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Analysis and Exploration of the Development and Application Status of 5G Communication Technology

Nan Ding

*Ph.D. Candidate, Faculty of Computer Science, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia
2022636766@student.uitm.edu.my*

MARINA ISMAIL*

*Doctor, Faculty of Computer Science, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia
marina393@uitm.edu.my*

Nor Aziah Daud

*Doctor, Faculty of Computer Science, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia
aziah@tmsk.uitm.edu.my*

<i>Article History</i>	<i>Abstract</i>
<p>Received: 28 April 2023 Revised: 18 June 2023 Accepted: 27 August 2023</p>	<p>The advent of 5G has invited opportunities for many socioeconomic benefits. The core principle of 5G is an array of contemporary technologies, which makes 5G render efficient networks, fostering new services, creating new ecosystems, and increasing revenues. The technologies in 5G continue to be developed from the new 5G ecosystem, which can transform the vertical industries. This work provides a comprehensive treatment of the 5G technologies, with its characteristics, new technologies that are a part of 5G, comparison with existing technology with a special mention of the technological advantages and disadvantages. The work analyses the salient features of 5G in the context of latency reduction, more connectivity, imparting spectral efficiency, and providing network services without compromising the QoS to a wider range of populations. The limitations of 5G technology are also discussed in the work, which throws light on futuristic research directions.</p>
<p>CC License CC-BY-NC-SA 4.0</p>	<p>Keywords: <i>Fifth Generation, Communication Engineering, Analytic Research, MIMO, Millimeter Communication, IoT</i></p>

1. Introduction

The fifth generation mobile communication technology, also known as 5G, is a new broadband mobile communication technology with high efficiency, less delay, and strong connection characteristics, and is an important Internet infrastructure for human-computer interaction. As a new mobile communication network, 5G should not only meet the problem of human-to-person communication but also bring more immersive ultimate service experience to customers, such as reality enhancement, reality virtualization, ultra-high-definition video, and strengthen the connection between people and things, and between things, and meet the needs of Internet of Things applications such as medicine, vehicle-road collaboration, smart home, industrial control, and environmental monitoring [1]. Therefore, 5G technology will penetrate into all industries and fields of China's

economy and society, forming an important new infrastructure to support the transformation of China's economy and society into digitization, Internet, and intelligence [2], [3].

It has been two years since 5G was first commercially available in 2019. 169 operators in 70 countries in the world have officially released 5G [4]. If you add in the operators who are investing in 5G, the total number has reached 400. The European Union, the Asia-Pacific region, and Central and North America are all the first-mover regions of 5G and have basically realized the commercialization of 5G Internet technology; South Asia, Eastern Europe, North Africa, Central, South America, and other regions will also follow closely to achieve 5G deployment and pre-commercial; In Africa, east of Western Sahara, 5G is still blank in most regions. From the perspective of 54 operators, the maximum speed of 5G in the market is mostly between 1Gbps and 2Gbps, which is basically the maximum capacity provided by 100M broadband technology based on Sub6G; Some operators can achieve more than 4Gbps [5]. The average transmission rate provided by the 54 telecom operators has also exceeded 1145Mbps, far exceeding the network capacity in the 4G era, which also reflects the advantages of 5G [6].

From the perspective of mobile 5G frequencies invested by telecom operators in various countries, n77 (3300~4200MHz) and n78 (3300~3800MHz) are absolutely dominant, followed by n257, n258 and n261 millimetre wave frequencies, followed by 700MHz, 2.6GHz, 2100MHz and 1800MHz. In China, in addition to serving as the maximum capacity layer of 3.5GHz and 2.6GHz, 2100MHz will also become the deep coverage layer of China Unicom and China Telecom, while 700MHz will become the wide coverage layer of mobile and radio and television systems, and is being constructed in full swing. At present, the NSA is still the leader of the 5G deployment network, but the number of developments is gradually slowing down. The SA network will begin to appear in 2020 and will gradually expand. With the large-scale deployment of 5G in China, it will certainly promote the development of China's 5G technology in the vertical industry, thus promoting the improvement of the SA environment [7]. At present, the regions that invest in 5G SA are the first-mover regions of China's 5G, such as the United States, the European Union, China, South Korea, Australia, etc. The advantages of the SA network have also been widely recognized by developed regions.

The number of end users supporting 5G SA has been growing rapidly and has reached 50% of the total. At present, all major chip manufacturers have relatively mature products that can support both NSA and SA modes, so the newly launched end users can usually support SA in hardware, and manufacturers may also make targeted software choices according to the network conditions of various countries. In terms of the frequency range supported by end users, the two TDD frequencies, n78, and n41, are definitely the mainstream, which should also have a great relationship with the domestic market, especially n41 (2600MHz). Next is the FDD frequency band n1 (2100 MHz). Since this frequency has been used in 3G and 4G in a large area, many telecom operators will choose to upgrade part of the bandwidth to 5G to further expand the coverage area. The types of 5G terminals are also extremely rich. In addition to mobile phones, CPE used as FWA and application devices such as on-board Internet routers are also included, which more fully shows the wide application of mobile 5G technology [8]. Figure 1 shows the investments in 5G [9].

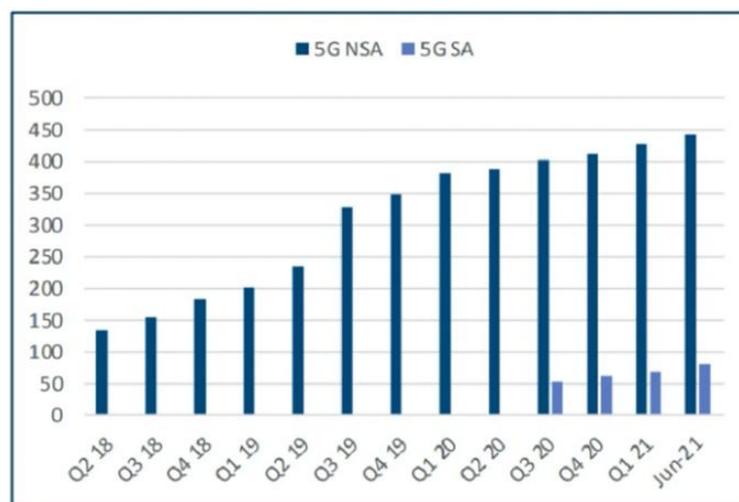


Figure 1. Number of 5G NSA and SA Operators' Investments

2. Characteristics of 5G Communication Technology

2.1 Fast Information Transmission and High Spectrum Utilization

In terms of data and message transmission speed, 5G communication technology is much higher than traditional 4G communication technology. Theoretically, in the case of continuous large-area coverage and high mobility, the maximum transmission rate of a 5G network will be able to exceed 10Gbit/s, effectively overcoming the problem of signal transmission delay. Therefore, compared with the peak speed of 4G technology, 5G mobile communication technology will be able to expand to 10 to 100 times [10].

This is mainly due to the multi-antenna technology in 5G mobile communication technology. Compared with traditional technology, this technology is very stable and better. The coverage is not only larger, but also the sensitivity is higher without being affected. The previous generations of communication technologies only relied on millimetre waves to transmit information, so they could not provide multi-antenna support. The 5G mobile communication technology can not only increase the speed of signal transmission but also greatly improve the accuracy of signal transmission after continuous updating and upgrading [11].

2.2 Reduce Energy Consumption and Operating Costs

Compared with the market economic value brought by the current 4G network, 5G communication technology can achieve faster data transmission efficiency under the same energy consumption conditions because of its low energy consumption, which not only effectively reflects that 5G communication technology has greater advantages in saving energy costs, but also has higher economic value [12].

The smaller and smaller size of multiple antennas has changed the traditional large base station mode and gradually evolved into a small base station mode. The advantages of small base stations are very prominent [13]. They can not only cover a wide range of areas but also cover the range of peripheral networks that cannot be reached by traditional technologies. They can also be adjusted to the appropriate spacing according to the actual needs. The advantages of their size ensure that operators can flexibly set up a variety of small base stations in each city to build a close network system. Secondly, small base stations can complete the transmission of information at high speed and high quality, which is mainly due to the ability of each small base station to receive and send signals, thus greatly improving the overall information function [14]. In addition, the power consumption of small base stations is far less than that of large base stations, so even if several small base stations are built, the overall cost is far less than that of large base stations.

2.3 High Resource Utilization

The 5G communication method can have a higher development and use of high-frequency spectrum resources, thus greatly improving the penetration and transmission reliability of radio waves. With the help of the 5G communication method, the resource efficiency of mobile 5G can be significantly improved by integrating optical fibre technology, wireless broadband, cable TV broadband, and mobile information technology. 5G communication technology has the advantages of a large support scale and a large number of links. In a very short distance, it can even complete one million communication tasks at the same time, which greatly adapts to China's current huge demand for Internet applications and can also adapt to the communication requirements of various users [15].

3. Application of 5G Technology in Communication Engineering

3.1 Application in Communication Engineering Construction

After investigating and analyzing the relevant data published in the 5G mobile pilot city, in future communication construction, we can use 5G communication technology to increase the coverage of the network and also optimize the user's use experience, thus greatly improving user satisfaction. At present, the wireless communication

Technology is still based on the base station to build a star network structure, which will not only cost more but also be affected by the topology structure and cannot achieve the purpose of real-time communication [16]. 5G communication technology realizes data communication by means of end-to-

end direct connection. On the one hand, it can ensure data transmission in a close area, and on the other hand, it can greatly reduce the impact of intermediate nodes so that end users can complete data communication in real-time, thus making the network speed reach a higher level. The operators of China's traditional communication construction need to build information systems through network construction and installation, and it is easy to consume huge network resources in this process. The advent of 5G technology has solved this problem well. It can not only effectively reduce the construction cost but also ensure the quality of network communication, thus greatly reducing the time spent in network communication, making the choice more free, the structure more rich, and the way more diverse, forming a comprehensive information technology communication network and system cluster, and thus realizing the further development and innovation of China's network industry [17].

3.2 Application in the Field of Intelligent Communication

Compared with 4G, 5G communication technology has a higher level of intelligence. This feature also ensures that 5G has better application ability in communication engineering and can also clearly reflect the high intelligence characteristics of 5G communication technology. Introducing 5G communication technology into the communication field can effectively improve the speed and quality of service of network information transmission. At present, human society has an increasing demand for intelligence and informatization. According to this demand as the starting point, the 5G network can be used not only in mobile users' mobile phones and other electronic products but also in the Internet of Things, making the Internet of Things more closely compatible with human daily life, for example, it can be applied to street lights, electronic display boards and other urban public facilities, or it can be modified intelligently. Thus, more personalized and intelligent elements are given to urban architecture [18]. In addition, 5G technology has many advantages in signal transmission rate, accuracy, stability, etc. Among the communication projects, the smart city transportation project is also a very important project. The use of 5G communication technology can achieve the goals of unmanned aerial vehicle remote control and intelligent driving of vehicles. Its key technologies mainly include the key technologies of the Internet of Things, big data cloud platform, and comprehensive technology of human resources information. The first process of building an intelligent city is to fully understand its structural characteristics so it can be subjectively positioned as the city's perception layer and basic business layer, and objectively, it can be further subdivided into the information data layer, transmission network layer, and intelligent application layer. In order to further complete the comprehensive coverage of the network, it is necessary to quickly cover the 5G network in the whole network so that data transmission can be more rapid, accurate, reliable, and safe [19].

3.3 Application in the Internet of Things Communication Technology

Although 4G technology has been used more and more widely, it still has a lot of room for improvement in the stability of data transmission in the communication network [20]. If it is necessary to further improve the speed and efficiency of data communication on the original basis, it can also be improved from the sensitivity of the system. In practical use, 5G mobile communication technology can be based on the specific needs of Internet information and effectively deal with the problems arising from it, thus making the service strategy more targeted, which also provides a better prerequisite for the vigorous development of the service industry. In the era of rapid and vigorous development of information, the types of Internet of Things connection facilities are also increasingly diverse. According to the background of industrial services, with the further demand of the 21st-century society for the transmission of Internet of Things information, the connection between mobile communication technology and Internet of Things platforms will also be closer because they are no longer independent individuals [9], [21], [22], [23].

4. Wireless Transmission Technology

4.1 Large-scale MIMO Technology

As an effective technical means to improve system spectrum utilization and data transmission security, multi-antenna technology has been widely used in wireless communication systems. According to information theory, the more the total number of antennas, the more significant the improvement of spectrum efficiency and security. In particular, when the total number of transmit

antennas and receive antennas is large, the MIMO antenna channel volume will increase almost linearly with the smallest of the total number of receive antennas. Therefore, using a large number of antennas can provide an effective way to greatly improve the capacity of the system. With the development of research and development, the application of large-scale MIMO technology in 5G has also been given deep expectations, and large-scale MIMO technology will also become one of the main technologies in 5G that are different from the existing systems [24]. Figure 2 shows the MIMO technology in 5G.

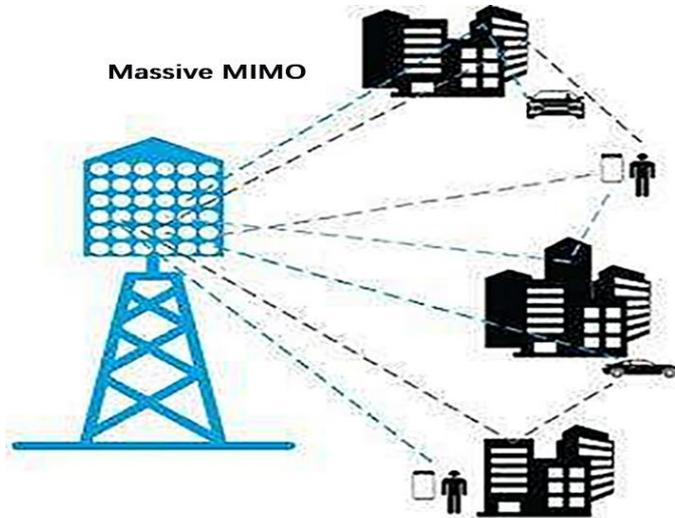


Figure 2. Large-scale MIMO Technology

4.2 Multi-carrier Technology Based on Filter Bank

Filter bank multi-carrier technology (FBMC) is regarded by scholars as one of the most promising multi-carrier technologies in future wireless communication. The FBMC uses a filter with excellent time-frequency focusing characteristics. The signal band leakage is very low, so there is no need to protect the signal band between users, thus greatly improving the spectral efficiency. At the same time, the FBMC can effectively offset multipath attenuation without using CP [25]. In addition, because FBMC adopts non-orthogonal processing, it does not need strict channel synchronization and is especially suitable for asynchronous communication occasions, such as uplink asynchronous access, cognitive radio and multi-point cooperation (CoMP), and other different scenarios. The nature of FBMC is shown in Figure 3.

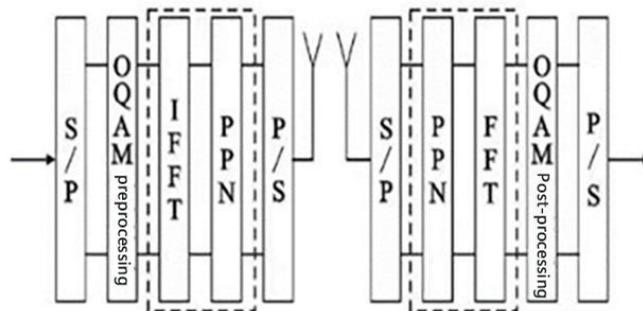


Figure 3. FBMC System Frame

4.3 Full-duplex Technology

Full duplex data communication technology refers to a technology that can conduct two-way communication at the same time and at the same frequency. Full-duplex means that the switch can receive data information while transmitting data information, and the work of the two is completed synchronously. This is just like people on the phone at ordinary times. When they talk, they can hear each other's voices. The full-duplex operating system allows data transmission between two electronic devices. Switches should support a full duplex. The general telephone and mobile phone are full-

duplex operating systems, so both sides can also hear each other's voices when talking to each other [26]. A full-duplex network system can only be described as an ordinary two-way lane. Because trains in two directions use different motorways, they cannot interact with each other, which indicates that a higher data transmission rate can be achieved under the full-duplex transmission method.

5. Wireless Network Technology

5.1 Ultra-dense Heterogeneous Network Technology

In all base station coverage areas, the future wireless network will fully deploy various wireless nodes with a number of more than ten times the current network sites. The distance between the stations will be kept within 10 meters, and at the same time, support the provision of services for more than 25000 end users within each square kilometre. At the same time, the ratio of active users to the number of outlets can also be more than 1:1; that is, the end users and business nodes are in one-to-one correspondence [27]. Highly closely deployed network systems shorten the distance between end users and nodes, significantly improve the total power and spectrum resource efficiency of the network system, expand the coverage of the network system, expand the capacity of the network system, and greatly improve the flexibility of services in various connection technologies and between different coverage stages [28].

5.2 Self-organizing Network Technology

Self-organizing network technology. The network information exchange of this technology adopts the packet switching mechanism in the computer network, which is different from the circuit switching mechanism in the telephone switching network. In addition, the user terminal is a portable terminal that can be moved, such as a notebook, mobile phone, etc. The user can be moved or still at any time. Router and host functions are provided by each user terminal in a wireless ad hoc network [29]. As the host, the terminal can run different user-oriented applications. As a router, the terminal needs to run the corresponding routing protocol. This distributed control and centerless network structure makes the remaining communication can still be maintained after part of the communication network is destroyed, reflecting strong robustness and invulnerability. The technical characteristics of 5G are shown in Figure 4.

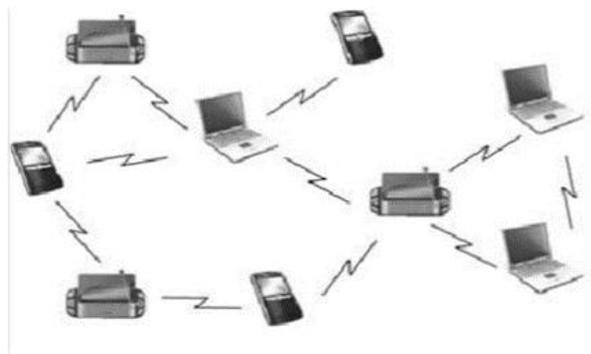


Figure 4. Technical Characteristics of a Self-organized Network

5.3 Software-defined Wireless Network

Software defines network information technology as a new and high technology originating from the Internet. In the original Internet network system structure, management and forwarding are integrated, and the network interconnection nodes are completely closed while forwarding management needs to be implemented in the local area, making their management functions very complex, so the complexity of the computer network system is very large [30]. In order to overcome this practical question, the researchers at Stanford University in the United States gave the idea of defining the network system by software. Its basic idea is to separate the route decision and management functions in the router from the equipment and to use the system software to complete the management uniformly by the central console, thus separating the management and forwarding functions, which makes the management more flexible and the equipment simpler. Because of the introduction of the central controller, the wireless management and Internet collaborative optimization

of heterogeneous networks composed of different connection technologies in wireless will also be more convenient in the future.

The application of 5G technology in the current industrial development is one of the main application scenarios of 5G technology. The development of the industry is closely related to the survival of human beings and the economic and technological development of the whole country. It can be said that the development of industry directly affects the economic development of the whole country to a large extent. The main case of applying 5G technology to the development of the manufacturing industry is the vigorous development of China's smart industry. In the development of China's manufacturing industry, enterprises can use 5G technology to better transmit information in production warehouses, manufacturing plants, environmental monitoring, quality control centres, and other aspects in a timely manner and assist different departments in transmitting information more quickly, to complete information transmission in a timely manner. It is convenient for management, maintenance, and control personnel to collect and analyze information better at the same time and use 5G technology in remote control work more quickly to achieve the purpose of improving the overall production quality and efficiency of the factory. Through 5G technology, the speed of information transmission is faster, which is well demonstrated in the information transmission between intelligent devices in the factory. Faster information transmission can better reduce the problems of low coordination between intelligent devices caused by untimely information transmission. In addition, 5G communication technology enables networked UAVs to also be applied in industry [31], [32].

In the development history of modern industry, some industries, some links, and some places are not easily accessible by ordinary people, and it is very difficult to supervise and maintain. By using UAVs to assist people in monitoring and evaluation, and with the help of 5G communication technology, the signal transmission speed can be improved to a large extent so as to assist people in better monitoring and evaluation [33]. In the course of development, the application range of networked UAVs has also become wider. So far, other UAVs can be widely used in various fields such as air sampling, pesticide spraying, power grid inspection, cargo handling, live broadcast, etc. With the assistance of 5G technology, we believe that it can better improve people's quality of life.

6. Prediction and Analysis of 5G Technology Development Trend

6.1 Wireless Communication System Based on Network Security

Compared with the wireless communication technology widely used in the world, 5G wireless communication technology has a broader application prospect and will be reused in many fields. At the same time as the application, 5G wireless communication technology needs to have a perfect security system. But it is the nature of the 5G wireless communication system that leads to its perfect security system. Therefore, the 5G wireless communication system is very reliable in most cases, which means its reliability is high. At the same time, there is still a certain degree of control delay in the current wireless communication network. However, 5G wireless communication technology will always effectively improve this phenomenon, improve its timeliness and reliability, and fully protect people's interests.

6.2 Hardware Transmission

The high-speed information transmission capability of 5G technology makes it have great development potential in many aspects. Its huge advantages in reading and writing speed will eliminate many low-end storage devices on the market. Its high-speed information transmission capability will shine brilliantly in mobile phone systems and other aspects. Android system is a mobile phone system with open-source code, and 5G nanotechnology can be applied in the core layer of the Android system so that the hard disk drive and system basic files can be separated. In other words, the mobile phone will be more closely connected from the cloud to the storage of hardware. The storage space of the mobile phone will be greatly saved, and more support will be available on the hardware, which will greatly improve the performance of the mobile phone.

In conclusion, all countries and major communication enterprises in the world have invested huge human and other resources in 5G technology, and they have achieved many excellent results in many basic aspects, which also laid a solid foundation for the arrival of the 5G era. However, there are still some technical difficulties to overcome in 5G technology, so the development direction of 5G

technology in the future must be technological research and development and improvement, focusing on the application value in social life.

6.3 Comparison of 5G with other Technologies

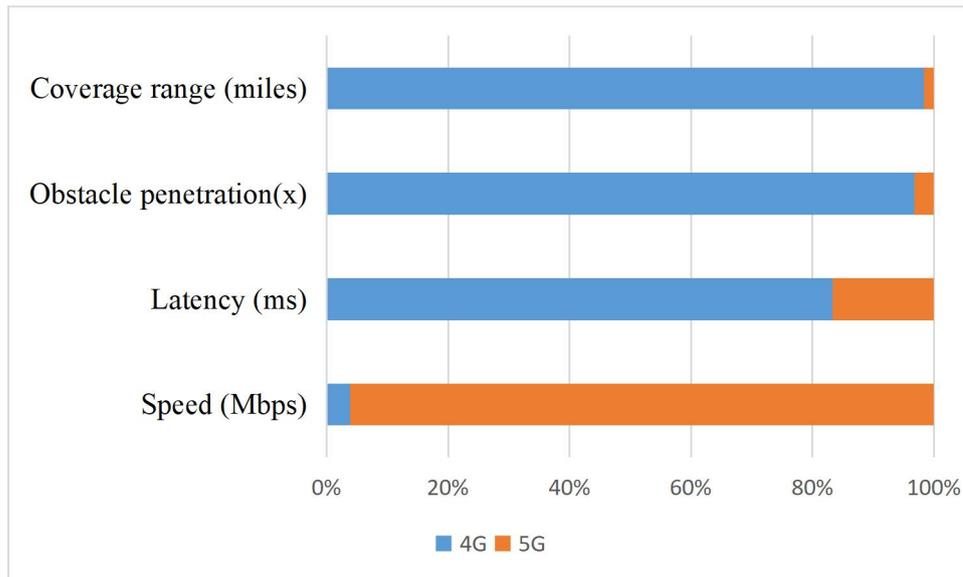


Figure 5. Comparative Analysis of 4G and 5G

The 5G technology harnesses the help of many recent innovations to enable faster communications. Figure 5 shows a comparative analysis of 4G and 5G technology in various criteria.

6.4 Comparison of 5G with other Technologies

The 5G technology has been the talk of the town since its introduction. There are many potential advantages of deploying 5G networks in this fast-growing era:

1. **Faster speeds:** The 5G network operates more quickly on digital devices with enormous upload and download capacity. This speed can greatly improve the quality of automation, web conferencing, and other activities that involve multimedia support.

2. **Shorter latency than 4G:** The prowess of 5G has enabled the networks to handle contemporary cutting-edge technologies like Augmented Reality, Virtual Reality, Blockchain Technologies to be handled in a more efficient way as the technology promises quicker response or latency [34].

3. **Increased capability to handle more devices:** The 5G network can be scaled up to handle more devices than the existing networks. This enables many devices to connect to the network without any hurdles.

4. **Wider bandwidth range:** The extensive bandwidth fosters better data processing. Wide bandwidth complements the technology to include more devices in the network. The spectral efficiency is shown using Equation 1.

$$\text{Spectral efficiency} = \frac{\text{5G throughput}}{\text{Channel bandwidth}} \quad (1)$$

5G technology has some potential disadvantages, which are actually research challenges for futuristic research.

1. **Lack of wide coverage:** 5G technologies have been successfully launched and deployed in very few locations for a variety of reasons. As with any technology, this is more beneficial to the cities.
2. **Shorter broadcasting range:** The 5G devices are not designed to broadcast to longer ranges,

which necessitates the installation of relay points, repeaters, and base stations at frequent intervals.

3. Uploading rate: Though 5G exercises better-downloading rates, its uploading rate is not encouraging. Upload rates are much shortened to around 100 Mbps, which is a major setback of 5G.
4. Issues at the end device: End devices like mobile phones emit much heat with faster drain of battery power. This is hazardous to the users as well as to the equipment.
5. Security threats: As 5G uses higher bandwidth, its software is much more vulnerable to security attacks. Hence, businesses need to invest much more amount in imparting security to the 5G network.

7. Conclusion

The ever-growing demand for low latency and high-speed applications increases dramatically in developing countries, which has motivated the evolution of 5G technologies with greater flexibility and advanced techniques to cater to the requirements of modern-day devices. Its capacity has increased multi-fold to provide network connectivity to a wider range of populations. The primary reason for the evolution of 5G technology is the need for fast information transmission, better spectral resource utilization, intelligent communication, etc. This work elaborates on the 5G technologies with a detailed analysis of features like self-organizing structure, full duplex technology, multi-carrier technology, large-scale MIMO, and ultra-dense deployment of network devices. The security aspects of the 5G technologies indicate the significant presence of threats and vulnerabilities, which are addressed by institutions and researchers. The work also discusses the potential applicational areas where the 5G is currently used. The detailed advantages and disadvantages of the deployment of 5G technologies are discussed. Also a competitive analysis of the 4G and 5G technologies in terms of performance is also presented in this work. The challenges in the deployment of 5G technology pave the way for future research directions.

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