Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Toward 6G wireless communications: Vision, applications, and technologies

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ARTICLE INFO

Article history:
Received 4 June 2020
Received in revised form
16 August 2020
Accepted 20 August 2020

Keywords:
5G
6G
Wireless networks
Cellular

ABSTRACT

5G is the latest standard for wireless networks that are still being slowly deployed to replace 4G and even 3G networks. Although it brings great improvements beyond 4G, it will not be capable of fulfilling the future requirements driven by the steadily increasing demands of the digital society. Therefore, the focus is now shifting toward the sixth generation of wireless communication systems (6G). Enhanced wireless connectivity that can serve the next decade is the mission of 6G. The latest initiatives have discussed the framework and the required performance capabilities of 6G cellular systems. This paper investigates the concept of the next generation of wireless communications. Therefore, ambitious scenarios of the future of wireless communications are presented. To defend the need for transitioning beyond 5G in the next decade, this paper explores the expectations, the use cases, the key performance indicators (KPIs), and the enabling technologies that will not to be available until 6G networks are deployed.

1. Introduction

Five generations of cellular communications exist with approximately 10 years between each one. The first generation was introduced back in the 1980s. Since then, the growing requirements of end-users and network operators have been motivating the development of all the generations of wireless communications. However, we are gradually transforming to data-centric societies where most of the things are going to be automated and data-dependent. Autonomous machines will soon be on the air, roads, see, etc. Therefore, billions of sensors will be exploited in the future to run all of these systems, which will be dependent on artificial intelligence (AI).

Future networks will be required to deliver a great amount of data with much greater speeds. The year 2021 is expected to witness 23 times increase in the global data traffic compared to 2005. According to the International Telecommunication Union (ITU), the overall mobile data traffic will grow exponentially until it reaches 5 zettabytes per month in 2030, as shown in Fig. 1a. Moreover, there will be a huge increase in the data trafficked through each mobile device (ITU, 2015). Fig. 1b shows that this volume will reach 275.1 GB in 2030 compared to only 5.3 GB in 2010 (ITU, 2015). These numbers depict the importance of constantly improving communication systems. To meet the requirements of this decade, the fifth-generation (5G) is gradually being deployed all over the world. Although 5G will offer significant improvements, it will reach its limit by 2030 because it will not have enough capacity to support the fully automated and intelligent systems. Therefore, researches focus is shifting towards 6G mobile cellular networks, which will be to be ready for deployment before the beginning of 2030 (Berardinelli et al., 2018; Dang et al., 2020; Letaief et al., 2019).

The constraints that prevent the 5G from supporting further development will naturally lead to the development of 6G. Therefore, the first 6G summit was held in Finland in March of 2019, where beyond 5G requirements, visions and candidate technologies have been discussed. The second summit was held virtually in March of 2020. These two summits discussed the future of wireless communications and its role in supporting emerging applications such as autonomous cars, E-health, sensing, smart wearable, and 3D mapping, where massive volumes of data at very high data rates and unprecedented speeds must process.

Studying the directions of future 6G communications is the purpose of this paper. Thus,

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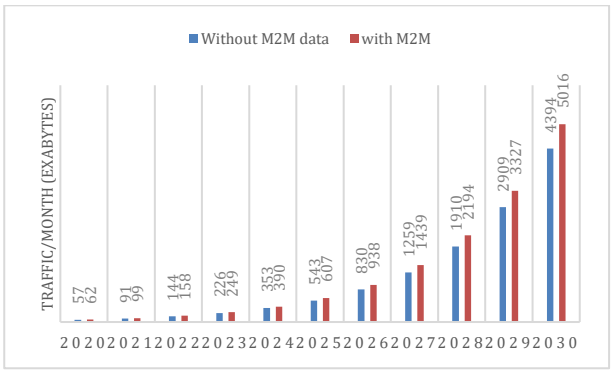
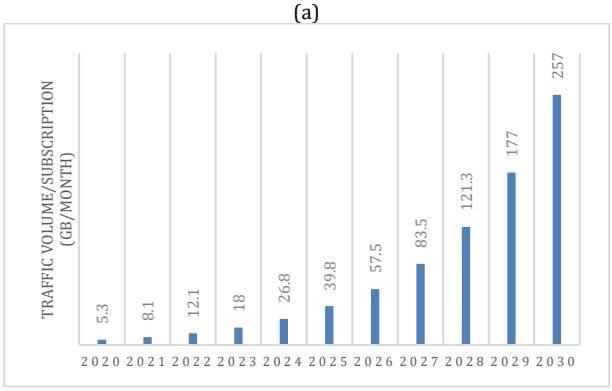
some of the key applications and technologies that we will not enjoy until 6G are pointed. Although the framework of 6G is still in progress and some of the ideas will only emerge later as more research is conducted, this paper emphasizes the main aspects of 6G and describe their capabilities that are far beyond 5G.



(a)



(b)

Fig. 1: Forecast of Global mobile data traffic by ITU (a) total traffic volume (b) traffic per subscription

2. Use cases of 6G

While ordinary means of communications like smartphones and tablets will still be used, it is man-machine interfaces that will significantly increase information consumption in the future. Fig. 2 shows some part of the things that we will witness in the 2030s:

- Autonomous mobility: There is no doubt that transitioning to a full unmanned transportation system will result in enhanced traffic management, which leads to safer traveling. Due to the increase in free time, data consummation will substantially increase in the form of entertainment or education. Moreover, the vehicles themselves are also going to be consuming a tremendous amount of data because they are connected together, where data sensors will be uploaded in real-time to the network. This will require levels of reliability and latencies that have not been precedented (Giordani et al., 2020).
- E-Heath: Health-care will also go through a revolution. It will be possible to monitor vital parameters 24/7, whether a person is healthy or sick, using various wearable devices, some of which will be connected to devices that are implanted inside the body. Also, remote surgery will be possible after eliminating space and time obstacles.
- Sensors and surveillance: With improvements in machine learning and artificial inelegance AI and their capacity to gather a massive amount of information from videos and images, a huge number of sensors and wireless cameras are going to be used everywhere.
- Virtual reality (VR) and augmented reality (AG): In order to accommodate the increasing demand for video-over-wireless, the mm-Waves spectrum has been adopted in 5G. This will unlock the potential of applications that are much more data-dependent, such as VR and AG because the key driving element of their operation relies on 3D projections and AI. The adoption of VR application in 5G will eventually exhaust the 5G spectrum and increase the required system capacity to 1 Tbsp instead of the targeted 20 Gbps for 5G (Zhang et al., 2019). Also, the data rate per user will need to be in the Gbps instead of the 100 Mbps, which has been targeted for 5G. Hence, VR and AG would be one of the most important features supported by 6G communication systems through joint design integration.
- Improved Connectivity: It is estimated that the mobile data traffic in 2021 will be 3-folds the numbers of 2016. In fact, the number of mobile devices per km^2 would be 10^7 in the dense area compared to 10^6 in 5G (Zhang et al., 2019). 6G will connect billions of sensors, as mentioned earlier, cars, personal devices, etc. Thus, higher overall energy efficiency will definitely be required in 6G to allow scalable and low-cost deployment, lower the impact on the environment, and enhance coverage.

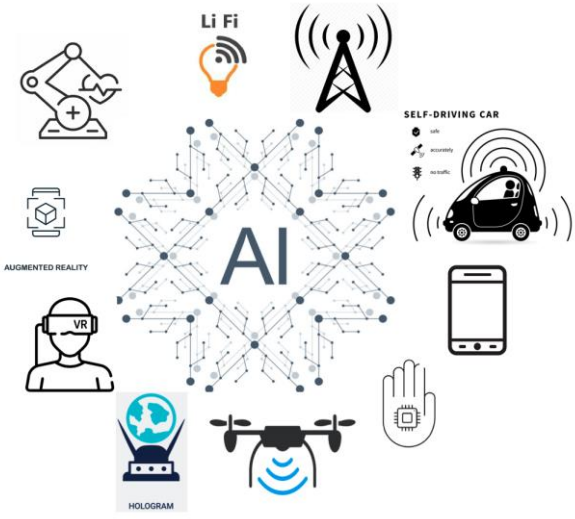


Fig. 2: Use cases of 6G

- Telepresence: 6G will enable the departure from video conferencing to virtual in-person meetings. Hence, the hologram will be an alternative for work and social interaction where real-time sounds and moving 3D projections are transferred instantly (Wakunami et al., 2016). It will simply become

possible to make a certain object or someone appear in a location while they are somewhere else. For example, a teacher can be home and appear to be in class with his students. This is going to represent a great challenge for 6G networks because connecting remotely with great reliability will be preferred. The data rate and latency required for holographic telepresence would be 4.32 Tbps and sub-milliseconds, respectively (Xu et al., 2011).

- Li-Fi: Wireless networks in 6G will need to deliver data constantly as the principle of the internet of things (IoT) become popular. Light fidelity (Li-Fi) technology is a great candidate that can serve this purpose by providing full-duplex communication via the visible light. The advantages of LiFi include the immunity against electromagnetic inferences and the ability to provide 1000 times spectrum than the usual wireless communications.
- Smart societies: The super-sophisticated features of 6G will result in societies that enjoy an improved quality of life that are also able to monitor the environment. Energy harvesting and automation that depend on AI and M2M communications are also going to be accelerated. The integration of Mobile devices, self-driving cars, AI, etc. will make our societies super smarter with the help of 6G wireless connectivity. For example, smart drones will deliver your favorite meal from your local restaurant within minutes of its preparation. Also, smart home systems will be so common in the 6G era where any device can be controlled remotely.
- Onboard aircraft connectivity with high quality: All the efforts that have been made so far in 4G and 5G to provide onboard communication services were not satisfactory. Doppler shift, lack of coverage, and the high speed that result in frequent hand-overs are all examples of the factors that prevent onboard aircraft communication services to be provided with high-quality (Dang et al., 2020). Currently, acceptable service quality communications onboard aircraft is provided using costly satellite communications (Zhang et al., 2018). Consequently, a novel networking paradigm and new communication technologies must be used in 6G communications to upgrade the quality of on-board aircraft communications service.

3. The KPIs of 6G?

Flexibility, data rate, capacity, latency, scale, throughput, and reliability are all classic key performance indicators (KPIs) for all the previous generations of wireless communications, and 6G will not be an expectation. However, given the use cases mentioned in the previous section, it is likely that there will be a number of additional new features that must be satisfied in 6G. These requirements can be put in 6 categories, as shown in Fig. 3. Three of which are similar to previous generations, and the rest are new (Viswanathan and Mogensen, 2020).

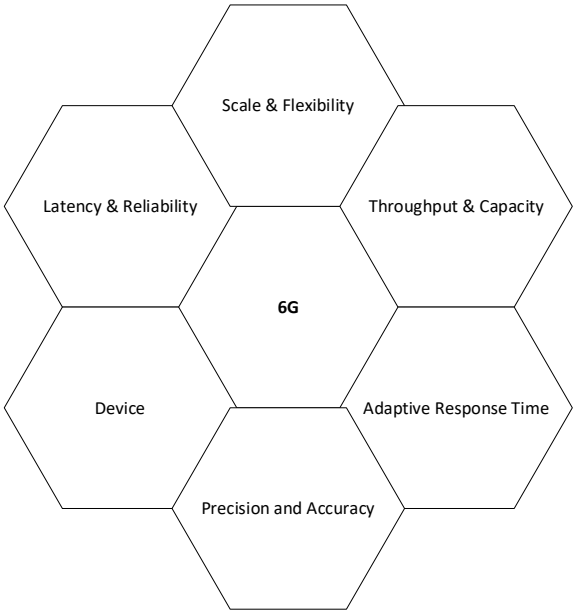


Fig. 3: Key performance indicators of 6G

It is safe to assume that end devices will be revolutionized during the 6G era. First, the power consumption of future devices will be extremely low. Also, they will depend on the network to power them while they have smaller batteries. This major revolution can enable end device to serve as a part of a network of devices. For example, parts of a machine such as drivers and controllers can be connected together through a machine-area network. Devices also will have seamless interfaces by allowing access and control using gestures instead of typing.

An important feature of 6G would be sensing and positioning. Therefore, precision and accuracy are vital for positioning and sensing, respectively. The precisions levels on the order of centimeters. False alarm (FA) and missed detections (MD) will be reduced to very low numbers in 6G, which will be used to measure the sensing accuracy.

Artificial inelegance (AI) and machine learning (ML) techniques will be embedded in the 6G network. Therefore, it will become very vital that the various nodes can adapt quickly to any change in the network. Also, most, if not all, the components of these networks will be automated. Thus, reducing or eliminating manual intervention will the criterion.

4. Enabling technologies for 6G

After discussing some of the most promising applications of 6G, it is obvious that various state of the art technologies is needed. These technologies will be enabling the features of 6G.

Incremental enhancements in spectral efficiency have been improving the capacity of all the existing generations of wireless communications. However, with all the advances that have been made in 5G like millimeter-wave, network densification, and massive MIMO, the improvement of spectral efficiency in 6G would be insignificant given the Shannon limit boundary. On the other hand, new technologies must

be used in 6G communications to enhance security and privacy. Current cryptosystems are becoming insecure as advances in Big Data and AI technologies are made. Device and network energy efficiency, intelligence, and affordability are all aspects that will be enhanced in 6G.

The following technologies are fundamental to 6G communications.

4.1. Artificial intelligence and machine learning

6G systems will utilize AI and ML as the foundation for operation rather than just being an enhancement tool. Aspects such as propagation environments, communication services, and networking will all be based on high intelligence. Pervasive intelligence about wireless channels in a particular communication environment results in a self-optimizing 6G network where reliable communications are conducted in fully intelligent methods (Yang and Wang, 2007). Also, high-quality personalized services can be provided through high-performance networks. For example, deep learning can improve the indoor positioning, and intelligent IoT can be used to collect data to provide healthcare in a smart way (Belmonte-Hernández et al., 2019; Zhu et al., 2015). Finally, resources like frequency bands, transmission power, communication devices, etc. will be allocated using advanced ML in an efficient way so that the network performance is almost optimum (Mao et al., 2018).

4.2. New spectrum bands

A higher capacity that supports higher peak rates has always encouraged the utilization of higher spectrum bands. 6G will not be an exception, and this trend will continue. Parts of the terahertz bands that lie between 0.1 THz and 10 THz will be used in 6G. Therefore, electronic/photonic transceivers will use this terahertz for free-space optical communications where the terahertz signals can be generated and sent with an optical laser. It is obvious that this technology can provide large amounts of bandwidth where communications are immune to weather conditions (Nagatsuma et al., 2016). For example, point to point communication can be conducted on the terahertz spectrum to support the backhaul networks, short-range communications, and in data centers.

4.3. Enhanced energy efficiency

One of the most annoying things about today's smartphones and tablets is that they must be charged on a daily basis, especially when operating in 4G networks (Almazroi, 2018). This will continue to be the case during the 5G period. Therefore, energy-efficient devices and batteries with much longer life will be developed to overcome the frequent need for charging, which will, in turn, result in smooth communication services during the 6G era. One of the proposed ways to improve energy efficiency is to conduct all computations of a certain device on the cloud (Huynh et al., 2018). Also, the transmit power of the mobile devices will be reduced with significant network densification because signals will only need to propagate for short distances (Yunas et al., 2015). On the other hand, new energy harvesting methods such as sunlight, micro-vibrations, and wireless charging will be used in lengthen battery life in 6G communications (Ulukus et al., 2015).

4.4. Advanced security

Despite all the research effort that has been done in the last two decades to improve reliability, network throughput, latency, and the capacity, the security issues in 4G and 5G are still handled with conventional methods. Therefore, classic encryption algorithms are becoming vulnerable, as computers are becoming more powerful. A Quantum key that is exchanged through visible light communications can be used to protect data (Chen et al., 2016). Nowadays, private data that are collected in large scales by service providers with their subscribers' consents are sometimes leaked because of the occasional cyber-attacks. To solve this problem in 6G, new technologies must be explored, such as decentralization, untraceable and total anonymization (Henry et al., 2018).

5. Conclusion

The convention of introducing cellular generations on a decade basis will continue. Thus, 6G will be deployed in the early 2030s. All of the new applications that were introduced in 5G are going to be optimized, and their cost will be reduced in 6G, which will lead to greater adoption. 6G will be enabling new applications that we never thought of nor thought possible.

Acknowledgment

The author would like to thank the deanship of scientific research at the University of Hail in Saudi Arabia for supporting and funding this project.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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