5G Network: Architecture, Protocols, Challenges and Opportunities

Iqra Javid
Department of Electrical, Electronics and Communication Engineering
Sharda University, Greater Noida, India

Sibaram khara
Department of Electrical, Electronics and Communication Engineering
Sharda University, Greater Noida, India

2022 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS) | 978-1-6654-6200-6/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICCCIS56430.2022.10037605

***Abstract*—The 5th Generation system is being established to give unmatched connectivity that will connect anything anywhere. 5G networks are designed to deliver high-speed, reduced latency for increased mobile broadband, large machine-to-machine communication and real-time applications. High data rates, high coverage, high reliability, cost-effectiveness are all advantages of 5G. This article discusses architecture, protocols, enabling technologies like mmWave, massive multi-input-multi-output, heterogeneous network, application areas of 5G and challenges in the 5G network.**

Keywords*—*5G, MIMO, Beam-forming, Millimeter wave, Latency

I. INTRODUCTION

Developments in communication technology have significant impact on all other dimensions of development being done by humans. High-speed Internet access and greater data rates are in high demand and have advanced significantly over the last decade. This also plays a significant role in the world's smart economic development and digitalization. Virtual reality, IoT, and cloud-based services have evolved in recent years and have become a vital part of the new generation's routine. Every day, nearly 40 Exabytes of data are transferred over the internet [1]. According to a recent study, every third person uses more than two internet-connected devices on an average [2]. This massive amount of data is generally associated with the increased usage of internet-connected smart gadgets. Existing technologies like 3G and 4G are unable to satisfy the demands, and they are not suitable for LPWA (low-power wide-area) technology. With the transition from 1G to 4G, there has been significant advancement in wireless communication over the last three decades.

The New Radio (NR) standard supports milli-metre wave communication and antenna arrays for MIMO systems, with modifications at the radio layer [3]. The 5GC (5G core network) has been rebuilt to provide service adaptability and flexibility. This technology offers ultra-low latency and ultra-high dependability, paving the way for new services in a wide range of industries.

International Telecommunication Union (ITU) standards have been used to identify 5G application services. Some of the services provided include eMBB (Enhanced Mobile Broadband), mMTC (massive Machine Type Communication), URLLC (Ultra-Reliable Low- Latency Communication)[4]. The eMBB is expected to address common end-user requests, such as increased bandwidth for Internet access for online surfing, virtual reality, and HD video streaming. Smart cities, sensor networks, actuators, electrical appliances, street lights, smart agriculture, and other equipment would all be connected to the Internet and each other via mMTC.

In March 2018, the 3GPP released 15th release of mobile communication system standards, forming the basis for the 5G (5th generation). The core network of 5G is based on the Release 15 edition of 3GPP specifications, and is established commercially around the world at sub-6 GHz and millimeter wave frequencies. The second phase of 5G is based on the Release 16 version of the 3GPP specifications. Release-16 focuses on URLLC and Industrial IoT, such as time dependent communication, updated Location Services, massive MIMO, whereas Release-15 focused on improved mobile broadband services. 5G Evolution mainly concentrates on three primary areas i.e. improvements to features introduced in Release-15 and Release-16, operational upgrades, and new features to broaden the 5G System's applicability to new markets and use cases.

The minimum and maximum data rate of 100 Mbps and 20 Gbps should be expected for each user [5]. According to the ITU's radio communication International Mobile Telecommunications (IMT) 2020 vision, each 5G network must have at least 800 MHz spectrum. Fig. 1 shows the three segments of the 5G frequency spectrum. [6].

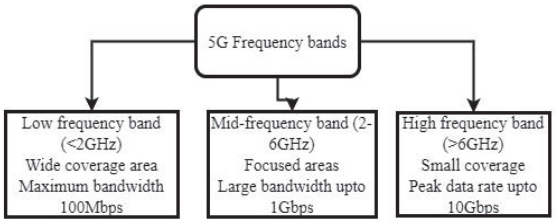

Fig. 1. 5G frequency spectrum

Many industries will get benefited from 5G and will boost Mobile Edge Computing applications. To meet the needs of mobile phone users and vertical sectors, 5G will require more spectrum (licensed and unlicensed).

With the emergence of new wireless generations, underlying technology has always been changed and the speed for data transmission is enhanced. A comparison study of three popular generations i.e. 3G, 4G and 5G is done and is presented in table (1).

Table 1. Comparison of 3G, 4G and 5G technology.

PROPERTY	**3G**	**4G**	**5G**
Frequency	1.6-2GHz	2-8GHz	3-10GHz
Bandwidth	25MHz	100MHz	30-300GHz
Bit rate	8Mbps	50Mbps	10Gbps
Types of traffic support	Voice, Data	Voice, Mobile broadband services	Voice, Data, Real time services
Spectral Efficiency	0.8 bits/Hz	1.9 bits/Hz	2.84 bits/Hz
Access System	CDMA	CDMA	OFDM/ BDMA
Core Network	Packet Network	Internet	Internet
Mobility speed	384kbps	100mbps	10gbps
Latency	100-500ms	10-20ms	<1ms
Architecture		MIMO	Massive MIMO
Real time applications	Not Supported	Not Supported	Supported

II. ARCHITECTURE OF 5G

The Access Plane, Control Plane, and Forwarding Plane make up 5G logical network architecture. Access plane contains different types of BSs and access devices. Between BSs and wireless devices, there is more interaction and a richer networking topology resulting in better resource usage. Control plane is responsible for overall network's global control strategy. The traffic from devices is forwarded via forwarding plane. Fig. 2 shows Service based architecture (SBA) of 5G [7].

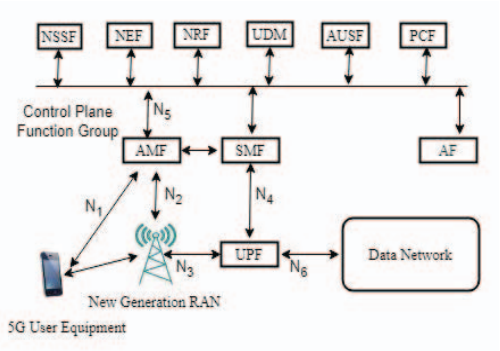

Fig. 2. Service based architecture of 5G

User equipment can be any device or sensor that is 5G compatible. Frequency bands are provided by new generation Radio Access network (NG-RAN). This NG- RAN is linked with access and mobility function (AMF) via interface N_2 and User plane function (UPF) via N_3 whose main function is forwarding and routing which in turn is connected with the SMF (Session Management Function) and data network via N_4 and N_5 interfaces. SMF creates updates and removes sessions. It also manages session context with UPF and allocation of IP address. AMF is responsible for access control, registration, mobility management and is connected to the control plane via N_5 interface. NSSF selects network slice instances for the user equipment. NEF securely opens the network to the third part applications. NRF maintains the updated records of services that are provided by other network functions. UDM generates authentication credentials and authorizes access that is based on subscription data. AUSF is responsible for 3GPP access and non-3GPP access. Policy rules for control plane are framed by PCF. AF interfaces with 3GPP core network for traffic routing, policy framework interactions and so on.

From infrastructure perspective the access network, metropolitan area network, and backbone network constitute a 5G network as shown in fig. 3. Control functions include core network and access network control function. Core network control functions are placed centrally within the metropolitan area network and backbone network for low latency and high reliability, while the access network control functions are placed at the edge of the mobile network or incorporated into the BS.

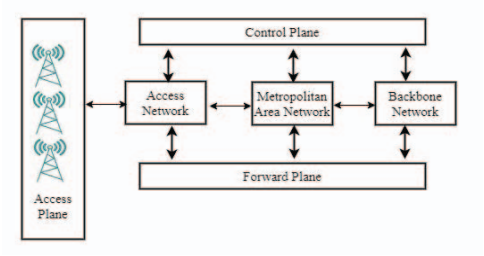

Fig. 3. 5G network

III. PROTOCOLS

In user equipment plane 5G contains physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP) layers same as LTE. New layer has been added i.e. service data adaption protocol (SDAP) and is present between radio resource control (RRC) and PDCP. In the 5G architecture next generation NodeB (gNB) between Central Units (CUs) and Distributed Units (DUs) allows dynamic adaptation of QoS functions and is based on real-time radio conditions, user density, and a dynamically controlled geographical area. CU covers higher layer protocol functions such as SDAP and PDCP, while DU covers lower layer protocol functions such as RLC, MAC, and PHY. The CUs are arranged in a computing hardware pool. The gNBs are linked together using an X_n interface. Fig. 4. shows the protocol stack for 5G

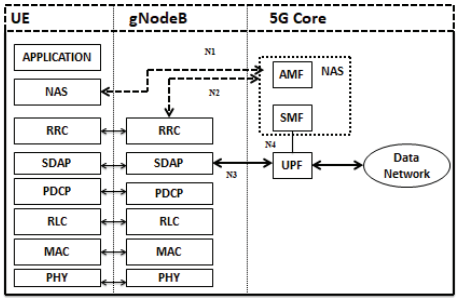

Fig. 4. Protocol stack for 5G

The main function of SDAP layer is to maintain the Quality of service (QoS). Physical layer involves aspects that are relevant to the communication channel between user equipment such as modulation-demodulation of physical channels, error detection, frequency and time synchronization. MAC layer prioritizes hybrid automated retransmission requests i.e. error correction. RLC organizes and retransmits the data. PDCP is based on LTE. RRC is used to exchange control information with the devices to set useful parameters for the session. Network attached storage (NAS) makes stored data more accessible to networked devices.

IV. ENABLING TECHNOLOGIES AND FEATURES

5G technology is enabled by a few key enablers. Each enabler has its own set of characteristics. Some of the key enablers are given in fig. 5.

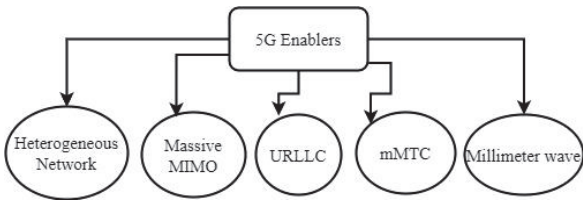

Fig.5. Enablers of 5G

A. *Heterogeneous network:*

Het-Nets integrate different cell types and access methods. A Femto-cell BS connects a variety of devices to cover several small subsets of macro BS. More research on implementing this network to increase the QoS to end users and minimize the interference is required [8]

B. *Massive MIMO (Multi-Input Multi-Output):*

Massive MIMO uses the beam-forming technology to increase data rates while reducing interference. It is achieved by using large-scale, sophisticated antenna arrays that can be modified vertically and horizontally in terms of breadth and tilt. Beam-forming is a spatial filtering approach that tries to promote system security while improving spectral and energy efficiency [9].

C. *URLLC:*

The primary aspect of 5G is its ultra-low latency (< 1 ms) [10] and also increasing the bandwidth of radio resource blocks in which a certain quantity of data is delivered. This can also eliminate radio transmitterqueuing delays.

D. *mMTC:*

The mMTC platform is designed to accommodate new IoT-based services and applications [11]. With the eventual adoption of 5G, mMTC will not only support the IoT concept, but can also provide an unprecedented opportunity to innovate with the Internet of Everything (IoE).

E. *mmWave:*

Many researches have looked towards mm-Wave as a solution for tackling spectrum scarcity difficulties in order to realize 5G architecture. The mm-Wave band spans 30 GHz to 300 GHz [12]. Because of its short wavelength, it can only travel over a few hundred meters and is readily obstructed by any barrier in its route. This feature, on the other hand, is useful for object imaging and short-range networking.

Some of the features of 5G network are discussed below:

a) Small Cell:

These are low-power base stations that serve a limited geographic area (10m to few kms). These cells provide a number of advantages, including the ability to operate at minimal power and at high data speeds. For high-speed data transmission, small cells utilise innovative techniques including MIMO, beamforming, and mmWave. Small cell hardware is designed to be simple, making implementation quicker and faster. The different types of small cell towers include femtocells, picocells, and microcells. MmWave provides ultra-wide bandwidth and has many benefits, but has some drawbacks too. These signals are very high-frequency signals and collide with obstructions in the air more frequently, causing the signals to lose energy quickly. They are also obstructed by buildings and trees, resulting in a lower range. Various small cell stations are placed to bridge the gap between the end-user and the base station to address these concerns. Since a small cell has a relatively short range, its installation is dependent on the population of a certain area.

b) Beam-forming:

Beamforming is a major wireless network technique that sends signals in a directional manner. Using 5G beamforming, a robust network can be formed and the efficiency can be improved. Analog Beamforming is used to increase the coverage area. One beam is created per set of antennas in digital beamforming. Analog beamforming reduces pathloss. Both digital and analog constitute hybrid beamforming [13]. The signals in 4G wireless network are dispersed over broad regions. As a result, users seeking to access these signals have interference problems and energy soon runs out. The beamforming technology is used in the 5G network to address this issue. Signals appear to travel in an unseen cable like laser from base station to user. It helps to attain a faster data rate while consuming less energy and causing less interference.

c) Mobile Edge Computing:

MEC is a type of cloud computing that extends the reach of cloud resources to the end-user. This boosts cloud computing performance, and services such as video conferencing, virtual software, and so on. MEC is differentiated in two parts. The Ist part exists on a cloud server and 2nd part is available on user device. User does not need to download the entire application on device, which in turn improves the device's speed [14].

d) 5G Security:

The significant aspect in the telecommunication network sector is security, and it's required at multiple layers to manage 5G network applications like IoT, digital forensics, and intrusion detection systems. 5G employs the 5G Authentication and Key Agreement (AKA) authentication mechanism that provides a mutual authentication process between UE and its home network by sharing a cryptographic key [15]. In order to restrict network accessibility, 5G provides access control measures to establish a safe environment and is regulated by network providers. To authenticate access Simple public key infrastructure (PKI) certificates are used. The primary focus is secure communication, and attackers are primarily focused on user equipment, mobile carriers, core networks, and access networks. Encryption techniques are used to ensure the users and network'sprivacy.

V. APPLICATIONS

5G is high speed network and has a maximum down- link throughput upto 20Gbps. It supports the 4th Generation World Wide Wireless Web and is built on IPv6 and functions in the same way as that of optic fiber internet connection.

5G plays a significant role in establishing IoT. Appliances, sensors, devices can be linked to the internet through IoT. These days, smart home appliances and devices are in high demand. Owing to high-speed communication the 5G network brings smart homes closer to reality. The 5G network also aids in the development of smart city applications such as automated traffic management, local area broadcasting, efficient power supply, smart lighting, energy conservation, water resource management, weather updates, crowd management, and emergency control and so on.

5G technology will considerably benefit agriculture and smart farming. Farmers can track and manage live crop attacks using 5G sensors and GPS technologies. Irrigation, pest, bug, and electrical control are all possible applications for these smart sensors.

All classrooms can be connected via the 5G network, which will make it easier to participate in seminars and lectures. Patients can use 5G technology to communicate with doctors and receive advice. As a result of technological advancements, the doctors and practitioners can execute innovative medical operations. To help patients with chronic medical conditions, scientists are creating smart medical gadgets. Cloud storage will be simpler to access with 5G, enabling global access to healthcare data. Doctors and other healthcare professionals may quickly store and transfer large information, including MRI findings within seconds.

VI. CHALLENGES AND OPPORTUNITIES

5G efficiently provides voice and high-speed data access. Small cells will bring new benefits to mission-critical applications such as excellent coverage, power savings, easy cloud access, high-speed data transmission. It can be widely used in technologies and applications that can be used in the fields of healthcare, transportation and energy. Therefore, 5G network can widen the opportunities in different areas. The network system is rapidly evolving. Problems and solutions must be addressed in accordance with 5G rollout, which promises network enhancements for IoE- enabled services. 5G enables new services, applications and new mobile experiences. With these new applications and services various demands on the network like latency, throughput, capacity, and availability had increased. Heterogeneous devices and the necessity for high-capacity data transmission have resulted in dense regions. Due to this multi-user interference, security issues, and service degradation occurs. Moreover, the demand for big bandwidth by various devices results in a scarcity of spectrum.

VII. CONCLUSION AND FUTURE SCOPE

5G is more than just a mobile broadband network unlike earlier generations of mobile networks. It is a milestone in communication technology with this many sectors will get a boost. In this paper we have discussed architecture, protocols, enabling technologies and key features related to 5G technology. 5G will act asa catalyst in the process of technological development and will have significant impact on human‟s duly routine.

Multi-user interference is a severe problem in dense networks, especially in licensed bands. As the number of networks, devices, and data traffic grows worldwide, so does the amount of pollution produced. As a result, the ICT industry's energy usage is seen as one among the most serious global environmental problem. New approaches to wireless communication networks are required to reduce energy usage and CO_2 emissions globally. Spectrum efficiency is improved by multi-hop communication and it adds significant switching time. 5G wireless networks will not be able to meet the expectations due to significant rise of centralized data and autonomous industry in the future. As a result new wireless network technology known as 6G will push mobile generations to new levels. 6G wireless networks will have bit rate of around 1 Tbps per-user and can deliver wireless connectivity that is 1000 times quicker than 5G networks.

References

[1] Z. D. Stephens et al., „„Big data: Astronomical or genomical?“‟ PLoS Biol., vol. 13, no. 7, p. e1002195, 2015.

[2] M. Amadeo et al., „„Information-centric networking for the Internet of Things: Challenges and opportunities,“‟ IEEE Netw., vol. 30, no. 2, pp. 92–100, Mar./Apr. 2016.

[3] A. L. Swindlehurst, E. Ayanoglu, P. Heydari,and F. Capolino, „„Millimeterwave massive MIMO: The next wireless revolution?“‟ IEEE Commun. Mag., vol. 52,no. 9, pp. 56–62, Sep. 2014.

[4] E. Dahlman, G. Mildh, S. Parkvall, J. Peisa, J. Sachs, Y. Selén, and J. Sköld, „„5G wireless access:Requirements and realization,“‟ IEEE Commun. Mag.,vol. 52, no. 12, pp. 42–47, Dec. 2014.

[5] M. Nekovee, Opportunities and Enabling Technologies for 5G and Beyond-5G Spectrum Sharing. Singapore: Springer, 2018, pp. 1–15.

[6] W. S. H. M. W. Ahmad, N. A. M. Radzi, F. Samidi, A. Ismail, F. Abdullah, M. Z. Jamaludin, and M. Zakaria, “5G technology: Towards Dynamic Spectrum Sharing using Cognitive Radio Networks,” IEEE Access, vol. 8, pp. 14460–14488, 2020.

[7] Y.B.Lin, C.C.Tseng and M.H.Wang, “Effects of Transport Network Slicing on 5G applications” Future Internet 13.3 (2021): 69

[8] U. Siddique, H. Tabassum, E. Hossain, and D. I. Kim, “Wireless backhauling of 5G small cells: Challenges and solution approaches,“‟ IEEE Wireless Commun., vol. 22, no. 5, pp. 22–31, Oct. 2015

[9] M. A. Albreem, A. H. A. Habbash, A. M. Abu-Hudrouss and S. S. Ikki, "Overview of PrecodingTechniques for Massive MIMO," in *IEEE Access*, vol. 9, pp. 60764-60801, 2021

[10] R. Ali, Y. B. Zikria, A. K. Bashir, S. Garg andH. S. Kim, "URLLC for 5G and Beyond: Requirements, Enabling Incumbent Technologies and Network Intelligence," in *IEEE Access*, vol. 9, pp. 67064-67095, 2021

[11] S. R. Pokhrel, J. Ding, J. Park, O. -S. Park and J. Choi, "Towards Enabling Critical mMTC: A Review of URLLC Within mMTC," in *IEEE Access*, vol. 8, pp. 131796-131813, 2020

[12] C. Seker, M. T. Güneser and T. Ozturk, "A Review of Millimeter Wave Communication for 5G," *2018 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 2018, pp. 1-5,

[13] G. Barb, M. Otesteanu, F. Alexa and A. Ghiulai, "Digital Beamforming Techniques for Future Communications Systems," 2020 12th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), 2020, pp. 1-4.

[14] N. Hassan, K. -L. A. Yau and C. Wu, "Edge Computing in 5G: A Review," in IEEE Access, vol. 7, pp. 127276-127289, 2019.

[15] Q. Tang, O. Ermis, C. D. Nguyen, A. D. Oliveira and A. Hirtzig, "A Systematic Analysis of 5G Networks With a Focus on 5G Core Security," in IEEE Access, vol. 10, pp. 18298-18319, 2022,