduce carbon emissions by 30%, total cost ownership (TCO) by 30%, and 90% reduction in energy consumption per bit. The ubiquitous intelligence facilitates information processing, analysis, and detection, making for applications that operate in the ubiquitous environment. The 6G must also meet the cyber-security of a total coverage network. The analyst estimates 6G standard will be approved by 2030, however, 6G will be a reality by 2035.

V. CONCLUSION

This paper discussed 1G to 3G in brief and then 4G-LTE including 4G-LTE-Adv., and 4G-LTE-A Pro. Three key pillars namely eMBB, mMTC, and uRLLC have been discussed including their use cases. The 5G does not replace 4G.

The future is to connect billions of connected devices which includes connected and autonomous vehicles, smart cities, all of which brings huge amount of devices that require connection to wireless network. Finally, in 6G six usage scenarios including enhancement of 3 key pillars of 5G, and 4 overarching aspects have been discussed. The 6G frequency band will be beyond 300GHz to 3THz. The THz frequency can offer ultra-high speed. The LEO (lower Earth Orbit) satellites will boost in-flight network connection speeds and reduce latency. The 6G will need integration of terrestrial, airborne, and satellite network in to a single wireless system. In 6G AI technology will optimize the operation and management which will lower the operation expenses and enhance network key performance.

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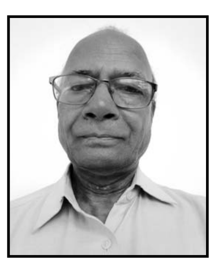

Prof. Prem Chand Jain, FIETE (b. 1 July, 1946), obtained B.E., M.E. (Electronics) from BITS, Pilani in 1968, 1972 respectively, and Ph.D. from University of Louvain, Belgium in 1979 specialized in video compression using transform coding for digital video broadcasting. Possesses research experience in speech and video compression over 35 years at CEERI, Pilani and HFCL R&D, Gurgaon; Teaching experience in multimedia communication, communication & networks, cellular mobile commmuniations and IoT at C-DAC, Noida and Shiv Nadar University, G. Noida. Published 158 research papers in various international/national juornals/conferences. Visited Belgium, Germany, USA, Singapore, Hongkong for PhD, as an Expert, Post Doc., Broadcast Asia, Collaboration with Star TV respectively. Life Fellow/member of IAFI, IETE, BES, CSI. Presently associated with IAFI and TEC in 6G, Broadcasting, and IoT group for standardization.