Into the wild: The Design Challenges and Opportunities of Sixth-Generation Wireless System

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***Abstract* - Wireless communication technologies are constantly evolved for the past few decades. Various stakeholders, such as industrial solutions providers, academic research groups, standards bodies, and end-users, have all substantially benefited from the unconventional changes led through the most recent developments. The ongoing deployment of 5G cellular systems is continuously exposing the inherent obstacles of this system, as compared to its original premise as an enabler for the Internet of Everything applications. 6G and beyond will satisfy the requirements of a fully connected world and provide ubiquitous wireless connectivity for all. Transformative solutions are anticipated to drive the surge for accommodating a rapidly developing number of intelligent devices and services. This paper presents a holistic, forward-looking vision that defines the tenets of a 6G system.**

***Index Terms* - 5G, 6G, AI, Blockchain, Cellular technology, Wireless Communication.**

1.INTRODUCTION

Sixth generation communication systems aim to achieve high spectral and energy efficiency, low latency, and massive connectivity because of extensive growth in the number of Internet-of-Tings (IoT) devices. IoT devices are predicted to reach 25 billion by the year 2025 [1], and therefore, it is very challenging for the existing multiple access techniques to accommodate such a massive number of devices. Even fifth generation (5G) communication systems, which are being rolled out in the world at the moment, cannot support such a high number of IoT devices.

Currently, there is little information about the standards of 6G. However, it is estimated that the international standardization bodies will sort out the standards for 6G by the year 2030 [2]. The work at some of the research centers has shown that 6G will be capable of transmitting a signal at a human computational capability by the year 2035[3]. While the rollout of 5G is still underway, the researchers across the world have started working to bring a new generation of wireless networks. A tentative timeline for the implementation of 5G, B5G, and 6G standards by international standardization bodies is shown in Fig. 1 with respect to the vision of 6G wireless networks. It is predicted that ITU (International Telecommunication Union) will complete the standardization of 6G (ITU-R IMT-2030) by the end of the year 2030, whereas 3GPP will finalize its standardization of 6G in R23 [3]. ITU has established a focus workgroup for exploring the system technologies for B5G/6G systems in July 2018 [4]. The Academy of Finland has founded, 6Genesis, a flagship pro-gram focusing on 6G technologies, in 2018 [5]. Similarly, China, the United States of America, South Korea, Japan, Russia have also started the research for B5G/6G communication technologies [2, 3, 6–8]. The authors in [9] and [10] give a predictive technical framework for industries in future generations of communication systems mainly focusing on the specifications of future generations of the communication system. Cell-less architecture, decentralized networking, and resource allocation, and three-dimensional radio connectivity including the vertical direction are expected in next-generation communication systems (Fig 1).

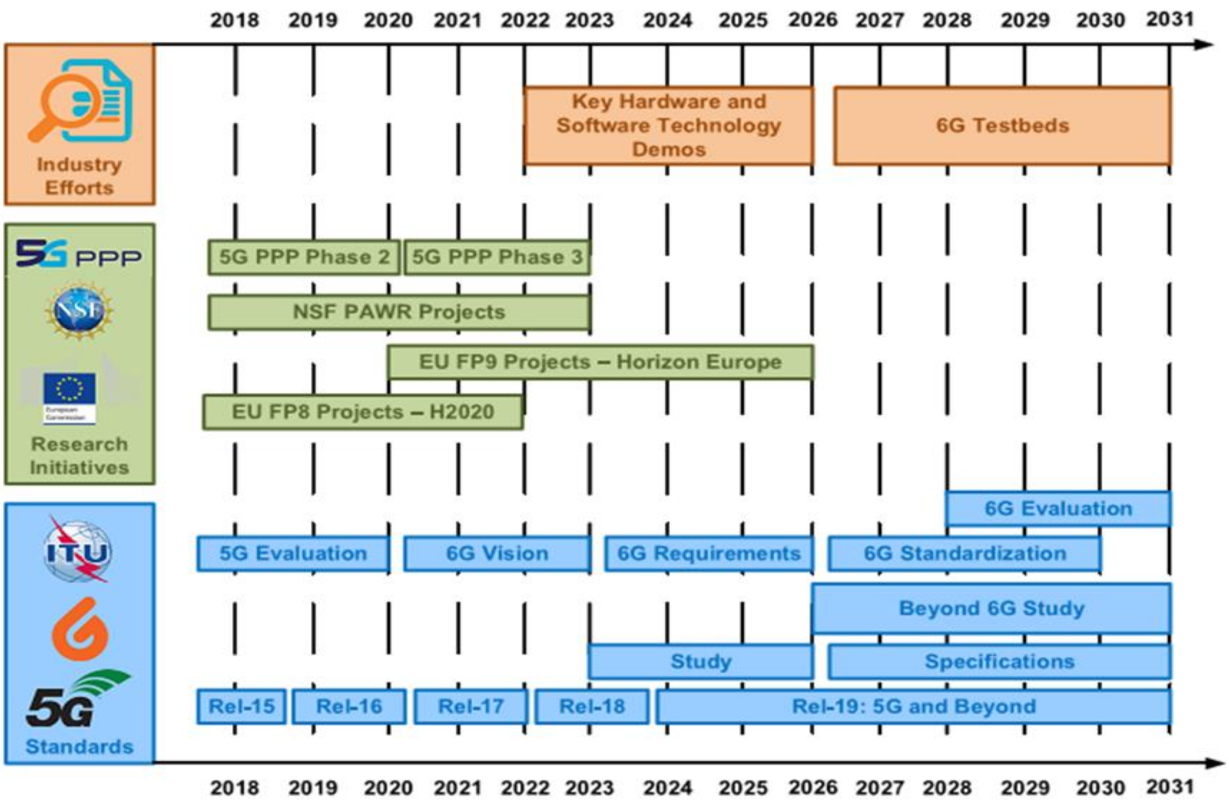

Fig 1. Timeline of 6G mobile system evaluation.

2. LITERATURE REVIEW

The earliest article [11] that discusses the topic of 6G was published in September 2018, where David and Berndt tried to address the question of "Is there any need for beyond 5G?" by reviewing the key services and innovations from the 1G analog system to the virtualized and software-defined 5G infrastructure. In [12], Rappaport et al. described the challenges and potentials of terahertz (THz) communications in the development and implementation of 6G networks. Later, the authors of [13] provided a brief description of vision and potential techniques.

The evolution of wireless systems from 1G to 6G is outlined in [14]. The authors in [15] presented the role of intelligent surfaces in the architecture of 6G networks. The authors in [16–19] presents the expected technologies, possible applications of 6G. The articles [20–24] present the system-level perspective of the 6G scenario with use cases, vision, and technologies. The authors in [25] analyze the application of blockchain for the security and privacy measures in upcoming 6G networks. The potential role of optical communication in 5G/B5G and 6G communication networks is described in [3]. The article [26] presents the feasibility of the application of mmWave communication in satellite communication as an enabler of 6G networks. The article [27] gives an analysis of potential applications of device-to-device communication in 6G. The authors in [6, 28–30] elaborate on the multiple challenges in integrating artificial intelligence (AI) and its potential role in future communication networks. The authors in [31, 32], have focused on the vision for the next generation of wireless communication systems. Blockchain and AI are the potential technologies for the next generation communication systems. Blockchain can be used for efficient resource sharing and AI can be implemented for the robust, self-organizing, self-healing, and self-optimizing wireless network [33].

3. FROM THE BEGINNING

Since the Nippon Telegraph and Telephone Public Corporation (NTT) initiated the world's first cellular mobile communication service in December 1979, the technology of mobile communications has continued to develop every decade, evolving to new generation systems [34]. With the progress of technology, services have continued to evolve. From the first generation (1G) to the second generation (2G), voice calls were the main means of communication, and simple e-mail was possible. However, from the third generation (3G), data communications such as "i-mode" and multimedia information such as photos, music, and video could be communicated using mobile devices. From the fourth generation (4G), smartphones have been explosively popularized by high-speed communication technology exceeding 100 Mbps using the Long-Term Evolution (LTE), and a wide variety of multimedia communication services have appeared. 4G technology continues to evolve in the form of LTE-Advanced and has now reached a maximum communication speed close to 1 Gbps (Fig 2). The proverb of wireless communication is 2G enable internet, 3G sent pictures, 4G streamed video and what 5G and 6G will do?

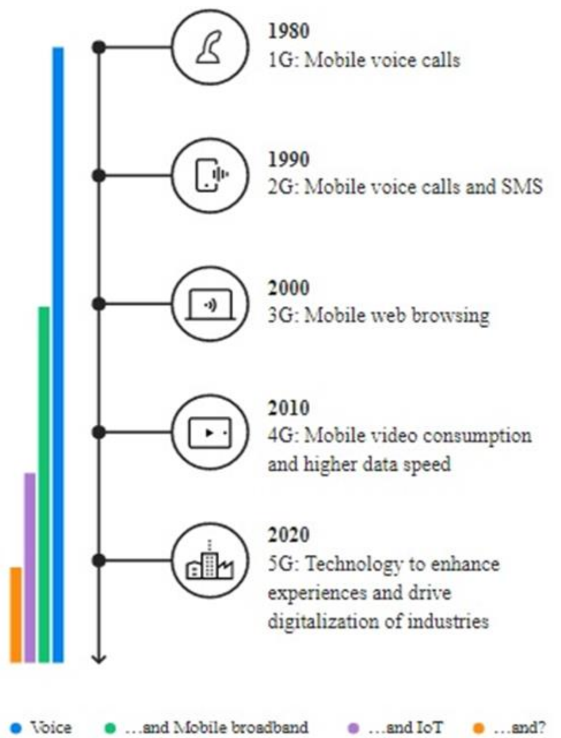

Fig 2. Evolution of wireless communication

4. IS 5G NOT ENOUGH?

5G is fifth generation wireless technology that brings three new things to the table: wider channels (speed), lower latency (responsiveness) and more bandwidth (the ability to connect a lot more devices at once). That provides services of Enhanced Mobile Broadband, Fixed Wireless Access, Massive Internet of Things, Industrial Automation, Virtual Reality, and Driverless car etc [35].

Fig 3. Applications of 5G [35]

5G requires unique perspective on the physical and higher layer challenges relating to the design of next-generation core networks, new modulation and coding methods, novel multiple-access techniques, antenna arrays, wave propagation, radio frequency transceiver design, and real-time signal processing [36, 37].

The technical details behind all this can get very confusing, but the bottom line is that mm Wave technology (which is the only version of 5G that Verizon currently offers but also is being used to a lesser degree by AT&T and T-Mobile) can go very fast, as in up to about 50 times faster than standard 4G, but not very far. Sub-6 5G, on the other hand, is very robust and capable of traveling long distances, particularly the "low-band" sub-segment of the technology.

4.1 Challenges on implementation of 5G

- First, it needs a whole new infrastructure. Cell phone provider, for example, will need to install a lot of new equipment for this new technology because 5G uses a totally different wavelength than the 4G standard your phone currently uses[38, 39].
- The 5G standard uses millimeter waves [40, 41], which are a lot shorter than the wavelengths 4G uses. The shorter wavelength means 5G can carry a lot of data much faster than 4G, but it also means a much shorter range. 4G wavelengths have a range of about 10 miles. 5G wavelengths have a range of about 1,000 feet, not even 2% of 4G's range. So to ensure a reliable 5G signal, there needs to be a lot of 5G cell towers and antennas

everywhere. Probable, every lamppost, traffic light, etc. because even trees can block 5G signals [42]. Another issue is security and privacy in D2D (Device 2 Device) communication because of routing users' data through other users' devices [43]

- One of the biggest problems they face is actually local governments, local communities, who don't want these carriers to build towers or antennas all over the place. Or maybe they're afraid of the health risks, which is another big concern.
- You can expect 5G phones to cost you about $200 to $300 more than one without 5G
- The important challenges in the implementation of 5G from the technology aspects including mm Wave communications, backhaul technology, Technology maturity, energy consumption, EMF and business aspects including business models, ecosystem maturity, Coordination of industry verticals and regulation aspects including spectrum management and fragmentation [44].

5. ROADMAP TO 6G

The development of a sixth-generation system is driven by not only the exponential growth of mobile traffic and mobile subscriptions but also new disruptive services and applications on the horizon. In addition, it is also driven by the intrinsic need of mobile communication society to continuously improve network efficiencies namely cost efficiency, energy efficiency, spectrum efficiency, and operational efficiency. With the advent of advanced technologies such as AI, THz, and large-scale satellite constellation, the communication network is able to evolve towards a more powerful and more efficient system to better fulfill the requirements of current services and open the possibility for offering disruptive services that have hitherto never been seen. We are in an unprecedented era where a large number of smart products, interactive services, and intelligent applications emerge and evolve in a prompt manner, imposing a huge demand on mobile communications. It can be foreseen that the 5G system is hard to accommodate the tremendous volume of mobile traffic in 2030 and beyond. Due to the proliferation of rich-video applications, enhanced screen resolution, machine-to-machine (M2M) communications, mobile cloud services, etc., the global mobile traffic will continuously increase in an explosive manner, up to 5016 EB (Exabyte) per month in the year 2030 compared with 62 EB per month in 2020, according to the estimation by ITU-R [45] in 2015(Fig 4).

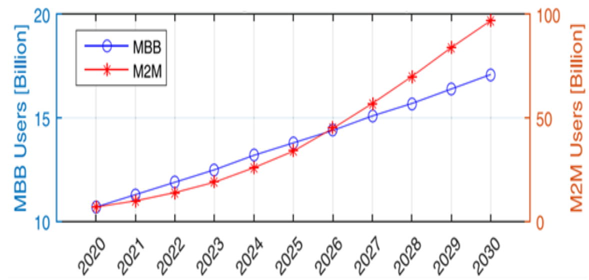

Fig 4. Usage trend of M2M and broadband users

The various use cases of 6G are given below (Fig 5)

- Holographic−Type Communication (HTC)
- Extended Reality(ER)
- Tactile Internet
- Multi−Sense Experience
- Digital Twin
- Pervasive Intelligence
- Intelligent Transport and Logistics
- Enhanced On−Board Communications
- Global Ubiquitous Connectability

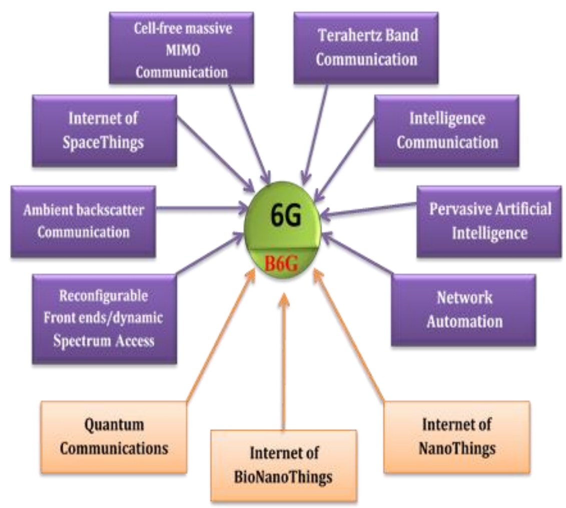

Fig 5. Use case of 6G and Beyond 6G (B6G)

5.1 6G system architecture

Next-generation wireless networks will consist of massive number of connected devices and with the base stations (BSs)/access points (APs) leading to mMTC. Multiple BSs/ APs may serve one or more devices simultaneously to form a coordinated multi-point (CoMP) transmission [46]. The huge amount of data produced by massive devices will require very high-performance processing units and robust backhauling links. The central processing units may utilize ML and AI algorithms and the backhauling links may utilize optical fiber and or photonic communications. Remote user, in 6G communication systems, can use several relays or transmitters for a remote user to transmit, and the user's SINR may be improved by using the technique of diversity as in virtual MIMO systems.

By intelligent networking, all the end devices would be aware of the location and features of BSs/APs in their vicinity, and all of the BSs/APs would be aware of the locations, features, and QoS requirements of devices in their vicinity. Robust interference management/optimization techniques can be applied to maximize the efficiency of the wireless network. Central processing units will be fast enough to manage and switch the resources (bandwidth, time, power) among multiple end-users, and data processing will be conducted at the base-band processing units (BPUs). Figure 3depicts some of the major components in the 6G system architecture that will cause a major paradigm shift towards the realization of 6G standards. The air interface is the main component that causes a major improvement in the wireless generations. Orthogonal frequency division multiplexing (OFDM) played a major role in the development of 4G, as code division multiple access (CDMA) was the key player in 3G. Similarly, the development of the new air interface will be an essential component of 6G system architecture.

AI and ML is another crucial component of the 6G system architecture. AI and ML will play an important role in the self-organization, self-healing, self-configuration of 6G wireless systems. Spectrum congestion has also pushed the 6G to adopt a new spectrum for communication. Therefore, this new spectrum will also be an active component in the 6G system architecture. Since 6G will accommodate a wide range of communication devices ranging from IoTs to live HD video transmission, 6G will need to be in line with all previous technologies. Therefore, flexible and multi-radio access technologies (RAT) system architecture will be an essential component in the 6G network

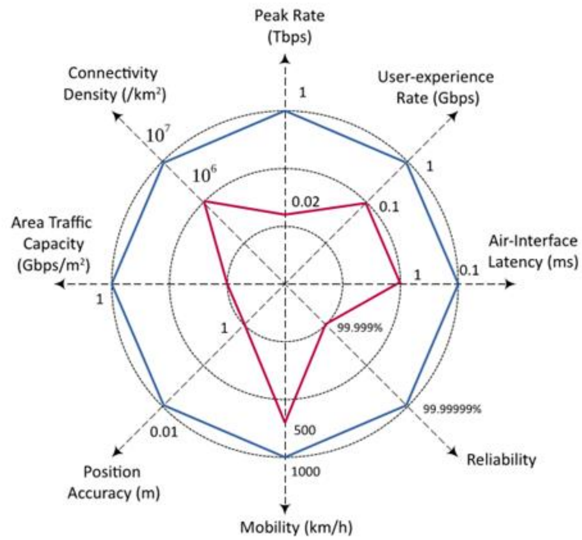

Fig 6. Quantitative KPI comparison between 5G and 6G

Figure 6 comprises quantitative comparison of the technical requirements between 5G and 6G w.r.t eight representative KPIs (Key Performance Indicators). The vertices of the inner polygon stand for the KPIs for 5G, while the vertices of the outer octagon represent that of 6G. Different dotted circles indicate quantities in an exponential manner instead of proportional scale, where the value in a bigger circle stands for one order of magnitude "better" than that of the neighboring smaller circle. For example, the minimal latency of 5G is defined as1msin comparison with0.1msexpected in 6G, amounting to 10 times better, while the peak rate of 6G is envisioned to be 1Tbps that is 50 times over 5G.

6. CONCLUSION

This paper explores the research possibilities and trends of next decade wireless systems and outlines a holistic top-down approach in describing 6G systems. This take a look at begins with the challenges of 5G and imparting a vision for 6G, followed through a detailed breakdown of the subsequent-technology use cases, which includes high-fidelity holographic communications, immersive reality, tactile Internet, and beyond 6G. The introduction of recent network architecture for the 6G core network is also mentioned in this article. After a prolonged evaluation dissecting many system components, as well as exploring viable solutions, the research can conclude that there may be a thrilling future that lies ahead. The road to overcoming the challenges is full of obstacles, yet we provide sufficient insights to begin research towards promising directions.

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