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Critical Aspects of 5G Technology- A Study on the Drivers, Technology Enhancement, Performance, and Spectrum Usage

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Pursuit for a new feasible technology has always been the main intention of every telecom company to satisfy the dire needs of the increasing demand for higher data rates and uninterrupted communication. The Fourth Generation (4G) network deployed presently works on an All-IP Network architecture providing features like low latency and high data rates. Owing to many user applications which make use of constant internet connection and high data rate, 5G was launched. Keeping in line with current trends, user preferences, and requirements, technology standards have evolved from 1G, 2G, 3G, 4G, and now 5G. Thus, 5G mobile technology makes use of Flat-IP Network architecture which fulfills the need for high data rates and ultra low latency thus providing overall latency. Thus, this paper intends to discuss the various performance parameters, necessities, evolutionary enhancements, the shift in the architecture and protocols involved from 4G to 5G to achieve a full real wireless world, and also about the spectrum management and challenges.

Keywords: API; E-UTRAN; 5G; Dynamic Ad Hoc Wireless Network (DAWN); Radio Access Network (RAT); network Slicing; MIMO.

1. INTRODUCTION

The First Generation 1G was first floated in 1979 by Nippon Telegraph and Telephone (NTT) and employed the use of analog signals for data transmission which led to many problems such as data encryption and security, thus 1G technology provided seamless mobile connectivity introducing voice services [1] In 1991, the Concept of 2G network was launched by Radiolinja in Finland to overcome the challenges of 1G, it had a Data Bandwidth of 64 Kbps and used Time Division Multiple Access (TDMA). It worked on Circuit Switching and Public Switched Telephone Network (PSTN). There was a remarkable improvement in the quality of phone calls and an increase in the voice capacity [2] The launch of 3G in 1998 by NTT Docomo in Japan led to the concept of Packet Switching because of the low bandwidth constraint in the 2G communication, it had a Data bandwidth of 2 Mbps and used Code Division Multiple Access (CDMA) in the core network. But the lower spectrum and latency had been the downside of the third generation. Thus, with the launch of 4G in 2015, which provides the Data Bandwidth of 1 Gbps and has CDMA Multiplexing. It works on Packet Switching, thus providing the mobile user with the ultra-broadband access. Under this standard, traditional voice call was replaced by IP Telephony [3].

According to research, there is an increase in 1000 scales in the traffic demand and more than 100 billion connected IoT devices, which impose a big challenge for future wireless communication technology [4]. To meet the challenges of high capacity demand, high radiation and latency, mobile industries started working towards 5G and all the countries are gearing up towards the successful launch of 5G all over the world.

To fulfill the need for high data rates, uninterrupted communication links, and decreased latency, 5G Technology was introduced in 2012 at Mobile World Congress. It will have a Data Bandwidth of more than 1Gbps where Orthogonal Frequency Division Multiplexing (OFDM) is used. It works on the concept of Packet Switching with a vast coverage area. 5G frequency ranges from 30 GHz to 300 GHz with high throughput in the millimeter range, which enables a data speed of 20 Mbps up to 2 km. Thus 5G was introduced to eradicate the drawbacks of 4G and provide a future ready wireless technology that supports both WWWW (World Wide Wireless Web) and Robust DAWN (Dynamic Ad Hoc Wireless Network) [5].

There is an ever-growing demand for a wireless technology that can support a wide variety of Applications such as Internet of things (IOT), Infotainment systems, and Security in vehicles to name a few [6].

This paper focuses on critical aspects of the 5G network. The paper is structured in the following manner. Section 2 deals with the transition from 4G to 5G. It includes an overview of 5G, its deployment, its performance parameters, its evaluation and spectrum usage. In section 3, the paper concludes with a discussion of future directions and prospects.

2. TRANSITION FROM 4G TO 5G

This section deals with the evolution of 5G, the architecture of 4G, its transition to 5G and 5G architecture.

2.1 Architecture of 4G Mobile Network

The core network architecture of 4G comprises of three layers such as the Transport layer, the Service Middleware (offering various services) and the Applications layer. By the use of Routers, the Transport layer is configured to establish the network interconnection between the hardware and software devices or things.

The Service Middleware is employed in the Server which makes the provisions for Application Programming Interface (API) by making use of protocols such as JAIN and Parlay [7].

The network IP core for 4G is IPv4 which has to be upgraded to IPv6 to support more number of devices or things that may get connected by the use of 5G technology. In 5G technology the IP core will be executed by Asynchronous Transfer Mode (ATM) [6].

The evolution of wireless technologies from first generation to 5^{th} generation is illustrated in Fig. 1. 5G is the fifth generation of wireless technology which promises high data rate and connectivity.

The 4G LTE network consists of sub-networks of Evolved Universal Terrestrial Radio Access Networks (E-UTRAN) which looks after the air interface. The Evolved Packet Core (EPC) along with the User Equipment (UE) provides the mobility and the backhaul connectivity. According to the standards of 3GPP LTE, EPC consists of control plane functions along with a set of logical data. LTE works with high peak data rates with a downlink speed of up to 150 Mbps and an uplink speed of up to 50 Mbps [9].

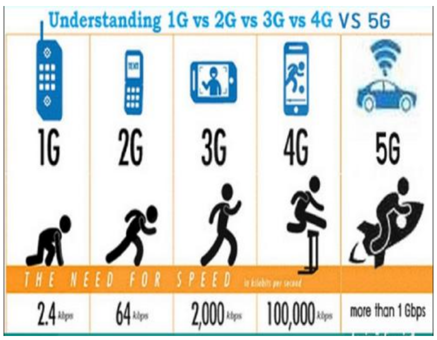

Fig. 1. Evolution of 5G [8]

The four major functions of EPC are the Packet Data Network Gateway (PGW), the Serving Gateway (SGW), the Policy Charging and Rules Function (PCRF) and the Mobility Management Entity (MME). Wireless operators usually own or lease the backhaul network. There is no constraint as to which transport protocol technology can be used, some of them are employed in backhauls such as optical packet, IP/MPLS, packet microwave, GPON, Carrier Ethernet, and xDSL [10,11].

2.2 Transition

The base station deployed in 5G technology includes D2D, Massive MIMO (multiple-input multiple-output) and User Densification Network (UDN). These base stations are Horizontally coordinated with each other which are faster when compared to 4G networks, thus 5G technology will provide a robust, flexible, and dynamic wireless mesh network. When compared to 4G, the 5G terminals are expected to have various web accessed error-control and error- correction schemes along with a variety of complex modulation schemes and software defined radios present at its dynamic wireless mesh network.

5G terminal will dynamically choose the different network providers, providing a specific service to be allocated for a wireless or a mobile medium by exploiting the concept of network slicing, this choice of dynamic allocation of resources depends on the mobile phone's open intelligent middleware. [12].

2.3 Architecture of 5G Mobile Network

5G Mobile network is a dynamic IP based model deployed for the wireless and mobile networks, this system has a new architecture in which the user terminal along with various individualistic and autonomous radio access technologies play a major role. Each mobile terminal should have a unique Radio Access Technology (RAT). In order to ingress four different RATs, four different access with specific interfaces should be defined in the mobile terminal to make this architecture work [13].

Fig. 4 represents the difference between the OSI Stack and 5G New Radio Network Stack**,** a communication system that works on the foundation of a layered protocol stack, the prominent feature of the stack is how compatible it is with other open-source protocols.

The layers of 5G network stack are explained as below:

OWAL Layer: The first two OSI layers namely, the physical layer and data link layer are combined together to form an Open Wireless Architecture layer (OWAL) that defines the New Radio Access Technologies (N-RAT) across which Internet access is provided along with the supportive mechanisms such as Quality of Service (QoS).

Network Layer: There is a dual network layer such as upper network layers and lower network layers.

Open Transport Layer: It provides the structure and support of both the session layer and transport layer.

Application Layer: It encrypts and decrypts the data and also selects the best wireless connection for a given service.

In 5G, the User Equipment (UE) is connected to more than one base station thus providing the user with endless streaming and connectivity. The Sockets are used for Application connections between clients and servers for the internet. The IP tunnels which are using the IP interfaces to provide the network abstraction, is achieved by creating the terminal connection through the access technologies available to a mobile user. Based on certain policies, the tunnels are established to the Policy Routers which takes place just after the Internet connectivity is set up over radio access technology (RAT) and it is initiated using Virtual Network-level Protocol.

2.4 5G Protocol Enhancements

Control and User Plane Separation (CUPS): CUPS determines the separation and architecture enhancement for EPC nodes such as SGW, PGW and TDF. It also enables the network deployment and operation.

Packet Forwarding Control Protocol (PFCP): This protocol is used on the Sx/N4 which is used to interface between the control plane and the user plane function which is a 3GPP protocol.

Network Slicing: Network slicing is a form of virtualization of the network which allows different logical networks to run on top of a shared physical network infrastructure in the network. It works on the similar principles of the fixed network, Software Defined Network (SDN) and Network Functions Virtualization (NFV).

Some of the other enhancements include PHY layer flexibility, MAC Layer Slicing, Latency reduction.

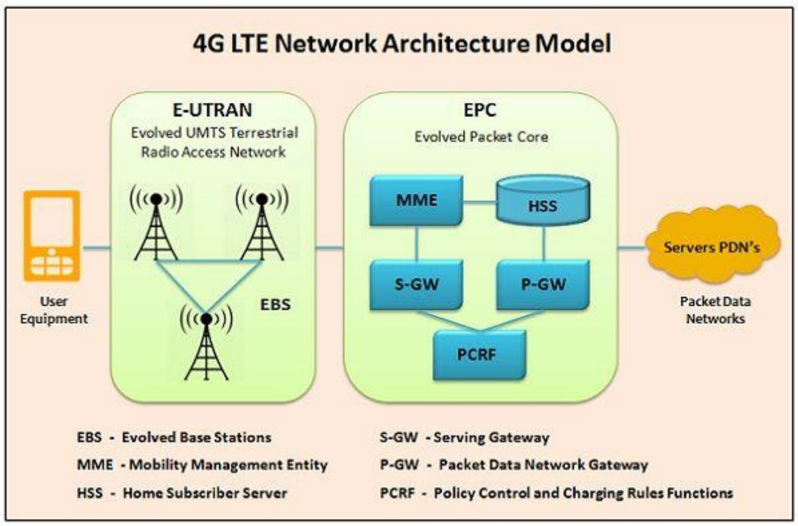

Fig. 2. Functional representation of an LTE/4G technology network (techdifferences.com)

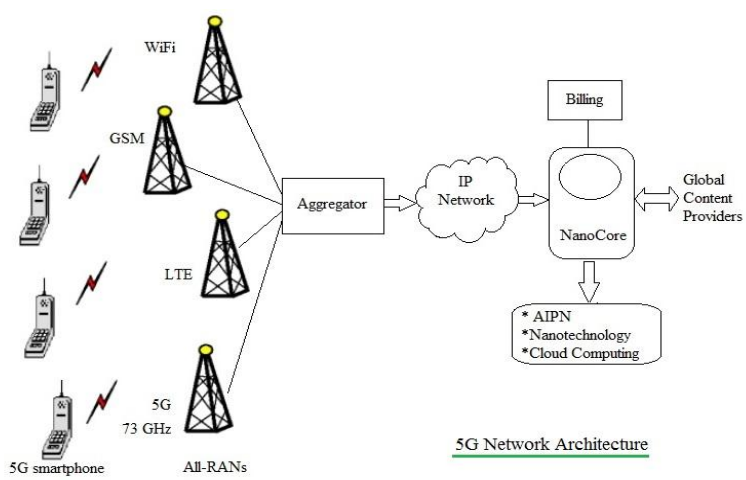

Fig. 3. Functional representation of a 5G network [14]

2.5 WHAT IS 5G?

5G is an evolution of wireless cellular network which provides portable mobile internet facility anywhere anytime to the user. 5G will provide a multi Gbps data rate from 10 to 100x improvement over existing 4G and 4.5G networks. These networks are capable to provide 98% of reliability and availability to the users, such that there is a very little downtime to perform any task or operation i.e. 1-millisecond latency.

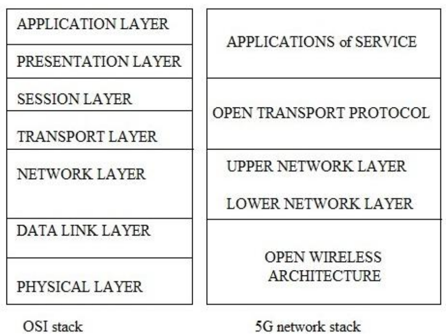

Fig. 4. Representation of 5G Network stack [15]

5G will provide a greater coverage area with a 90% reduction in network energy usage, due to this the battery life of low power IoT devices will go up to 10 years. 5G technology will enable us to connect up to 100x number of devices per unit area when compared with 4G LTE or LTE-Pro. An increase in bandwidth per unit area will go up to a thousand folds. Appropriate QoS (Quality of Service) is provided to the people according to their requirements. The main goal of quality of service is to give priority to networks with less latency, a checked jitter and dedicated bandwidth. It aims at providing ubiquitous connectivity, more software options to upgrade and a wide range of applications. Spectrum allocation for different applications is shown in Fig.5.

5G network will be both Flexible and Robust, flexibility of the network will provide open networking, high mobility, increased agility, sustainability, and ease of programmability. On the other hand, robustness provides the network to be scalable, secure, reliable, and standardized. There is presently no standard for 5G deployment however international agencies like IEEE, IET, ITU and FCC are working on the standardization of 5G. The International Telecommunications Union (ITU) has lately start researches that outline stipulations for International Mobile Telecommunications (IMT) 2020. [6]

2.6 Need for 5G

According to studies, global mobile network traffic is set to boom, nearing about 100 Exabytes per month in 2023, having data flowing in from 31.6 billion mobile devices. This sudden growth in mobile data traffic and advancement in the latest technology is set to expand the mobile sector. With the advent of data explosion and booming IoT technology, the need for 5G has further intensified. The increasing penetration of mobile internet and exponential growth of the infotainment sector has created an extensive need for the data usage and thus we need a technology that supports the immense amount of device connectivity, with high data rate and low latency, thus 5G came into the picture [16].

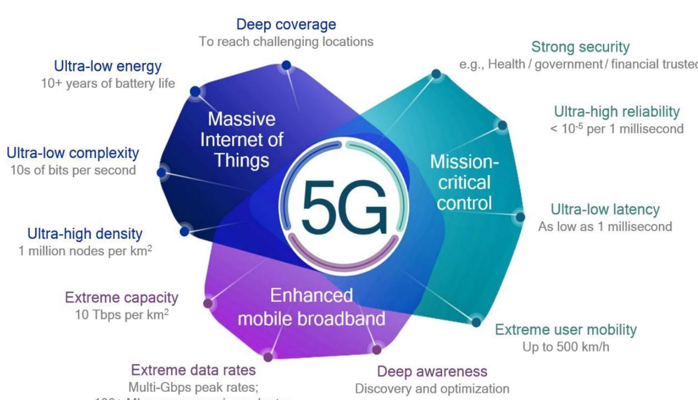

Fig. 5. What is 5G (Qualcomm technologies, Inc. September, 2016)

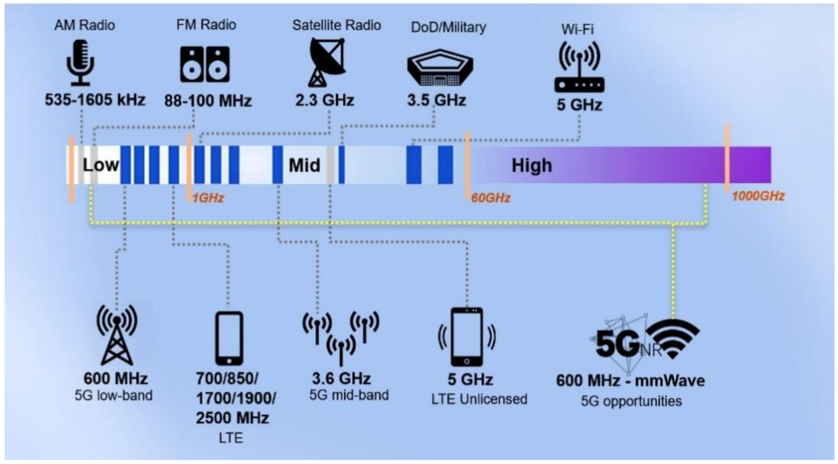

Fig. 6. 5G spectrum stack

The 5G NR radio design innovations across diverse services is shown in Fig. 7. Due to high speed, low latency and availability all the time, 5G finds applications in IoT, mission critical applications which require low latency, high reliability etc.

2.7 Enablers of 5G Technology

New technologies and computational techniques have evolved which enables the 5G implementation in real time, they are Densification, Software Defined Radio (SDN-NFV), Spectrum Reuse Efficiency, New Spectrum of mmwave, advanced modulation schemes, radio access techniques and distributed computing. The flexible air interface framework for 5G would enable efficient multiplexing of various 5G services and provides forward compatibility for future services. It also enables lower latency and scalability at much lower latencies compared to the existing LTE networks. The air interface framework for 5G new radio is shown in Fig.7.

2.7.1 Network slicing

Network slicing allows the creation of multiple logical networks on the top of a commonly shared physical infrastructure; thus network slicing allows the network operator to provide dedicated virtual networks which are particular to that specific service. By isolating the physical network, we can slice it into different virtual networks that support various multiple RANs (Radio Access Networks) which can include several service types working on that isolated RAN.

Fig. 7. 5G New radio [17]

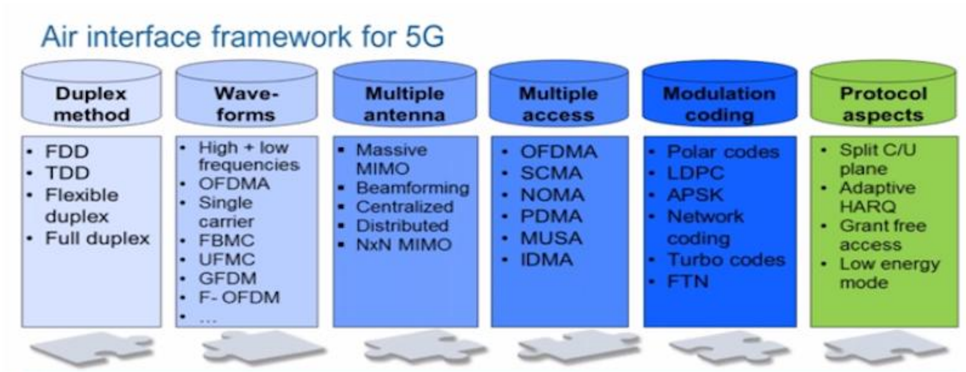

Fig. 8. Air Interface Framework 5G New Radio [18]

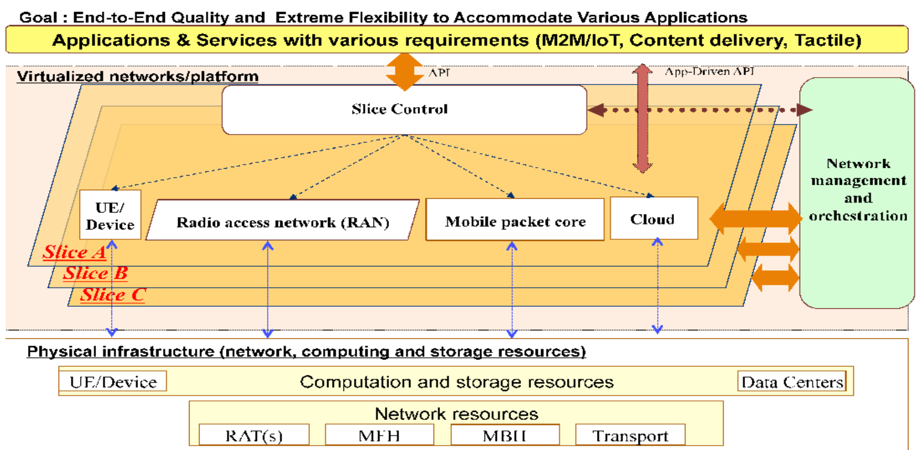

Fig. 9. Network slicing operation [19]

The network slicing operation can be done in two ways either Horizontal Slicing or Vertical Slicing. Horizontal Slicing is used when it has to provide the service within the sliced network and Vertical Slicing is used when the network has to provide the service to another sliced network.

The flexibility created by network slicing enables 5G, to optimize the infrastructures and the resources which consume greater energy and bandwidth, thus network slicing increases the cost efficiency when compared to the previous networks [16].

2.7.2 MIMO

Multiple-Input Multiple-Output wireless systems greatly exploits the concept of diversity to provide huge network capacity in terms of higher data throughput and higher number of users served. It is a wireless communication method where multiple transmitting and receiving antennas are used to improve the capacity of a link. It utilizes the concept of multipath propagation, where a single radio signal can reach the receiver via multiple different paths.

MIMO splits the signal into several sub-signals of low data rate, which are then transmitted via spatially separated antennas on the same frequency channel. Due to multipath propagation, they are received via different paths at the receiver. The receiver then separates these signals into parallel streams, which are then processed to recover the original signal.

MIMO significantly increases the channel capacity without any additional bandwidth and power consumption. It is possible to linearly increase the channel throughput with the addition of transmit and receive antenna pairs.

MIMO technology has been standardized for 4G mobile communication networks and they are now in commercial use. 4G-LTE has different MIMO schemes for uplink and downlink. LTE downlink schemes assume a 2x2 configuration as the baseline i.e., two transmit and two receive antennas. Each transmit antenna transmits a different data stream while each receive antenna can receive streams from all the transmit antennas, thus the Precoding of the streams before transmission results in spatial multiplexing.

There are two options here: SU-MIMO (Single user MIMO) and MU-MIMO (Multiple user MIMO). In SU-MIMO, the access point can use multiple spatial streams to send data to an individual client, while in MU-MIMO the access point can use multiple streams to send separate transmissions to distinct clients simultaneously.

5G mobile communication networks aim to improve the capacity of a channel beyond that of 4G-LTE. One of the solutions to this is Massive MIMO technology. This goes beyond the 2x2 configuration of conventional MIMO, using several simultaneous transmit and receive streams to improve network capacity. The larger antenna array used in Massive MIMO also improves spectral efficiency via better spatial multiplexing. Each antenna in the array will have its own RF and digital baseband chain, allowing for complete coherent digital signal processing of the received signals from all the antennas. This reduces the dependence of assumptions on the propagation channel and allows fast response to changes in the channel [21]

2.7.3 Beam forming

The main objective of beamforming is to reduce the interference and to identify the most effective and efficient data delivery path for a specific user. Hence beamforming can be considered as a traffic signaling system used in the cellular base stations. It can be implemented in many ways according to situations and conditions.

The Base Stations will have multiple arrays of antennas popularly termed as Massive MIMO (i.e. 62x62 Antenna Grid at present), which exploits the signal processing aspect to perform the detection and estimation of the arrival time and packet movement, which will allow the multiple users and antennas of Massive MIMO Array to communicate more information at a given point of time thus enhancing the concept of Beamforming.

Hence beamforming is useful as it mainly focuses on a signal which is pointing in the direction of the user that is a concentrated beam rather than broadcasting in all directions. This approach will condensate any chances of signal loss, multipath fading and reducing interference.

Millimeter waves will play a very crucial role in 5G mobile network, mmwaves are high-frequency waves which will provide the integration of mobile network infrastructure cells into smaller cell size, that will increase the scalability, capacity and density of that cell. This increase in benefits has a complex system design and higher loss criteria to deal with.

Another important feature of Massive MIMO systems is Beam Management Unit which deals with the following operations: Beam acquisition and tracking, Beam Refinement, Beam Feedback, Beam Switching, Maintenance and updating the Beam Index [22].

2.8 Performance Parameters and Its Evaluation

Several 5G parameters are considered for inspecting and monitoring the quality and performance of the networks.

2.9 Network Performance Parameters

Network performance refers to the analysis and review of certain attributes in a collective network that help in improving the service quality. The performance level of a given network can be measured using its qualitative and quantitative processes. We have experienced a subtle change in parameters from 4G to 5G which can be stated as.

2.10 QoS (Quality of Service) Parameters

QoS Parameters are used to obtain the overall performance of the network, Bit rate, IP packet loss, transmission delay, throughput and availability are the parameters under the measure.

IP Packet loss: ITU-T recommends that for 5G QoS packet-loss should be less than 1x10-5 for a large end-to-end QoE link [23].

Network Availability: Network Availability can determine the totally free time of a network which includes the network peripherals such as routers, multiplexers and switches. Contention Expected ratio: For 5G it will be around 50:1 [6].

2.11 Evaluation of Performance Parameters

Evaluation of any technology plays a very crucial role before implementing and maintaining the standard. Henceforth the performance parameters of 5G can be analyzed using the following simulation tools:

WiSE (Wireless Simulator Evolution): It is a dynamic system-level simulator used in the evaluation of 4G-LTE which has Beam Forming CSI-RS transmission, Class A Precoder-f and advanced CSI feedback. It has been validated with the 3GPP calibration [24].

NS3 Network Simulator: mmwave model for 5G network simulation using Evolved Packet Core (EPC) is written in open source network simulators such as C++ or Python using OOPS method which provides support for TDD and OFDM.

Opnet Simulator: This simulation tool analyses the behavior and performance of any given network. It is an event driven simulator that uses LTE-A model along with IEEE 802.15c standard. [6]

2.12 Spectrum Usage and Challenges

This section deals with the spectrum usage in 5G and the challenges that are faced in implementing 5G.

2.12.1 Spectrum bandwidth

The New Radio 5G technology will operate in 6 GHz frequency range. We know that as the radio frequency increases the distance travelled by the radio wave decreases. The problem of sending and receiving the signals in the old radio frequency is tedious as the frequency ranges are very congested. Thus we need a new radio frequency range to operate with, this new frequency range can be harnessed from millimeter range. That is why 5G is called as New Radio. The 5G network cells provide very high bandwidth, but the coverage area is reduced when compared to that of 4G, this is because the radio frequency increases as the distance travelled by the millimeter wave decreases. Thus, 5G technology may require the deployment of more number of smaller base stations per cell area. The average coverage of 5G will come up to 300 meters in the outdoors and as low as 2 meters indoors.

2.12.2 Frequency bands allotted by CCITT

The initial 3GPP 5G standard will be submitted as a candidate for IMT-2020 and it will comprise several different technologies. This includes 5G New Radio (NR) which supports existing mobile bands as well as new wider 5G bands. It will support channel sizes ranging from 5 MHz to 100 MHz for bands below 6 GHz range, and channel sizes from 50 MHz to 400 MHz in bands above 24 GHz range. The ITU's minimum technical requirements to meet the IMT-2020 criteria – has specified at least 100 MHz channels per operator. They have also specified the support up to 1 GHz per operator in bands above 6 GHz range.

There are more than 50 frequency bands that are below 3.6 GHz range in the current LTE system. For the 5G FR-1 [NSAN] (Not Stand Alone Network), the frequency used for early deployment is sub-6 GHz range i.e. (between 3.5GHz and 6 GHz range) which is an unlicensed spectrum that will be used for the first generation of 5G networks. 5G FR-2 [SAN] (Stand Alone Network) will operate on 28.6GHz range (pure millimeter waves technology) the design of hardware at millimeter waves is much complex [25].

2.12.3 Spectrum management issues

Safety of life radio communications, radio navigation, aeronautical mobile and satellite services: Implementation of access devices using dynamic 5G spectrum in the frequency bands which are employed for the applications involving the safety of life will threaten the safe of aviation and maritime services.

Mobile-Satellite and Radio determination Satellite Service (both uplink and downlink): Bands which are allocated in the direction of the earth to space in order to protect the links involve MSS or RDSS, the permissible interference is monitored by the satellite receiver.

Earth exploration: The 5G will provide active and passive satellite services along with radio astronomy services making use of DSA System. This system is used to stop over emissions and avoid interference with sensors [27].

2.12.4 5G spectrum management in India

The spectrum allocation in the Indian cellular market lies within 700 MHz and 2.6 GHz. In

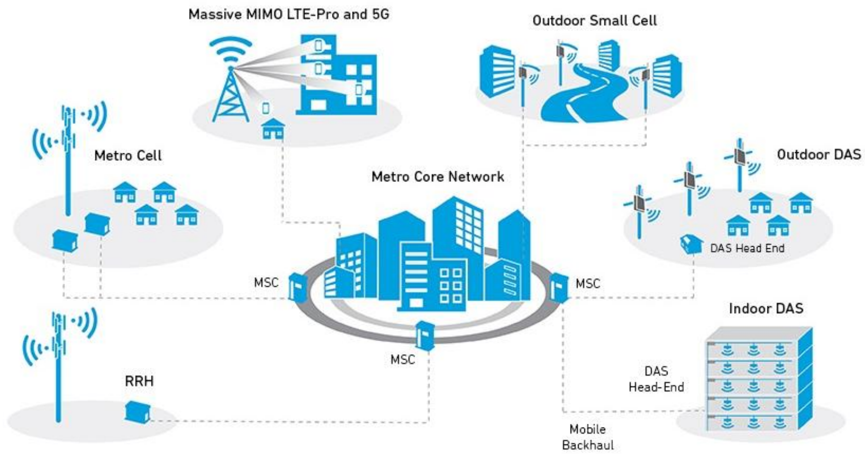

Fig. 10. Massive MIMO use case [20]

Fig. 11. Spectrum bands allocated for 5G [26]

Table 1. Changes in network parameters from 4G to 5G

Parameters	4G LTE	5G
Data rates	500 Mbps in 4G	1-10Gbps in 5G
Capacity	100s GB/user	36TB/user
Latency	About 10ms	About 1ms
Frequency Bands	700-2100 MHz	28-40 GHz
Spectral Efficiency(DL)	15 bps/Hz	30 bps/Hz

India, they are planning to launch a 5G FR-1 [NSAN] (Not Stand Alone Network) in 2020 which will operate in sub 6 GHz frequency range i.e. between 3.5 GHz to 6 GHz range, which will be compatible with the present 4G technology which is operating in 2.3 GHz range. Indian global coordinating organizations for 3GPP are COAI and TSDSI.

Once the first phase of 5G will be implemented successfully, then the pure millimeter waves technology will be deployed which will be 5G FR-2 [SAN] (Stand Alone Network) which will operate on 28.6 GHz frequency range [28].

3. CONCLUSION

In this paper, we have delineated all the critical aspects of 5G technology, and we have presented the insight into the steps and challenges involved in its standardizing process. Numerous conglomerates have executed many considerable prototype working models in order to hasten the process of launching this 5G standard, studying the drivers and deploying the developing technologies. We have also brought the picture of various spectrum requirements and usages and how far it has been utilized. With a high data rate, large coverage, low latency, high device connectivity commercial launch of 5G technology in India is expected in 2022 and this makes room for the challenges on which there is scope for further development in 5G Technology.

3.1 Future Directions and Perspectives

Future 5G infrastructure would be modular, software driven, software agnostic, virtualized and sliced. Though there are lot of challenges in implementing, plenty of opportunities are also available. 5G is driven by three broad requirements, enhanced mobile broadband devices, massive IoT devices, and ultra-reliable low latency devices, which have the capability of connecting more and more IoT devices in the healthcare sector, smart agriculture, transportation, and Smart City solutions for sustainable future.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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