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Procedia Computer Science 182 (2021) 150–158

Procedia Computer Science

www.elsevier.com/locate/procedia

17th International Learning & Technology Conference 2020 (17th L&T Conference)

Comparative Study of Efficiency Enhancement Technologies in 5G Networks - A survey

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Abstract

Mobile communication technologies are tremendously grown in the last few years. With the advent of the fifth generation of wireless networks, and with millions of base stations and billions of connected devices, the need for spectral and energy-efficient system design will be more convincing.

In this paper, the evolution of mobile communication networks starting from first-generation to the fifth generation with comparative studies are first introduced. Then, summarizing the recent research initiatives towards the next generation, 5G, evolution. The main requirements of 5G networks and emerging technologies are highlighted. Furthermore, an overview of several technologies that might be used to achieve the 5G requirements including Massive-MIMO, Millimetre-waves, beamforming, full-duplex, and Small-Cells are explained.

Finally, a comparative analysis survey of Spectral Efficiency (SE) and Energy-Efficiency (EE) based Massive MIMO techniques is introduced as a key contribution of this review article. Good trade-off conditions between EE and SE technologies based on various algorithms are explained with comparative analysis.

Peer-review under responsibility of the scientific committee of the 17th International Learning & Technology Conference 2020

Keywords: 5G networks; Massive-MIMO; 5G Technologies; Spectral efficiency; Energy efficiency

1. Introduction

Recently, wireless communication technologies have represented a phenomenal growth. As a result of further development in wireless transmission and mobile networking techniques, various wireless services have emerged and smart devices become more popular. This has led to massive increase in the data traffic of wireless networks. In the last decades, wireless technologies have experienced five generations of technology evolution, namely from the First Generation (1G) to the Fifth Generation (5G) [1].

The motivation for developing wireless networks has been the demand for larger channel bandwidth, and lower latency. The development of wireless networks requires the adjustment of key parameters, such as enhancing throughput related performance, decreasing channel interference, connectivity, scalability and compatibility with other legacy networks.

In late 2014, both academia and industry showed their interest to develop a new generation of wireless technology not only by enhancing the performance of the 4th Generation but also by supporting more capabilities [2]. The capacity and data rate of the developed network are the core of the 5th Generation technology. There are many developed 5G technologies such as; Massive MIMO, mm-wave spectrum, small cells, advanced modulation, and coding schemes, new multiple access techniques, optical-fibre networks and control/user plane split play effective

1877-0509
Peer-review under responsibility of the scientific committee of the 17th International Learning & Technology Conference 2020.
10.1016/j.procs.2021.02.020

rules in 5G platform. The concept of the 5th Generation relayed on the Wireless System for Dynamic Operating Mega Communications (WISDOM) which was developed by Prasad [3].

5G systems is considered to serve unexpected number of devices, providing ubiquitous connectivity as well as innovative and rate-demanding services. It is expected that there are more than 50 billion connected devices [4], [5] by the end of 2020. Hence, there are several requirements of 5G network to achieve higher data rate, larger bandwidth and lower latency.

Fifth Generation network is considered as the main platform for applying any future wireless applications. Where, 5G systems are expected to provide peak data rates up to 20 Gb/s, average data rates greater than 100 Mb/s, and connectivity for a huge number of Internet-of- Things (IOT) devices per unit area.

This paper briefly presents the evolution of mobile networks and concentrate on 5G advantages and its challenges. The paper is organized as follows; section 2 presents a brief description of mobile standards evolution technologies including comparative study among digital generations about their advantages and challenges. The emerging technologies based on 5G networks are described in section 3. The requirements of 5G networks to perform its main functions and support the pre-mentioned technologies are presented in section4. The 5G technologies required to perform its operation are classified into five main technologies as mentioned and detailed in section 5 including their advantages and challenges. Massive MIMO technologies including Energy Efficiency (EE), Spectral Efficiency (SE) and trade-off between them are explained in section6.

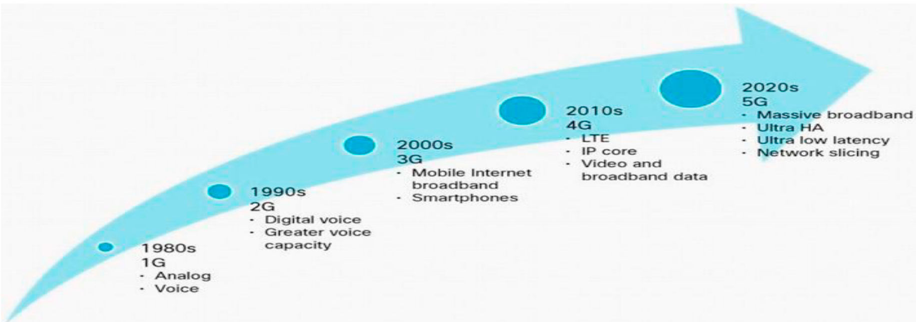


Fig.1 The evolution of mobile network standards [2].

2. Evolution of Mobile Technologies

Mobile communication has become one of the most common wireless technology in the past few decades due to the fast evolution of mobile technologies. As a result of rapid development in communication technologies, data rate, mobility, coverage and spectral efficiency are increased [6]. While stepping from the 2G GSM system into 3G UMTS system, higher network speed and faster download speed are considered to guarantee real-time applications like video call. LTE and subsequent LTE-A offered enhanced network capacity, reduced delay in app-server access making triple-play traffic (Data, Voice, and Video) access possible in wireless manner anytime and everywhere. Therefore, 4G is truly mobile broadband. Although 3rd Generation was the first mobile broadband standard, it was originally designed for voice applications with some multimedia and data consideration. Whereas 2G was designed as a first digital mobile voice communication standard to improve coverage than, 1st Generation, analog basis voice services.

The development of mobile technologies [7] from 1st Generation, passing by 2nd Generation, 3rd Generation and 4th Generation right down to 5th Generation is shown in Fig. 1. The brief characteristics, advantages and drawbacks description of these generations are summarized in Table 1.

Table 1. Comparison between Mobile Phone Generations.

Mobile Generation	GSM(2G)	CDMA(3G)	LTE(4G)	5G
Refers to	Second generation	Third generation	Fourth generation	Fifth generation
Deployment	1990	2001	2010	2020
Features	It uses digital signals. It provides services such as text messages etc	It provides faster communication. It has large capacities and broadband capabilities. It send/receive large email messages	provides additional services. It provides mobile ultra-broadband Internet access.	Interactive multimedia, voice, internet and others services are supported by 5G. It is more effective and attractive as compare to other generation.
Band width	200 KHz	5 MHz	20 MHz	Up to 100 MHz
Data rate	14.4 Kbps	3.1 Mbps	100 Mbps	20 Gbps- 100 Gbps
Latency	700 ms	< 200 ms	< 30 ms	About 1 ms
Modulation Technique	GMSK	QPSK, 16QAM	QPSK, 16 QAM and 64 QAM	256 QAM
Applications	Voice and Slow data rate communication	Advanced applications(various services like data services access to television/video)	high rate data Applications, wearable devices	device-to-device, machine-to-machine, internet of Things ,2-way gaming, virtual reality glasses, cloud-based computing and other technologies
Multiplexing	TDMA	W-CDMA	OFDMA and MIMO	OFDM, NOMA, FBMC and Massive MIMO
Standards	GSM,EDGE,GPRS	UMTS, CDMA2000, HSPDA,EVDO	LTE advanced, IEEE 802.16 (WiMAX)	CDMA,BDMA
Switching	circuit/packet	Packet	all packet	all packet
Hand over	Horizontal	Horizontal	Horizontal/vertical	Horizontal/vertical
Core type Network	PSTN	Packet- Network	Internet	Internet
Technology	Digital cellular	code division multiple access, universal mobile Telecommunications system	Long-Term evolution advanced, Wi-Fi	Multi- radio Access technology, Wi-Fi, Wi-Gig

3. The Emerging Technologies and applications of 5th Generation

It is expected that**,** 5G technologies will potentially connect more than 8.5 billion smart devices [8]. The two major characteristics of the 5th generation of wireless communication are network capacity and speed. Therefore, it allows smart phones and other devices to manage huge volume of data generated through software applications. Nowadays, several AI areas relay heavily on network communication to transmit and process data, and their major common concern is communication that includes data management and timing performance [9].

The stability of the robustness of the network is increased in 5G networks by utilizing advanced big data analytics and machine (deep) learning algorithms where any expectations in the given network are estimated. 5th Generation networks are capable of connecting heterogeneous technologies within its platform. Numerous cell phone producers and wireless devices’ providers, have designed their new devices to be compatible with 5G platform. The most of emerging technologies based on 5G network are summarized in Fig.2.

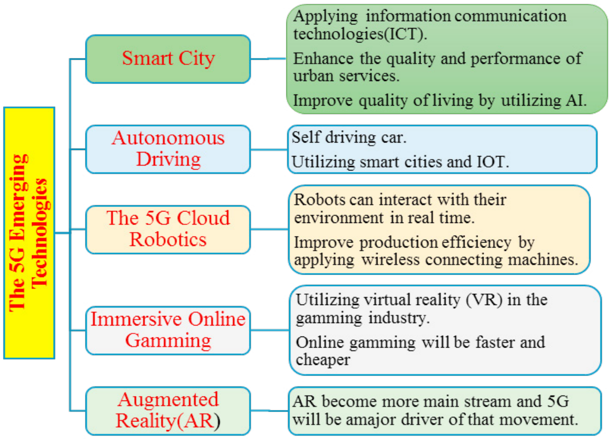


Fig.2. 5th Generation emerging technologies

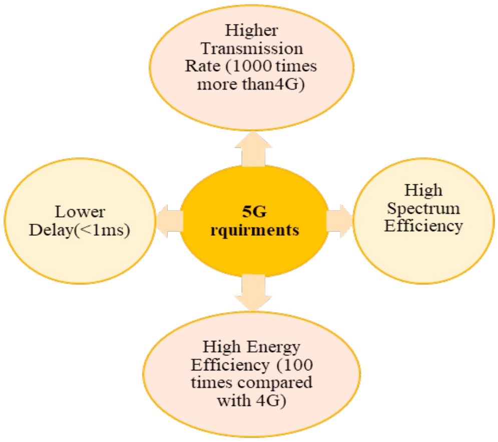


Fig.3. 5th Generation requirements

4. The requirements of 5th Generation networks

5G technology isn't just a regular improvement over 4G however, it's considered as a next major evolution of mobile communication technology. Moreover, 5G technology gives higher performance improvements of several orders of magnitude than today's working networks. The International Telecommunication Union (ITU), has established a 5G framework within Research and Development (R&D) program worldwide on International Mobile Telecommunications for 2020 and beyond values (IMT-2020) including the following expectations; 1000 times of mobile data rate volume per area higher than today's data rate. User data rate as well as the number of connected devices are expected to be multiplied also by 10 to 100. Battery life should also be 10 times longer especially for Machine to Machine applications (M2M) and Internet of Things (IoT) applications. Whereas, latency has to be shortening by 5 times. 5G requirements are briefly summarized in Fig. 3.

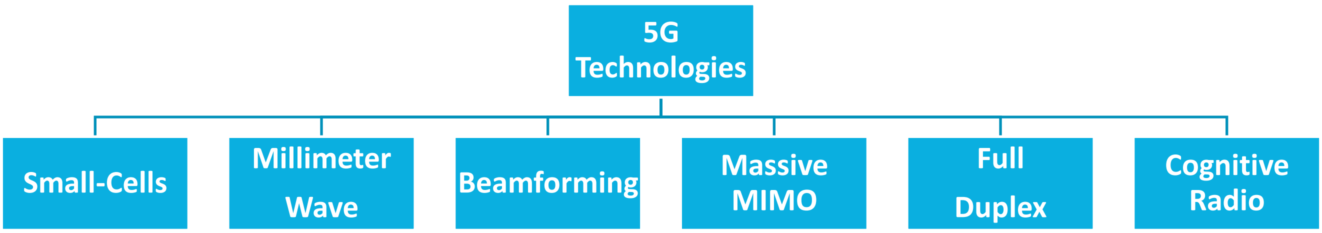


Fig. 4. Chart of 5th Generation technologies

5. The 5G Technologies.

Several technologies might be used to achieve the 5G requirements especially achieving a much higher data rate and lower latency properties [11]. These technologies can be classified into main five categories as shown in Fig.4.

5.1 Small Cells Technology

One of the simplest yet effective way to enhance the capacity of cellular network is to increase the number of cells per region and making them smaller in size where this concept has been deployed in different generations of cellular networks [12]. In the 1980s, the 1st Generation wireless telephone technology, which had analogue standard, used to have huge cell radius that could reach up to 30 km [13]. Few years later, the size of the cell is getting smaller for 2G and 3G networks where the cell could have a radius of 3 km. in today wireless networks, the base station can be serving users within a radius of 200 meters especially in dense metro areas. The networks are shrinking in terms of size to Pico cells with a range of 100 meters and to femtocells with a range of 10 meters which is the same range of Wi-Fi networks [14].

5.2 Millimetre-Waves

The microwave spectrum that is used today by mobile systems is limited within range from 300 MHz up to 3 GHz. Instead of using the limited electromagnetic spectrum at microwave frequencies, it is possible to use the huge amount of spectrum with range (3- 300 GHz) which is called Millimetre-Waves [15].

The International Communication Union (ITU) proposed a list of frequencies above 24 GHz that can meet the commercial needs [16]. After the proposal of ITU, in December 2016, the Federal Communication Commission (FCC) adopted rules for Mm-Wave bands above 24 GHz [17]. Mm-Waves can provide enough frequency for the demand by mobile applications in upcoming decades. The Mm-Waves have a wavelength ranging from 1 mm to 10 mm with a spatial resolution higher than what microwaves have.

5.3 Massive MIMO

Massive MIMO concept was proposed for the first time by Thomas Marzetta from Bell Labs in 2010 [18,19]. It is a scalable form of Multiuser MIMO where there are several essential differences between Massive MIMO and Multiuser MIMO [20]. The proposed concept of massive MIMO is to equip the base station with hundreds of antennas which is much larger than the number of users as shown in Fig. 5. The antenna array receives data signals from the user terminals and selectively sends data streams sharing the same time and frequency resources. On the downlink, each user should receive only the data stream that is intended to him [21]. However, in the uplink, the Base Station (BS) receives and recovers the data signals that were sent by the user terminals. As a result of the line of sight conditions, the BS supports individual beam for each user terminal as indicated in Fig.5. By increasing the number of antennas in the base station, the beams that are directed to the user terminal have much narrower beam widths and much focused power.

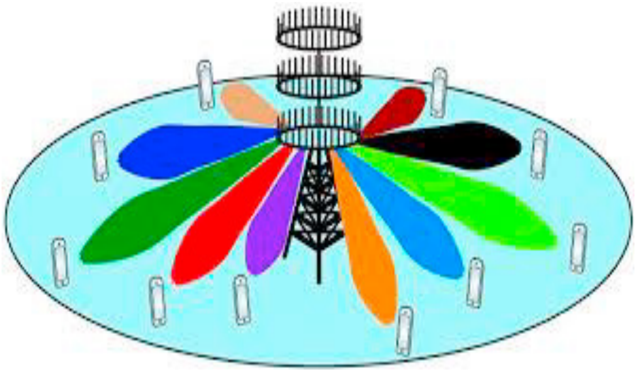


Fig.5. Massive MIMO Technology

5.4 Cognitive Radio

Cognitive Radio (CR) technology is based on the awareness of and sensitive to the changes in its surroundings [22]. The major function of Cognitive Radio (CR) networks is to sense the surrounding free spectrum that enables CR networks to be adapt with surrounding environments. 5G and Cognitive Radio are considered as the two emerging technologies to meet the need to heavy mobile data traffic for future wireless applications to provide higher capacity and a network speed up to ten Gbps [23]. From another hand, CR networks can utilize Artificial Intelligence (AI) techniques for optimization processes of dynamic sensing and decision making [24]. Therefore, utilizing AI-based cognitive radio results in significant enhancement in 5G network requirements and efficiency.

5.5 Beamforming.

Beamforming is like a traffic signal in the system. Its broadcasting signal in every direction would allow the base station to send focused stream data to a specific user as indicated in Fig.6. This precision prevention system is more efficient. That means; the station can handle more incoming and outgoing data at once. The process of this system can be described as follows. Suppose two or more devices are in the city around the obstacles then make a call [25]. Here, the first massive MIMO BS collects that data and send it to a specific user with specific data sending algorithm. That implies Beamforming through which users' data direct to wherever the user desires to send. This results in a new technology named full-duplex communication.

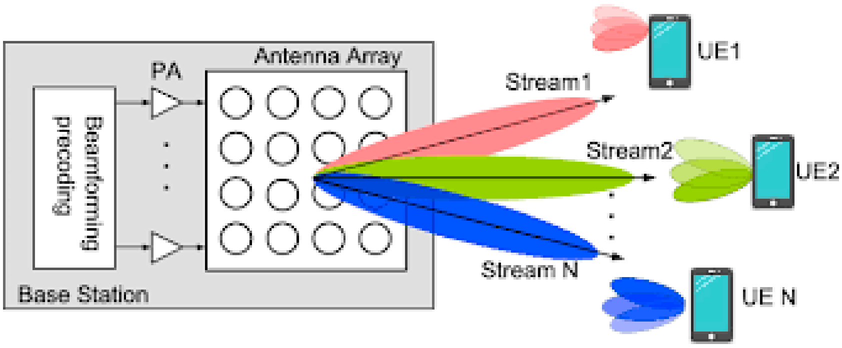


Fig.6.The Beamforming in 5G.

5.6 FULL DUPLEX

In one scenario data can either transmit or receives. This is called half-duplex communication like a walky-talky. Today's cellular base stations have the same problem. This is because of the reciprocity principle. If you transmit data on radio frequency, then it travels forward or backward on the same frequency. Therefore, if two devices are sending data at the same time, the error occurs due to reciprocity principle. [26]. In order to overcome this problem, researchers use a silicon transistor to create high-speed switches. This silicon transistor allows two users to transmit data at one channel.

Table 2 declare a comparison between the main 5th Generation technologies including advantages and challenges of each technology.

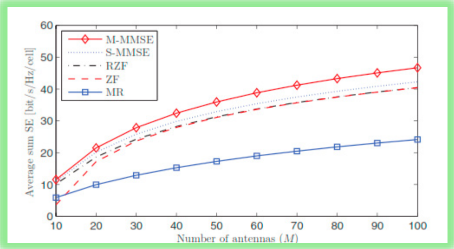
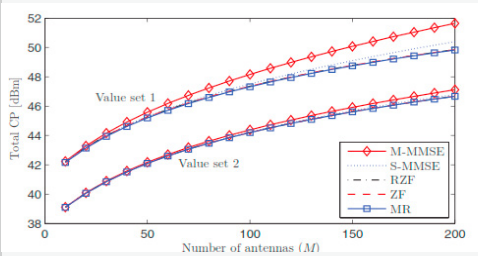
Table.2 a comprehensive study between 5G main technologies.

Technology	Advantages	Challenges
Small Cells	• Electromagnetic spectrum reuse. • The base stations will be smaller. • The BS require lower operation power. • The cos will be much cheaper. • Increase spectral efficiency.	• Increasing the cost of the backhaul because of using fibre connections. • The interference due to existing of very dense Wi-Fi networks.
Millimetre-Waves	• The size of the antennas and the equipment will be smaller. • The cost will be cheaper. • Mm-Waves require lower power supply voltage. • Increase data rate.	• Path loss since the transmitter and the receiver require line of sight connection. • The absorption due to rain and atmosphere condition.
Massive MIMO	• Increases the capacity 10 times or more • Improves the radiated energy efficiency on the order of 100 times. • Increase data rate. • Improves energy efficiency and spectral efficiency. • Reduces interference. • Enables a significant reduction of latency on the air interface.	• Pilot contamination. • Reducing the cost of the hardware components in Massive MIMO systems. • The hardware impairment. • The effect of correlation models on Massive MIMO systems need to be analysed

6. The Efficiency of Massive MIMO in 5G.

The Massive MIMO efficiency can be enhanced by improving Spectral Efficiency (SE) and Energy Efficiency (EE) [27:29] that are discussed in Table 3.

Table. 3 comparisons between SE, EE in massive MIMO

<table>
<tr><th>Type</th><th>Spectral Efficiency(SE)</th><th>Energy Efficiency (EE).</th></tr>
<tr><td>Definition</td><td>SE is defined as “the average number of bits of information, per complex valued sample, that can reliably transmitted over the channel under consideration".</td><td>EE of a cellular network "is defined as the number of bits that can be reliably transmitted per unit of energy or the ratio of capacity versus transmitted power consumption".</td></tr>
<tr><td>Equation</td><td>$SE = \frac{Data\ rate\ or\ Throughput(pbs)}{channel\ Bandwidth(Hz)}$</td><td>$EE = \frac{\text{Throughput [bit/s/cell]}}{\text{Power Consumption}[\frac{\text{W}}{\text{cell}}]}$</td></tr>
<tr><td>Unit</td><td>bit/s/Hz</td><td>bit/Joule</td></tr>
<tr><td>How to improve?</td><td>• Increasing the Transmit Power.
• Obtaining an Array Gain.
• Utilizing uplink and downlink Space-
• Division Multiple Access (SDMA).
• Acquiring Channel State Information (CSI).</td><td>• Resource allocation.
• Network planning and deployment.
• Energy harvesting and transfer.
• Hardware solutions.</td></tr>
<tr><td>Advantages</td><td>• Higher data rates to the user.
• Lower network cost to the operator.
• Coverage extension and higher service reliability.</td><td>• Increase Throughput.
• Enhance Outage capacity.
• Improve network benefit-cost ratio.</td></tr>
<tr><td>Discussion</td><td>• SE can be enhanced by increasing no of antennas by means using Massive MIMO As shown in this fig.

</td><td>• EE may be improved by enhancing CP under Massive MIMO as in fig below.
• Also EE can be enhanced by increasing throughput.

</td></tr>
<tr><td>Literature reviews</td><td>[30],[31],[32]and[33]</td><td>[34],[35],[36]and [37]</td></tr>
</table>

6.1 Trade-off between SE and EE in Massive MIMO

It is observed that performing a suitable tradeoff between spectral efficiency (SE) and energy efficiency (EE) has an essential impact on the emerging wireless communication systems. Therefore, a balance between SE and EE is urgently required. There are many proposed algorithms to achieve good trade-off based on the following.

In [38] the investigation of the EE-SE trade-off problem in downlink large-scale MIMO systems is formulated based on Pareto optimal set based multiple objective optimization problems with respect to the transmit power and the number of available antennas at the base station.

In [39] the minimum mean-square-error channel estimate and the rigorous closed-form expression of achievable downlink rate are derived firstly. Then, the Multi-Objective Optimization Problem (MOP) is formulated subject to maximum total transmission power constraint. Where, conflicting EE and SE are maximized simultaneously.

The algorithm introduced in [40] is based on maximizing a new metric of Resource Efficiency (RE) by multiuser downlink beamforming in massive MIMO systems. This metric has an advantage of striking the flexible balance between SE and EE based on Duality, but with some difficulties in solving the resulting problem.

Fig. 7 shows the EE-SE performance curve for a network described in [40]. For different resource allocation schemes, the curve shows that EE first increases as SE increases until reaches the optimal point. Beyond this point, the EE begins to degrade while the SE is still increasing.

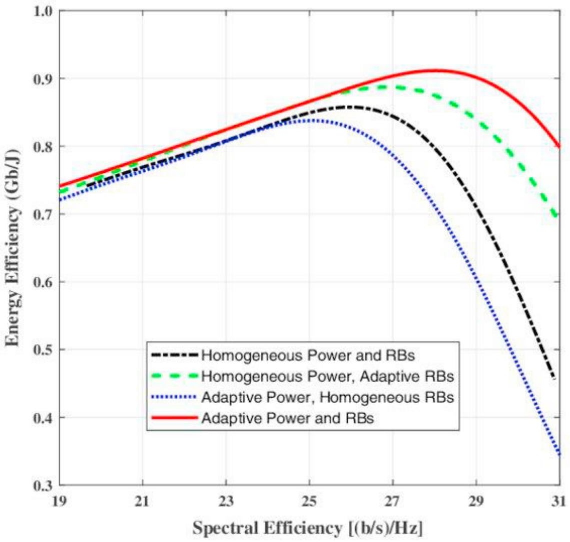


Fig. 7 SE and EE tradeoff curve [37]

7. Conclusion

Wireless communications are experiencing rapid evolution, wherein the mission for new services and applications pushes for the quick presentation of new technologies into the marketplace. In this paper, we have discussed the existing mobile wireless technologies besides the next-generation 5G technologies and challenges. There are lots of enhancements starting from 1st G passing 2nd G, 3rd G and 4th G until 5th G in the world of communication. 5th Generation will bring individuals to a new degree of mobile technology. Moreover, the main requirements of 5G and emerging technologies have been discussed. The most common 5th Generation technologies such as; Small cells, Millimeter-Waves, Massive-MIMO, Cognitive radio, Beamforming and Full duplex are explained with comparative analysis. In addition, a Comparative study of 5G based Massive-MIMO technologies including SE and EE trade- off were briefly explained.

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