A survey on key enabling technologies towards 5G

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Abstract. Recently the market has been hit with 5G innovations and ceramic materials are an integral aspect of its technical growth. Since the number of users is increasing day by day, a high data rate and improved spectral efficiency become the prime need of today’s wireless networks. 5G is an end-to-end network that provides improved data capacity, high-performance broadcast services, low latency, and can support millions of connected devices. The fifth-generation network claims to satisfy the tremendous demands of the growing number of users by using cutting edge technologies. Different characteristics of 5G mobile communication technology and its key requirements as given by its basis ITU (International Telecommunication Union) have been explored. This paper discusses the basic understanding of the key enabling technologies of the 5G network. Furthermore, it also focuses on the different applications of 5G wireless communication and throws light upon the challenges which are lying ahead in the development of the 5G era.

Keywords— Cutting edge technologies, D2D communication, 5G networks, energy efficiency, 5G materials

1. Introduction
A variety of new technologies, including IoT, smart grids, and AR/VR are projected to be provided in the framework of 5G networks. The introduction of several new technologies, advancements in digital modulations, and frequency re-use schemes have gradually led to the development of the mobile wireless industry [1]. While the companies are ready to experience the digital transformation process, the lucrative 5G industry is developing high-performance components to enhance reliable implementation. Managing extremely hot pressures inside the small encapsulated devices and providing good performance at low power have become the crucial challenges for electronic manufacturers. The commonly used material for producing 5G antennas are ceramic materials, barium carbonate, silicon dioxide, yttrium dioxide. The use of high-performance materials will overcome these obstacles. All these raw materials are taken in stoichiometric ratios to impart the desired performance.

The mobile communication technology changes its generation almost every decade. In 1980 mobile communication started with 1G and now in 2020, it has reached up to 5G. Every generation has observed new and improved features and better performance. Earlier generations mainly focused on telephone, mobile Internet, and simple file exchanges. But 5G will create a huge difference because it includes a wider range of applications and use cases that are going to be addressed [2]. The specifications issued by ITU are mentioned in International Mobile Telecommunications (IMT). The IMT covers the requirements and key performance index of each mobile network generation in IMT-2000, IMT-Advanced, and IMT-2020.
The 3rd Generation Partnership Project (3GPP) lists requirements for the development of 5G networks and is responsible for producing, regulating, and profiting the markets. 3GPP has defined key requirement related to the minimum requirement of 5G and categorized its diverse services in three usage scenarios, enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable and low-latency communications (URLLC) [2].

First scenario Enhanced Mobile Broadband (eMBB) characterizes higher data rates, improved latency, higher user density, and their traffic capacity for endless coverage and hotspots. Second scenario Massive Machine-type Communications (mMTC) deals with an area where power consumption and data rates are low and numbers of devices connected simultaneously are more. Third scenario Ultra-reliable and Low Latency Communications (URLLC) includes those applications which deal in safety-critical and mission-critical communications such as car automation, factory automation and remote-controlled surgery where responsiveness and reliability is required [3].

The 4G networking infrastructure is eventually inadequate to meet people’s increasing need for information transmission, and 5G technology is known for its reliability, timeliness, wide bandwidth, and information processing capacity for massive machines. There have been several improvements in 5G over 4G authentications[4]. The management models explain the logic behind how companies build, execute, and catch their worth. There is a huge impact of 5G technologies on such models[5],[6],[7].

5G aims to provide complete wireless networking with no limitation and numerous applications. 5G is a revolutionary stage of generations of wireless technology which will be able to support 1,000 times higher traffic volumes than previous traffic levels, according to ITU report of minimum technical performance requirement 20Gbps and 10Gbps are the minimum requirement for peak data date by downlink and uplink respectively. Minimum user experienced data rates are 100Mbps and 50Mbps for downlink and uplink respectively. Latency should be 4ms for eMBB, 1ms for URLLC, and 20ms for control plane latency [8].

Table 1 given below depicts the key differences between LTE and 5G NR based on the 3GPP standards.

| Parameter               | LTE                        | 5G NR                              |
|-------------------------|----------------------------|------------------------------------|
| Operating Frequency     | ≤ 6 GHz                    | ≤6 GHz, 28 GHz, 39 GHz, upto 52 GHz|
| Bandwidth support       | ≤ 20 MHz                   | ≤ 100 MHz (<6 GHz), ≤1 GHz (> 6 GHz) |
| Carrier Aggregation     | ≤ 32                       | ≤ 16                               |
| Analog Beamforming      | Not supported              | supported                          |
| Digital Beamforming     | supported upto 8 layers    | upto 12 layers                     |
| Channel Coding          | Data: Turbo, Control:Convolutional | Data: LDPC, Control: Polar |
| Subcarrier Spacing      | 15 kHz (fixed)             | ranges[15 kHz - 240 kHz]          |
| Introduced (year)       | 2009                       | 2020                               |
| Internet Service        | Ultra broadband            | Wireless World Wide Web            |

This paper is divided into 6 sections. In section II, the characteristics of 5G are discussed along with its use-cases. An overview of different 5G technologies is discussed in Section III of this paper. Next, the applications of 5G are investigated in Section IV. Finally, the upcoming challenges of 5G networks are discussed in Section V. Then, the last section of the paper provides the concluding remarks.
2. Characteristics of 5G Network

Internet traffic is increasing per day so 5G supports 1000 times more traffic. 5G is capable of providing an ultra-high-speed of approximately 10-20 Gbps. System capacity has increased 1000 times. Several connected devices have increased 10 to 100 times to support the Internet of things (IoT) or other connection-based applications. The spectral efficiency is expected to get increased by three times. For low power Massive Machine Communication (MMC) devices battery life extension is 10 times the earlier battery life. According to the International Telecommunication Union (ITU), latency will get decreased by almost 10 times and End-to-End (E2E) latency will get reduced by 5 times. Network efficiency is supposed to increase 100 folds and the 10 times increase in connection density can be expected when 5G comes in practice. As 5G is based on Software-defined networking (SDN) that is it is software-oriented so low maintenance cost will be required. It can integrate with previous and current cellular and Wi-Fi standards. Flexible bandwidth allocation and spectrum management scheme are the key features of 5G [3]. To meet such demands, drastic improvements need to be made in cellular network architecture [9].

Figure 1 given below illustrates the features of 5G networks.

![Figure 1. Features of 5G technology.](image)

3. Enabling technologies in 5G

5G mobile networks are far beyond the 4G cellular networks. These Next-Generation Mobile Networks Alliance provides significantly higher capacity and supports different types of emerging
applications that have stringent Quality of Service (QoS) requirements. This section describes the 5G enabling technologies that optimize spectral efficiency and enhance privacy as mentioned in Figure 2. The key technologies are described below as:

(i) **Millimeter Waves**: As several users are crowding the network day by day and their requirements for data rates and traffic are increasing. Spectral efficiency and bandwidth utilization are the main characteristics for increasing the capacity of the network to meet the requirements of congested traffic. The existing band of frequency on which all wireless communication is operated is between 300Mhz to 3Ghz. This band of frequency is also called sweet spot [10]. This band needs to be enhanced to meet the requirements so the Next-generation is exploring an unused band of frequencies ranging from 3-300Ghz. Frequency bands 57-64GHZ and 164-224GHZ are unavailable for communication [1]. In physics the waves with frequency 3-300 GHz is called millimeter-wave because their wavelength ranging from 1mm to 10mm. This new spectrum can support thousands of times of more data and enhance capacity as compared to the current spectrum. This high frequency, short-wavelength waves can transfer data at much higher rates to short distances. Millimeter-wave on one side opens a new horizon to meet demands of upcoming traffic explosion, on the other hand, raises many challenges like it is a disadvantage of millimeter-wave that they can pass by buildings and can be absorbed by plants and raindrops. However, this drawback can be solved by using small cells.

![Figure 2. Key enabling technologies of 5G network.](image-url)

(ii) **Small Cells**: Small cells are minified base stations placed 250 meters or more distant apart, require less power to operate. They are used to extend network coverage and capacity indoor or outdoor by mobile operators. The small cell may compose of femtocell, picocell, and microcell. As millimeter waves cannot travel larger distance so small cells are used to act as a relay. Small cells reduce call drop problems and help in fast switching but require security as data relaying is a threat to data security. By deploying thousands of low power mini base stations, assembled closely forming a team to transmit signals around the obstacles. This can allow users to receive signals continuously without having path loss to be occurred. This way cost and energy consumed by the retransmission process will be saved. Moreover, the device closed to small cell base stations will transmit a low power level which also lowers the power out of cell phones thereby increasing battery life.

(iii) **Advanced Massive MIMO**: Using advanced massive MIMO, the spectrum efficiency can be improved and the data rate also gets enhanced. MIMO refers to multiple-input and multiple-output. The network capacity of any wireless system can be improved by increasing
the number of transmitting and receiving antennas to the system. To handle large amount of data traffic, multiple transmission and receiving antennas can be used simultaneously. In 4G network, the number of ports on a base station for handling cellular traffic is twelve (MIMO). Out of 12, eight are for transmission and four are for the reception. In 5G this number grows to about 100 ports in a base station which makes it massive MIMO.

(iv) **Beam forming**: In the conventional cellular systems, the base stations transmit signal in all the directions but in the beamforming concept, it detects the User Equipment (UE) and transmit signals only in the direction of the user. With this concept of beamforming, base stations become more efficient in tracking the most optimal route of data-delivery to a particular user. It not only reduces interference and distortion but also enhances the reliability of the transmitted signal. Beamforming facilitates massive MIMO in making the right decision of choosing the correct path for transmission this way spectrum is also efficiently utilized.

(v) **NOMA**: NOMA stands for non-orthogonal multiple access. It is a technique in which multiple users are served by using the same time and frequency resources but different power resources. Multiplexing of the same frequency is done with different power transmission levels. Power domain is used for multiple access, unlike previous generations where FDMA, TDMA, CDMA, OFDMA domains are used for serving multiple users in 1G, 2G, 3G, 4G respectively. NOMA helps in increasing spectral efficiency and connection density. It also provides flexibility between the weak and strong user, along with this it also reduces multiple access interference [11].

(vi) **SDN**: Software Defined Network (SDN) allows the network operators to manage the network and control them with the help of programming by software application support. The network becomes more intelligent and can easily be automated. In SDN, the data and control planes are decoupled as mentioned in the SBA architecture of 5G.

(vii) **NFV**: Network function is the functional building block in a network system with multiple proprietary hardware devices. These hardware devices provide external interfaces and various functionalities. But the network functions are purpose-built physically installed which makes it difficult to upgrade after changes. Every time a new network function is to be added to the service, it creates an overhead to make changes in the whole interface. So, there is a new way of dealing with such changes through the network function virtualization (NFV). In simple words, NFV refers to the decoupling of network functions from hardware-based components like routers, load balances, firewall and moving these functions to run on cloud-based infrastructure or servers. This transforms the network management and service delivery operations. All the appliances in the network are virtualizing. The key benefits of NFV include simplification of network function, its installation, and upgradation. It is cost-effective as expensive hardware are replaced by cloud-based functions like switches, storage, and servers which are inexpensive.

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![Figure 3.](image-url) **Figure 3.** Figure depicting the types of D2D communication.

(viii) **D2D communication**: Device to Device (D2D) communication is determined as the communication between two nearby mobile users without connecting to the Base Station
or the core network in cellular networks. Here, the signals are transmitting without the involvement of the base station. With direct device to device communication, the burden on the base station gets reduced. The maximum transmission distance in D2D is in the range of 10-1000m. It offers a data rate of about 1 Gbps. The D2D communication is mainly classified into two major categories such as Inband and Outband as mentioned in Figure 3. Inband, as the name suggests operates in the band allocated to cellular network i.e. licensed radio spectrum. On the other hand, Outband operates outside the band allocated to cellular network i.e. unlicensed spectrum. Licensed or Inband spectrum is further categorized into overlay and underlay mode. In the overlay mode, there are separate dedicated frequency resources both for cellular users and D2D users. In underlay mode, there are common resources that are shared with cellular and D2D users. Unlicensed or outband spectrum is further categorized into controlled and autonomous modes. In controlled communication between cellular users and D2D users’ control is with the base station. In autonomous mode, the control is with users only [12].

4. Different applications of 5G

5G technology is designed with several distinct features that extend its applicability to a wide range of entities such as business, hospitals, education, security, etc. There are several use-cases as already mentioned in section I of this paper such as eMBB, URLLC and mMTC. 5G has many real-time applications like:

(i) **Industrial Automation**: It includes a quick and easy response from machines, auto controlled devices, and real-time accessibility. This application requires high speed and low latency.

(ii) **Smart systems**: 5G is an enabling technology for IoT applications. The evolution of smart homes and smart cities are relying only on 5G. Thus, the 5G network plays a key role in IoT systems.

(iii) **Intelligent Transportation**: Smart transportation includes vehicle to vehicle (V2V communication), vehicle to pedestrian communication, and automatic control which helps in time management by reducing congestions, speed control, accident management, and enhance driver’s experience.

(iv) **Robotics**: Robotics helps in applications that are dangerous or difficult for human beings. Such systems require very less response time, efficiency, reliability, and mobility. All this can be achieved with the help of 5G standards.

(v) **Virtual Reality (VR)**: Several applications such as micro-assembly, telemedicine, telesurgery, and hologram require very high precision and sensitivity for object manipulations. Virtual reality is also helpful in education, military, architecture, and much more.

(vi) **Health care**: In many healthcare applications like Tele-diagnosis, telesurgery, and telerehabilitation, 5G technology is really helpful as it provides low latency, high reliability and precision. The surgeries by robots are possible only if there are negligible latency and high efficiency.

(vii) **Gaming**: Wearable devices, real-time gaming, Ultra HD video streaming are all applications of 5G [13].Some games include problem-solving challenges used in training, education, simulation, and health.

(viii) **Communication**: A real-time full HD video calling, work, and play at the same time in the cloud and improved data/voice communication are possible with the help of 5G.

(ix) **Education and Culture**: People living in remote areas can get their education with the help of low latency Internet. This will be possible only if there is proper audio, video synchronization [14], [15].
5. Upcoming challenges in 5G

5G is anticipated in almost any part of our existence to have a huge effect on sci-fi-like technologies such as self-controlled cars, intelligent homes, and extremely high internet rates. Naturally, it presents certain challenges to make this kind of powerful technology a reality. Here are some of the challenges that demand attention:

(i) **Spectrum allocation**: One of the challenges that 5G is facing is that the spectrum is very expensive. In India, spectrum allocation for 5G is still pending and also the trials for technologies update by different operators are awaited.

(ii) **Base stations density**: More antennas and base stations are required to expand network connectivity if MIMO technology is to be used. Therefore, more space is required for installing new base stations.

(iii) **Heavy Costing 5G devices**: Affordable 5G devices are still not there in the market to increase the connectivity. Also, high cost is required for installing a large number of small cells.

(iv) **Energy Consumption**: Huge data is transmitted and received in the form of files, high-quality audio and HD videos; therefore new source coding such as H.264 is required to enhance the throughput, robustness, and energy consumption by achieving the required capacity of the network.

(v) **Irregular Cell size**: Different classes of base stations like pico-, Femto-, micro- is called as heterogeneous networks (HetNets). Inter-cell interference is a major problem in HetNets. This is because there is no planning while small cells are deploying which is because of the factor that operators have no control over small cell location. Also, irregular cell size by conventional macrocells is there which increases inter tier interference [16].

(vi) **Device discovery**: A major design challenge in setting and maintaining a large number of links is difficult at the time of a very high traffic load. To maintain direct communication devices must discover each other. In device discovery numbers of other requirements are also there such as energy efficiency, autonomous detection, and scalability [17].

(vii) **Privacy**: Privacy is always a big concern which needs to be taken into consideration while designing the system.

6. Conclusion

The considerable increase in demand for data by users leads to the overburden of the electromagnetic spectrum and therefore, the requirement of high data rate is becoming difficult to attain. So, the latest technologies are opening new dimensions to provide ultra high speed and performance. These technological innovations form the basis of 5G technology. This paper discusses various new technologies that are primarily enabling the 5th generation of the wireless network. Various applications and challenges of 5G are also a prominent part of this paper.

References

[1] Agiwal M, Roy A and Saxena N 2016 IEEE Communications Surveys & Tutorials 18 1617–1655 ISSN 1553-877X
[2] M2410-0 R I R 2017 Minimum requirements related to technical performance for IMT-2020 radio interface(s) Tech. rep.
[3] Shu Y and Zhu F 2020 Journal of Ambient Intelligence and Humanized Computing 11 503–510 ISSN 1868-5137
[4] Song L, Xu Z, Tian Z, Chen J and Zhi R 2019 Journal of Physics: Conference Series 1213 042048 ISSN 1742-6588
[5] Rao S K and Prasad R 2018 Journal of Multi Business Model Innovation and Technology 4 149–178 ISSN 2245-456X
[6] Ahokangas P, Matinmikko-Blue M, Yrjola S, Seppanen V, Hammainen H, Jurva R and Latva-aho M 2018 Business Models for Local 5G Micro Operators 2018 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) (IEEE) pp 1–8 ISBN 978-1-5386-5191-9

[7] Suryanegara M 2020 Journal of Physics: Conference Series 1502 012017 ISSN 1742-6588

[8] Rappaport T S, Shu Sun, Mayzus R, Hang Zhao, Azar Y, Wang K, Wong G N, Schulz J K, Samimi M and Gutierrez F 2013 IEEE Access 1 335–349 ISSN 2169-3536

[9] Gupta A and Jha R K 2015 IEEE Access 3 1206–1232 ISSN 2169-3536

[10] Rappaport T, Roh W and Cheun K 2014 IEEE Spectrum 51 34–58 ISSN 0018-9235

[11] Ding Z, Lei X, Karagiannidis G K, Schober R, Yuan J and Bhargava V K 2017 IEEE Journal on Selected Areas in Communications 35 2181–2195 ISSN 0733-8716

[12] Kar U N and Sanyal D K 2018 ICT Express 4 203–208 ISSN 24059595

[13] Parvez I, Rahmatî A, Guvenc I, Sarwat A I and Dai H 2018 IEEE Communications Surveys & Tutorials 20 3098–3130 ISSN 1553-877X

[14] Masoudi M 1999 International Journal of Heat and Mass Transfer 42 3529–3531 ISSN 00179310

[15] Wire B 2017 New IEEE 5G and Beyond Technology Roadmap White Paper. Tech. rep.

[16] Macia-Fernandez G, Garcia-Teodoro P and Diaz-Verdejo J 2009 IEEE Wireless Communications 16 88–94 ISSN 1536-1284

[17] Jung S and Chang S 2014 A discovery scheme for device-to-device communications in synchronous distributed networks 16th International Conference on Advanced Communication Technology (Global IT Research Institute (GIRI)) pp 815–819 ISBN 978-89-968650-3-2