Emerging applications, technologies, and services in wireless communications: 5G to 6G evolution

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Abstract

The fifth-generation (5G) of wireless communications was launched worldwide in 2020 with solid technical specifications and standards. Therefore, the focus of major vendors and academies is now switching towards deployment of beyond 5G (B5G) communications and 6G. As a result, provision and trends for global developments appear to outline requirements and services to satisfy future societal needs. This article provides a vision for the post-5G era of wireless communications, which serves as a research guide for scientists and commercial organizations. Current achievements of 5G New Radio (5G NR) are capable of bringing human-centric communications to their limit with applications such as Extended Reality (XR), Internet-of-Things (IoT), Smart Healthcare, 4K video streaming, etc. Therefore, we suggest that machine-centric communications will now emerge as a new part of 6G networks. To justify this perspective, we provide a systematic overview of emerging applications in wireless communications. We show how and why these services are possible by identifying key enabling technologies and advances in the manufacturing process. Further, we analyze trade-offs between solutions and required cost, which is essential for business model planning of 6G. Finally, issues behind the commercialization of future technologies, such as social and health factors, integration with existing networks, and inevitable performance limits from the basic sciences, are discussed.

Key words: Next-generation networks, 5G NR, B5G, 6G, emerging technologies, services, applications.

Introduction

After successfully commercializing 5G NR communication technologies, both industry and academy establish a foundation for the next generation networks, namely B5G and 6G. It typically takes a decade to standardize and do the research for the next generation (Dang S., 2020). Highlights on wireless communication history and future trends are outlined in Fig. 1. In the 1980s, analog wireless networks, known as 1G, started to appear to allow voice communication over the air. In the early 1990s, it was replaced by the digital version of cellular networks, 2G, which also gave a boost for new services. Notably, that is the time when digital encryption and short message service (SMS) were born. Further, in the 2000s, 3G took advantage of WCDMA and CDMA2000 technologies to bring new data services such as internet access, video calls, and mobile television. Those applications have boosted the development of digital devices, smartphones, etc. After another decade, in the 2010s, 4G/Long-Term Evolution (LTE) has brought great Quality-of-Experience and Quality-of-Service (QoS and QoE) by providing broad coverage and high-speed mobile data transmission. Following this trend, 5G NR is launched in 2020, bringing even higher data rates and enhanced low-latency and ultra-reliable connections. Moreover, since spectral efficiency is reaching

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its limits, millimeter-Wave (mmWave) came into play to provide additional bandwidth and therefore increasing the data rate. Regardless of current progress, forthcoming applications are imposing more challenges and higher QoS/QoE requirements, which creates a high demand for further development and new solutions, which will form the core of 6G. Hence, the wireless communication community has initiated studies in this direction.

The purpose of the article. Herein, we aim to extend the vision from the current 5G development to emerging services and applications of 6G and key technologies that are required. We suggest that machine-centric communications will play a significant role in future networks and support our vision with selected applications and services dedicated for machines exclusively.

Analysis of recent studies and publications. A noticeable number of researchers have presented their views (Viswanathan, H., 2020; Ericsson, 2020; Samsung Research, 2020; Brown, G., 2016; Huawei Technologies Co. Ltd.; Docomo NTT; Nakamura, T., 2020; Saad, W., 2019) on the future of wireless technologies. Mainly, leading industrial vendors, such as Nokia Bell Labs (Viswanathan H., 2020), Ericsson (Ericsson), Samsung (Samsung Research, 2020), Qualcomm (Brown, G., 2016), Huawei (Huawei Technologies Co. Ltd.), and DOCOMO (Docomo NTT., 2020; Nakamura, T., 2020) have published white papers, both marked the 2030s as a target for launching 6G. In there, authors agree upon key enabling technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), dynamic network deployment (cell-free), energy harvesting, exploiting terahertz (THz) spectrum bands, usage of Intelligent Reflecting Surfaces (IRS), new security, privacy and trust paradigms (trustworthy networks). However, all of those visions are diverse in terms of projected applications and services. Notably, (Viswanathan, H., 2020) suggests an expansion of the technology in the biological world, while (Ericsson, 2020) and (Brown, G., 2016) predict AI's growth embedded in a wireless network. Samsung Research projects the primary trend to be hyper-connectivity involving humans and everything. Huawei Technologies Co. Ltd. stresses the security enhancements and proposes novel safety architectures. The technologies and applications mentioned above will be discussed in detail in the rest of the paper. Next, we will show that it creates a suitable framework for machines becoming the primary user, i.e., machine-centric network.

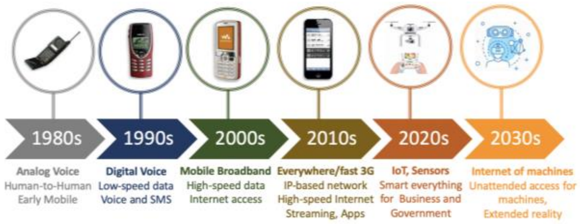

Figure 1. 1G to 6G Evolution, representing the trend of new generation per decade

What is 5G so far? Currently, at the first stage of implementation of 5G networks, both base station (gNB) and User (UE) manufacturers follow 3rd Generation Partnership Project 5G NR specifications for dense urban areas (3GPP TS 38.300). First, changes in the network architecture took place using network slicing. It allows mobile and service operators to create virtual networks over the physical infrastructure, to distribute virtual network resources for specific service needs. This gives the ability to tailor wireless systems according to the applications or even reconfigure the whole network without replacing hardware.

Currently, 5G networks operate on the 2-6GHz frequency bands, called sub-6GHz. However, humanity will experience a massive boost of internet speed with mmWave transmission and massive MIMO architecture (3GPP TR 38.901; Mezzavilla, M., 2018). This technology allows the exploitation of large frequency bands, while the main shortcoming is strong signal fading over distance compared to lower frequency channels.

Material and methods

As mentioned in the introduction section, rapid acceleration of global traffic demand is needed for multimedia streaming, online gaming, autonomous driving, extended reality, etc. As per key performance indicator values, these requirements are shown in Figure. 2 and include peak data rate, latency, connection density, positioning precision, battery life, and connection reliability.

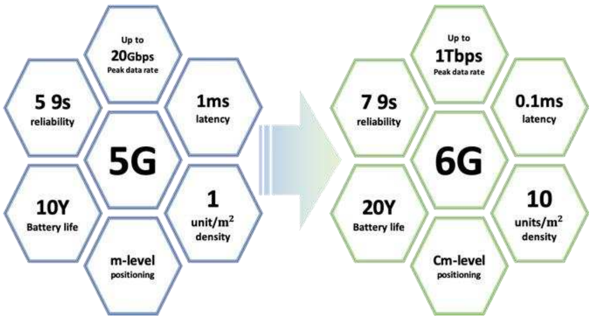

Figure 2. 5G vs. 6G key requirements comparison

Let us review critical technologies that will further augment wireless networks.

Key enabling technologies in 6G. Evolution to the next generation of wireless communication would be impossible without technological components that will boost current networks' performance and create new development frameworks.

The first such technology is *terahertz communications*, i.e., wireless transmissions in bands defined from 0.1THz to 10THz. These frequencies fall in the gap band between microwave and optical (visible light communications, VLC) spectrum. Hence, it is expected that transmission will take the form of a hybrid electronic-photonic form. Some initiatives in this direction have already been taken, as described in (Sengupta, K., 2018; Nagatsuma, 2016). This technology's main benefit is a vast band even compared with 5G, non-requirement for line-of-sight (LoS) link, and immunity to bad weather conditions. This expects to play an essential role in the uplink transmissions.

In 5G, network slicing has created an incentive for flexible networks and will further evolve. It is expected that the next generation of communications will be cell-free. Therefore, another significant change we can expect in the timeframe of 6G is *Dynamic Deployment and Context Awareness of Networks.* These two mechanisms will allow supporting cost-efficient deployment with high operation capability. Specifically, such networks allow an operator to switch performance modes by complementary focusing in either mMTC, eMBB, or URLLC with the same hardware components. Besides, the system should be able to reconfigure itself if environmental conditions would suggest so. For instance, when surveillance operation enters hazardous conditions, the reliability of connection must become the main priority for operation. Context-awareness also can allow machines to operate independently, thus creating a machine-centric perspective.

The most certain technology to power 6G has to be AI. Due to advances in machine learning in recent years and the massive availability of training data, *Edge AI* will emerge as a new paradigm. So far, there have been many great ideas about the usage of AI in wireless communications: physical layer designs such as channel estimation and precoding, resource allocation, traffic control, cache storage management, authentification and security, and the abovementioned context-aware network operations. As the amount of training data increases and tasks become more time-critical, traditional centralized learning will likely move towards federated (Servetnyk, M., 2020) and distributed learning and hence is an excellent field for researchers to propose new architectures and algorithms.

Recently advances in smart metamaterials give us a unique opportunity to take partial control over the communication environment, i.e., channel. Novel *Intelligent Reflective Surfaces (IRS)* are low-power passive devices (Wu, Q., 2019) including active frequency selection and active/passive reflect arrays. IRS can provide us access to design the channels we transmit in and create an intelligent environment. IRS is a low-cost and low-power device and thus can be densely and easily implemented.

The following key technology to enable future technology advance is *Interterritorial communications.* Indeed, to provide drones, aircraft, flying cars, and space stations, the current cellular network is not a suitable candidate. Apart from communications over the sky and on the ground, it is crucial to extend communication networks to the underwater environment, especially considering that most of the Earth's surface is water. This would significantly enhance marine monitoring and create new applications. Underwater communications are likely to exist in acoustic form; however, reliable high-data-rate development is required (Zeng, Z., 2016). Another aspect currently existing fiber-optics infrastructure used to connect continents may help be a gateway for basic underwater base stations.

Being discussed for decades, *Energy harvesting* or *Wireless Power Transfer* is another essential technology in 6G. Due to the network densification, the distance between nodes will become much shorter. Moreover, switching to higher frequencies will have a more considerable power amount transferred over the air and become a valid power source. This technology becomes even more meaningful as users or IoT devices become more power-hungry with the presence of AI at the edge. The improvements in this rely on new networking architectures and operational strategies. It is provisioned that the 6G base station could provide primary power transfer for low-power devices such as implants and sensors (Saad, W.,2019).

The next enabler of 6G communication is *Reliable and Secure Networks,* a vital component of the machine-centric network. In recent decades great emphasis was put on data rate, latency, reliability, and coverage, while security has been neglected. Indeed, the current RSA algorithm can increase their security guarantees by simply extending the security key length. However, given the growth of machines' computational performance, improvements in quantum computing, and the rise of AI technology, alternative approaches need to be investigated. Moreover, physical layer security for VLC and THz communication is a new security challenge for cyber protection.

Driving trends and potential applications in 6G. Evolution and progress in wireless communications are impossible without applications that would convince industry and researchers to explore it. With predicted capabilities, 6G would become a technology that will connect machines to humans and to other machines. Throughout the following applications, it becomes apparent that the main focus is located on non-presence techniques, i.e., remote control, remote presence, and full automation.

The first application of this kind is *Extended Reality (XR)*. This term combines Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). XR's advent with complete human-sense feedback would require high data-rates, extremely low latency, and accurate positioning for precise spatial mapping. Current AR technology (Samsung Research, 2020) requires 55Mbps to support an 8K display that is enough QoE on mobile display; however, XR media streaming would require nearly 0.9Gbps throughput is not currently available. One of the potential uses of this application technology is the real estate business. XR makes it simpler for real estate representatives to close a deal by allowing prospective homebuyers to feel the property's authentic feel. Other possible applications can be marketing, healthcare, education, Entertainment, and Gaming.

A complementary application to XR is expected to be *haptic (tactile) communications,* which allow remotely exchanging physical interactions through the tactile internet in real-time. Mainly it will be possible through communications between remotely located mobile nodes and wearable sensors on users. Mobile nodes can form a human-like robot with five basic human senses, while low-latency technology will ensure real-time experience. This application will be another step that allows accomplishing tasks without human presence using a robot. The importance of it becomes especially clear during the ongoing COVID-19 pandemic when interaction opportunities are limited.

A logical extension of XR and haptic communications is *holographic telepresence*. Nevertheless, unlike in the previous two technologies, no headset is needed. In such a case, bandwidth requirements will grow up to terabits. This technology would allow controlling entire physical space with the use of IRS and similar structures. Using special equipment in a studio or laboratory, projection equipment beams users into one or multiple venues. An example of such technology was shown ARTH Media company as a Virtual Global Stage Platform, shown in Fig. 3. However, at the current stage, physical interaction for the user is not possible.

Figure 3. Example of holographic telepresence. Left: presenter's setup. Right: presence at the venue

Combined with tactile communications, holographic telepresence will bring us new experiences as holographic calls, meetings, and tourism.

The growing and aging population create a huge load on the healthcare system. Several ubiquitous health monitoring devices have been created to measure various health indicators such as heart rate, blood pressure, temperature, glucose level, and brain activity to report to medical departments via IoT framework automatically. With this in mind, *E-Health* applications might become a valid alternative to traditional medicine. The concept assumes sending medical data directly to an AI server that can immediately decide about treatment or suggests visiting a relevant medical department. Given that patients' data is highly private, a high level of secrecy is needed. Another focus should be put on the communication reliability of communication in case of emergencies.

Another important concept that can find its application in industry and military is *Tele-operated Driving* or *Intelligent Transportation System*. The main requirements for this technology are extremely low latency, ultra-reliable connection, and increased security. Despite total human control, vehicles are required to be equipped with AI technologies that implement a collision-avoidance system coordinated by a combination of multiple sensors. Note that in addition to human-to-vehicle connection, vehicles have to exchange massive amounts themselves to update live-traffic conditions and report hazard information on the road.

Incorporating AI, IoT, and robots into automation and warehouse transportation is crucial for industry advancement. *Intelligent Automation and Manufacturing* is perspective direction as it allows to avoid human error, makes faster adjustments, and better monitor. Notably, 5G features industrial internet and industrial IoT to kick off factory transformations. It is expected that the next generation of factories will have an individual radio environment (private 5G/6G) with a very advanced network comprised of hundreds or thousands of robots. 6G is called to support the next industrial revolution by offering massive URLLC and massive IoT and embedded AI capability. The technology makes it possible to create connections between machines and exchange information per its request to regulate ongoing processes.

Finally, the last key component of 6G communications is blockchain-enabled Security and Authentication. With over 50 billion connected UE and IoT devices, 6G will need to secure data storage and dataflows across different platforms. Blockchain technology will be a significant component in securing and authenticating future communication systems thanks to the distributed ledger technology's inherent advantage. Some good use cases will include distributed security management for IoT, offloading in mobile edge computing, network function virtualization and content caching, etc.

Results and discussion

Machine-centric communications. The current and projected progress of implementing 5G networks is expected to reach the limit in terms of human user QoE. However, recent advances in AI, material science, and the exploitation of high-frequency bands create an incentive for further wireless network evolution and become next-generation communications. Performance of 6G is expressed in better internet connection, more reliable and low-latency connection. However, from the users' perspective, it will not create a new application niche; most likely XR, holographic telepresence, and E-health, which already exist in some forms, will evolve and become more spread and low-cost. A different situation is from the machines' perspective. With the increased security level, reliability, and AI onboard, machines will no longer need human intervention to operate, to request, and exchange information with other machines. This is reflected in futuristic applications such as smart manufacturing, intelligent transportation system, and E-health as the closed-loop of interaction can be established to complete tasks without external control during casual operations. Also, certain technologies such as terahertz and quantum communications are not likely to be carried on smartphones or inside home gadgets. Hence, it is expected that 6G communications will be *machine-centric*.

Factors hindering evolution to 6G.

Communication technologies are important but not in every field. In order to promote development, social, economic, technological limitations should be considered. A frequent topic in media nowadays is the "harm" of the 5G base station, which reflects health concerns about radiation in the high-frequency bands. This aspect is likely to get worse as even higher frequency bands will be used. Moreover, since machine-centric communication prevails in 6G, industrial interest will prevail over users and negatively influence social factors. Therefore, industrial investments should prevail. Many examples of promotion schemes and campaigns sponsored by governments and private companies are working to persuade the unconnected, distant areas to be connected and promote the concept of worldwide connectivity in the 6G era.

Current research is focusing on technology and applications while rarely on business models and commercialization. Further network densification improves performance according to the logarithmic curve, i.e., more cost is required to get less performance. Building new base stations is costly, and therefore it is undefined who should pay for it. Moreover, as break-through technologies are coming into play, backward compatibility with 4G and 5G remains an open question. The cost evaluation for updating existing infrastructure should be done and compared with building new infrastructures. It should be remembered that ordinary users will refuse to pay several times more for relatively small QoE gain.

Last but not least component that hinders the development of 6G is a dependency on the basic sciences. While THz communications and VLC are promising theoretically, there are very few works speaking about the constraint of the electronic circuit made by the manufacturing technologies or if commercial chips can process the signal on higher-frequency bands at all.

Major trade-offs in the 6G evolution. During the design of the new engineering systems, it is vital to determine a list of features that will be enhanced. While it is desired to maximize every system parameter, investing resources should be used wisely, and therefore critical trade-offs should be outlined. Moreover, improving certain features automatically leads to the degradation of others. For instance, the trade-off between *spectral efficiency versus energy efficiency* is traditional performance versus power dilemma. As longer battery life is required of 6G, energy harvesting must likely release power constraints. Besides, reconfigurable intelligent surfaces can ensure power resource delivery to user devices. The second trade-off is *security versus spectral efficiency*. To guarantee protection against fraud, part of the radio spectrum is used for encryption algorithms, decreasing the amount of useful information transmitted. Moreover, physical security algorithms such as frequency hopping also decrease spectral efficiency. The third trade-off regulates *privacy versus intelligence*. Despite a substantial boost in AI algorithms, they still rely on the training data, which is often private. A potential solution to this issue is introducing differential privacy algorithms, which modify every data point without distorting the global view. Also, performing training in a distributed fashion, such as only local AI models, is exchanged with a centralized server. That creates another trade-off, the *cost versus intelligence*, as both software and infrastructure advances, require new investments. The ultimate goal for 6G is to develop highly reconfigurable networks that would balance and fit the industrial and user requirements without rebuilding the overall system.

Conclusions

In this work, we discussed the evolution of wireless networks at the current stage. Following the trend of launching a new generation of the internet each decade, 5G implementation has started. At the same time, research and industrial community have started research about 6G. Its goals are similar to the goals of 5G: higher data-rates, increased reliability, shorter latency, and generally better QoS and QoE. Key enabling technologies, such as terahertz spectrum, edge AI, dynamic development, energy harvesting, and context-aware networks, will be used to achieve it. It is predicted that such networks' capabilities will exceed user needs and create a new paradigm – machine-centric networks. As a result, most of the applications will be dedicated to interconnecting machines and remote control for industry and other machine usages. At this stage, many trade-offs and limitation factors will guide future development and provide solutions, which will have a ubiquitous influence on many industries.

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