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Evolution of Mobile Networks

Mobile networks have been evolving since the 1980s, resulting in a new generation of mobile network every decade. Presently, fifth-generation (5G) mobile networks are being deployed. However, mobile communication research and development work suggest that we can expect to see sixth-generation (6G) mobile networks by 2030. After reading this chapter, you should be able to

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- Explain the evolution of mobile networks from 0G to 6G.
 - Understand the present context of 6G development.
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1.1 Introduction

While fifth-generation (5G) mobile communication networks are deployed worldwide, multitude of new applications and use-cases driven by current trends are already being conceived, which challenges the capabilities of 5G. This has motivated researchers to rethink and work toward the next-generation mobile communication networks “hereafter 6G” [1, 2]. The sixth-generation (6G) mobile communication networks are expected to mark a disruptive transformation to the mobile networking paradigm by reaching extreme network capabilities to cater to the demands of the future data-driven society.

So far mobile networks have evolved through five generations during the last four decades. A new generation of mobile networks emerges every ten years, packing more technologies and capabilities to empower humans to enhance their work and lifestyle. The precellphone era before the 1980s is marked as the zeroth-generation (0G) of mobile communication networks that provided simple radio communication functionality with devices such as walkie-talkies [3]. The first-generation (1G) introduced publicly and commercially available

cellular networks in the 1980s. These networks provided voice communication using analog mobile technology [4]. The second-generation (2G) of mobile communication networks marked the transition of mobile networks from analog to digital. It supported basic data services such as short message services in addition to voice communication [5]. The third-generation (3G) introduced improved mobile broadband services and enabled new applications such as multimedia message services, video calls, and mobile TV [6]. Further improved mobile broadband services, all-IP communication, Voice Over IP (VoIP), ultrahigh definition video streaming, and online gaming were introduced in the fourth-generation (4G) [7].

The 5G mobile communication networks are already being deployed worldwide. 5G supports enhanced Mobile Broadband (eMBB) to deliver peak data rates up to 10 Gbps. Furthermore, ultra-Reliable Low Latency Communication (uRLLC) minimizes the delays up to 1 ms while massive Machine Type Communication (mMTC) supports over 100× more devices per unit area compared to 4G. The expected network reliability and availability is over 99.999% [8]. Network softwarization is a prominent 5G technology that enables dynamicity, programmability, and abstraction of networks [9]. Capabilities of 5G have enabled novel applications such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), autonomous vehicles, Internet of Things (IoT), and Industry 4.0 [10, 11].

Recent developments in communications have introduced many new concepts such as Edge Intelligence (EI), beyond sub 6 GHz to THz communication, Nonorthogonal Multiple Access (NOMA), Large Intelligent Surfaces (LIS), swarm networks, and Self-Sustaining Networks (SSN) [12, 13]. These concepts are evolving to become fully fledged technologies that can power future generations of communication networks. On the other hand, applications such as Holographic Telepresence (HT), Unmanned Aerial Vehicles (UAV), Extended Reality (XR), smart grid 2.0, Industry 5.0, and space and deep-sea tourism are expected to emerge as mainstream applications of future communication networks. However, requirements of these applications such as ultrahigh data rates, real-time access to powerful computing resources, extremely low latency, precision localization and sensing, and extremely high reliability and availability surpass the network capabilities promised by 5G [14, 15]. IoT, which is enabled by 5G, is even growing to become Internet of Everything (IoE) that intends to connect massive numbers of sensors, devices, and Cyber-Physical Systems (CPS) beyond the capabilities of 5G. This has inspired the research community to envision 6G mobile communication networks. The 6G is expected to harness the developments of new communication technologies, fully support emerging applications, connect a massive number of devices, and provide real-time access to powerful computational and storage resources.

1.2 6G Mobile Communication Networks

The 6G networks are expected to be more capable, intelligent, reliable, scalable, and power-efficient to satisfy all the expectations that cannot be realized with 5G. The 6G is also required to meet any new requirements, such as support for new technologies, applications, and regulations, raised in the coming decade. Figure 1.1 illustrates the evolution of mobile networks, elaborating key features of each mobile network generation. Envisaged 6G requirements, vision, enablers, and applications are also highlighted to formulate an overview of the present understanding of 6G.

1.2.1 6G as Envisioned Today

The 6G mobile communication networks, as envisioned today, are expected to provide extreme peak data rates over 1 Tbps. The end-to-end delays will be imperceptible and lie even beneath 0.1 ms. The 6G networks will provide access to powerful edge intelligence that has processing delays falling below 10 ns. Network availability and reliability are expected to go beyond 99.99999%. An extremely high connection density of over 10^7 devices/km² is expected to be supported to facilitate IoE. The spectrum efficiency of 6G will be over 5× than 5G, while support for extreme mobility up to 1000 kmph is expected [12].

It is envisioned that the evolution of 6G will focus around a myriad of new requirements such as further-enhanced mobile broadband (FeMBB), ultramassive Machine-Type Communication (umMTC), Mobile BroadBand and Low-Latency

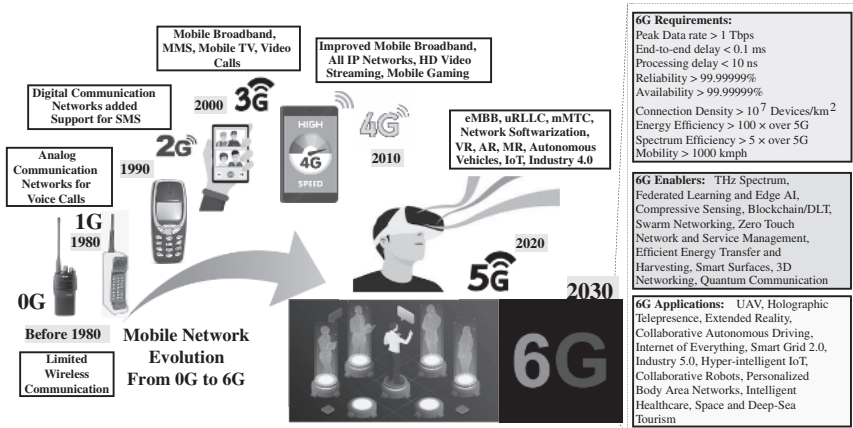


Figure 1.1 Evolution of Mobile Networks from 0G to 6G. Source: vectorplus / Adobe Stock.

(MBLL), and massive Low-Latency Machine Type communication (mLLMT). These requirements will be enabled through emerging technologies such as THz spectrum, Federated Learning (FL), edge Artificial Intelligence (AI), Compressive Sensing (CS), blockchain/Distributed Ledger Technologies (DLT), and 3D networking. Moreover, 6G will facilitate emerging applications such as UAVs, HT, IoE, Industry 5.0, and collaborative autonomous driving. In light of this vision, many new research work and projects are themed toward developing 6G vision, technologies, use-cases, applications, and standards [1, 2].

1.2.2 6G Development Timeline

The 6G developments are expected to progress along with the deployment and commercialization of 5G networks, and the final developments of 4G Long-Term Evolution (LTE), being LTE-C, which followed LTE-Advanced and LTE-B [16]. The vision for 6G is envisaged to be framed by 2022–2023 to set forth the 6G requirements and evaluate the 6G development, technologies, standards, etc. Standardization bodies such as the International Telecommunication Union (ITU) and Third-Generation Partnership Project (3GPP) are expected to develop the specifications to develop 6G by 2026–2027 [16]. Network operators will start 6G research and development (R&D) work by this time to do 6G network trials by 2028–2029, to launch 6G communication networks by 2030 [14, 16–18]. Global 6G development initiatives are illustrated in Figure 1.3, while the expected timeline for 6G development, standardization, and launch is presented in Figure 1.2.

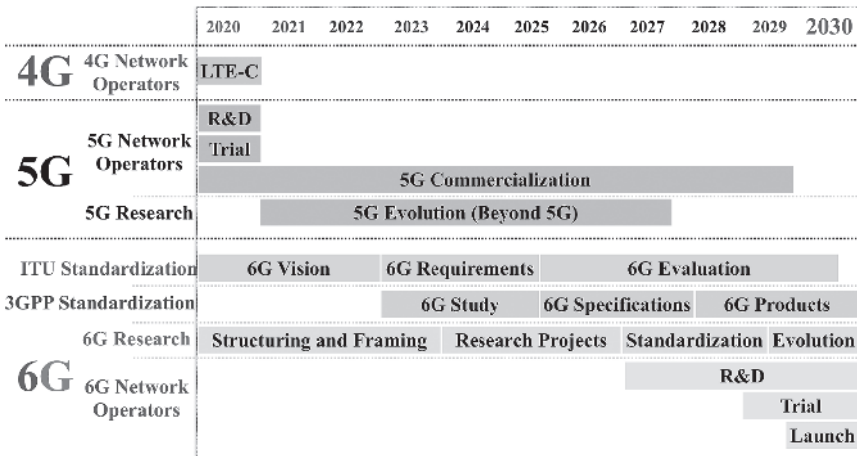


Figure 1.2 Expected Timeline of 6G Development, Standardization and Launch. Source: Adapted from [14, 16–18].

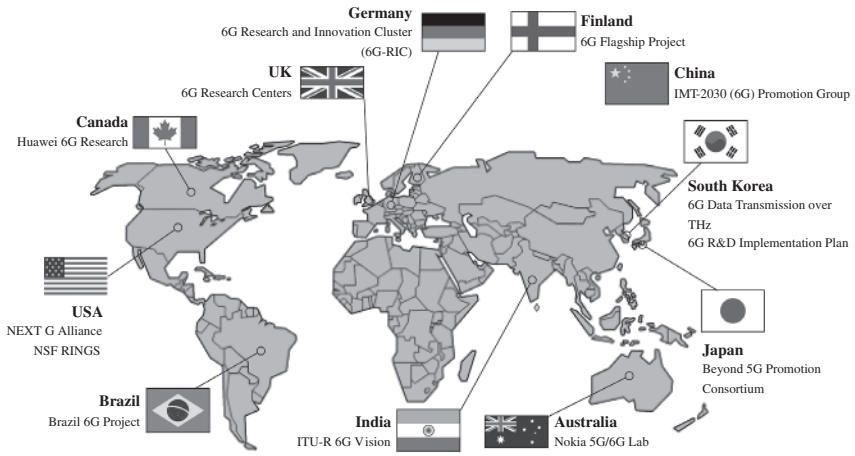


Figure 1.3 Global 6G Development Initiatives.

