5G Mobile Networks: What is Next?

DRAGORAD MILOVANOVIC, ZORAN BOJKOVIC
University of Belgrade
SERBIA
dragoam@gmail.com

Abstract: In this paper we discuss some issues that 5G will still leave open, and the possible evolution towards the next generation (6G) of wireless communication systems. The fundamental issues are higher system capacity, higher data rate, lower latency, and improved quality of service (QoS) compared to 5G system. We presents the motivation behind 6G, the way to move from 5G to 6G, the current industry trends for 6G, and the enabling technologies. We also outline the possible challenges and research directions to reach this goal.

Key-Words: wireless communication, enabling technologies, 6G

1 Introduction

The fifth generation (5G) communication system will be officially launched worldwide in 2020. As 5G research is maturing towards a global standard, the research community must focus on the development of beyond-5G solutions. Around 2030, our society will become data-driven, enabled by nearly instantaneous, unlimited wireless connectivity. Therefore, 6G will include relevant technologies considered too immature for 5G or which are outside the defined scope of 5G [1, 2].

In terms of speed, 6G will utilize higher frequency spectrum than previous generations in order to improve the data rate expected to be 100 to 1000 times faster than that of 5G. The networks will allow hundred Gbps to Tbps links by making use of multi-band high-spread spectrum; combination use of 1–3 GHz band, millimeter-wave (mmWave) band (30–300 GHz), and terahertz band (0.06–10 THz).

In terms of capacity, 6G will be able to flexibly and efficiently connect upper trillion-level objects rather than the current billion-level mobile devices. As a result, the 6G network becomes extremely dense, and its capacity may be 10 to 1000 times higher than that of 5G systems and networks.

In terms of latency, the evolution of mobile communication networks is centered on service people, and hence latency depends on human auditory reaction time (~100 ms), the visual reaction time (~10 ms), and the perceptual response time (~1 ms). For the application of tactile Internet, 5G technology will allow for a latency time of 1 ms. However, this is too long for Industrial IoT (IIoT) and some other latency-sensitive applications. For this purpose, 6G aims for an undectable (<1ms) or even nonexistent.

Some issues and challenges that, at present, have not been fully addressed in 5G mobile networks and that are attracting further research efforts are:

- Coverage issues and site densification to increase network capacity poses economic issues that may slow down considerably spatial and temporal 5G deployment.
- Emerging applications will push the required QoS to extreme levels that appear very challenging for currently 5G architectures.
- D2D communication challenges and vulnerability have not yet been addressed in a totally satisfactory manner in 5G.
- Mobile edge computing (MEC) at the edge of the radio access network (RAN) poses concerns.
- RAN virtualization and RAN intelligence should be based on the use of commercial *off-the-shelf* hardware and standardized open interfaces.
- Network orchestration and slicing based on NFV-SDN technologies promise to support the implementation of a large variety of services. Softwarized functionalities are hosted into cloud computing platform over data centres implemented with standard hardware. In the *slicing* concepts, different subsets of customers may subscribe a service contract with different operators (either real or virtual) and share in the end the same infrastructure, which paves the way to novel business models and opportunities for the network providers.

In this article, we present the evolution of requirements and give an overview of the standardization activities. Moreover, we outline a number of key technical challenges as well as the potential solutions associated with 6G.

2 From 1G to 5G

The last two decades have witnessed an extremely fast evolution of mobile cellular network technologies, from 1G to 4G, with 5G networks expected to be operational by 2020.

In general, in the evolution and development of mobile networks, emerging new transmission schemes, such as code-division multiple access (CDMA) in 3G, multiple-input multiple-output (MIMO), and orthogonal frequency-division multiplexing (OFDM) in 4G, the mmWave technique and massive MIMO in 5G, boil down to the question of how to innovatively exploit the degrees of freedom (DoFs) of time, frequency, and spatial resources to satisfy the diverse and refined requirements of society. Following on the innovation directions of previous mobile networks, 6G will be super-flexible in terms of the utilization of time-frequency-space resources in order to provide higher speed, greater capacity, and ultra-low latency for future faster than 5G applications. In general, the time-frequency-space resource utilization is interrelated [3].

Frequency dimension. 6G will utilize higher frequency spectrum than previous generations in order to improve the data rates. On one hand, high frequency bands, such as mmWave band, terahertz band, and even visible-light frequency band will be used for the 100 Gb/s+ transmissions in 6G.

Space dimension. For further taking advantage of multipaths, the number of antennas equipped on both the transmitter and receiver will be increased. Post-massive MIMO (PM-MIMO) techniques, such as ultra-massive MIMO (UM-MIMO) for terahertz communications, may support hundreds to thousands of transmit/receive antennas.

Time dimension. 6G will deliver the low latency and architectural shift that 5G is promising. Even more, the basic time slot unit in 6G may be more compressed to more efficiently use the high frequency bands and satisfy latency-sensitive services. The flexibility and versatility of the networks will be improved and hence facilitate their downward compatibility for 2G to 5G.

2.1 Services Evolution

The initial basic voice-only calls featured by 1G mobile systems evolved into a multitude of different services with the subsequent generations, from simple text messaging and basic high-latency data exchange to high-quality video streaming and chatting services, to radically new services supported by 5G networks. Services evolution was enabled by several factors, including ever-rising supported bit rates, advances in air interface design, signal processing at physical layer, and MAC layer procedures, technological advances in mobile terminals manufacturing, evolution of mobile internet protocols, cloud computing, advanced networking control paradigms [4, 5, 6].

2G global system for mobile communications (GSM) cellular networks initially provided digital voice service at bit rate 9:6 kbps. General Packet Radio Service (GPRS) and ultimately Enhanced Data Rates for GSM Evolution (EDGE) data services were subsequently introduced, with bit rates of a few tens of kbps and up to 200 kbps, respectively. These bit rates were largely increased in next generations. 3G generation UMTS offered up to 2 Mbps bit rate (often 364 kbps) initially, and then several tens of Mbps in downlink with High Speed Packet Access (HSPA). 4G LTE features up to 300 Mbps in downlink, with a target of 1 Gbps, and up to 50 Mbps in uplink.

5G cellular networks are expected to increase the bit rate significantly, up to 20 Gbps. These bit rates, end-to-end latencies down to 1 ms, ultra reliability (packet error rate 10^{-5} or less), and massive multiple access, will foster services such as enhanced mobile broadband, device-to-device (D2D) communication, ultra-reliable and low-latency Internet of Things (IoT) and machine-type communication (MTC), e-health, augmented reality and tactile Internet, industrial control for the Industry 4.0, automated driving and flying.

2.2 Standardization Activities

The 5G specifications have already been prepared, and even though it has already been launched in some parts of the world, the full phase of 5G will be deployed in 2020. Research activities on 6G are in their initial stages. From 2020, a number of studies will be performed worldwide on the standardization of 6G; 6G communication is still in its infancy. Many researchers have defined 6G as B5G or 5G+. Preliminary research activities have already started in the United States of America. China has already started the concept study for the development and standardization of 6G communications in 2019. The Chinese are planning for active research work on 6G in 2020. Most European countries, Japan, and Korea are planning several 6G projects. The research activities on 6G are expected to start in 2020.

For example, in September 2017, the European Union launched a three-year research project on the basic 6G technologies [7]. The main task is to study the next generation forward error correction coding, advanced channel coding, and channel modulation technologies for wireless terabit networks (https://futurecomresearch.eu). At the end of 2017, China began to study the 6G mobile communication system to meet the inconstant and rich demands of the Internet of Things (IoT) in the future, such as medical imaging, augmented reality, and sensing (www.china.org.cn). In April 2018, the Academy of Finland announced an eight-year research program, *6Genesis*, to conceptualize 6G through a joint effort of the University of Oulu and Nokia [8]. Research is organized into four unified planned parts: wireless connectivity, distributed computing, services, and applications. Scientific innovations will be developed for important technology components of 6G systems. More recently, the U.K. government has invested in some potential techniques for 6G and beyond, some universities in the United States have lunched research on terahertz-based 6G wireless networks, and South Korea Telecom (SKT) has started 6G research based on the cell-free and non-terrestrial network techniques. *Samsung Electronics* has opened an R&D center for the development of essential technologies for 6G mobile networks.

International Telecommunication Union standardization activities was based on IMT-2020. Consequently, ITU-R will probably release IMT-2030, which will summarize the possible requirements of mobile communications in 2030. Specifically, the newly established ITU Focus Group on *Technologies for Network 2030* will consider the long-term evolution of 5G and develop future ICT use cases [9].

3 Towards 6G

The new requirements of 6G will influence the main technology trends in its evolution process (Table 1). The success of 6G will have to leverage breakthroughs in novel technological concepts.

Table 1. Comparison of 5G and 6G requirements.

	5G	**6G**
Peak data rates	10 Gbps	1 Tbps
End-to-end latency	10 ms	1 ms (0.1 ms radio latency)
Maximum spectral efficiency	30 bps/Hz	100 bps/Hz
Energy efficiency	x1	x10
Traffic increase	x1	x10 000
Devices density	10^6/km^2	100/m^2
Mobility support	upto 500 km/h	upto 1000 km/h
Autonomous vehicles	partial	fully
XR	partial	fully

3.1 Technology Trends

- ✓ As of today, about one million Terabytes (1 Exabyte=10^{18}bytes) of data per day are exchanged over the mobile networks all over the world. The amount of data exchanged by mobile users will continue to increase, on one side due to the increasing number of non-human devices connected (including vehicles, UAVs, and autonomous systems), and to the enhanced quality 3D video / holographic type communication that will be used by humans.
- ✓ To deal with increased traffic, the mobile network will become more intelligent, with learning mechanisms to autonomously modify itself based on users' experience, and situation-aware decision making and networking.
- ✓ Network intelligence will be used to allow fast and flexible spectrum allocation/reallocation, with consequent large bitrates available to the users.
- ✓ Other human senses will be communicated to improve the quality of the tele-interaction, including 3D / holographic type communication, taste, smell, touch.
- ✓ Users will not necessarily need to bring a smartphone but will benefit of wireless-devices-as-a-service, with distributed devices available to anyone. All information being in the cloud, users will just need to be authenticated and then access the network by using any available device.
- ✓ The need to put devices on recharge will be dramatically reduced, so that the battery life will be substantially extended.
- ✓ We will see the appearance of quantum computers, capable to solve problems that are not solvable with nonquantum computers. Also, quantum communication and networks will be available, e.g., for cryptographic key exchange, also from satellites.
- ✓ The need for privacy and security for a proper management of personal data will be of paramount importance.
- ✓ The IoT and the Industry 4.0 will bring the network very close to the real infrastructures. Therefore a security breach on the networking side may quickly become a very important safety issue in the real life.

- ✓The NFV-SDN technologies and the related slicing capabilities will boost the emergence of virtual operators. This may lead to a significant innovation also in the business models and commercial strategies in the field.
- ✓

3.2 Challenges and Future Research Directions

The research in 6G is still in its infancy; hence, there are numerous open issues to resolve.

Sub-Terahertz and Terahertz communications. The availability of large bands beyond 100 GHz (D-band, 110 GHz to 170 GHz) will lead to transmission systems at high data rate over short distances, so releasing the lower band radio spectrum for long range uses.

Massive use of multiple antenna systems. The increase in the frequency will require multiple antenna systems able to exploit the multi-rays propagation, for larger throughput but also for precise localization and for energy transfer.

Dynamic spectrum allocation. The precious radio spectrum in the lower bands will be used more effectively by allocating the frequencies every second or so, based on the context.

Free-space optical communication. Optical free-space communication will allow high data rate, for both outdoor and indoor scenarios, so releasing the lower band radio spectrum for long range uses.

High accuracy indoor localization. Context awareness needs a precise user's localization.

Access schemes for massive wireless networks. New access schemes will be needed to handle a massive number of non-orthogonal users (more than 10 devices/m^2) in an efficient and scalable way.

Machine Learning & AI. The complexity of the network and the number of connected devices will lead to a network which will learn from the experience to modify itself and accommodate new services.

Wireless energy transfer. This could be in some situations a viable way to extend the battery life, avoiding frequent recharges.

Cybersecurity. The possibility to use non-personal devices for personal communication will impose new challenges on biometric authentication and privacy.

4 Conclusion

This paper briefly review the path from the first to the latest generation of mobile cellular systems, will discuss some issues not fully addressed in 5G systems, and finally will point out what we may expect beyond 5G.

Based on the regularity of market entry of 1G to 5G commercial wireless communication systems and the expectation beyond 5G, it is forecasted that 6G will start its commercialization in 10 years. In general, the 6G mobile network is expected to provide ultrafast speed, greater capacity, and ultra-low latency for supporting the possibility of new applications.

We review a range of recent research findings related to 6G design, including multi-band ultrafast-speed transmission techniques, super-flexible integrated network designs, multi-mode multi-domain joint transmission, as well as machine learning and big-data-assisted intelligent approaches.

Among the technologies to reach 6G goals we count machine learning, dynamic spectrum allocation, wireless energy transfer, free-space optical communication, use of bands beyond 100 GHz, massive use of multiple antenna systems, new access schemes allowing an increase in node density, cybersecurity for quantum attacks, high accuracy indoor localization, massive virtualization of network functionalities and novel, software driven, network control architectures.

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