BRIEFING

European Parliament

The path to 6G

SUMMARY

The European Union needs high-performing digital connectivity infrastructure to give all citizens the best access to digital services and to maintain prosperity. In the relentless pursuit of innovation and connectivity, the development of mobile communications technologies has been a defining force in shaping the way we communicate, work, and live.

As the 2030s approach, the groundwork for the next frontier in mobile communications is being laid – the era of 6G. Building upon the successes and advances of previous mobile generations, 6G promises to revolutionise the connectivity landscape. From ultra-high data rates and low-latency communication to the integration of artificial intelligence, 6G is poised to reshape the way we interact with the digital world.

However, with the promise of unprecedented capabilities comes a host of challenges. Critical aspects that demand attention in the development of 6G networks are privacy and cybersecurity. As 6G aims to push the boundaries of connectivity, enabling innovations such as holographic communication, seamless extended reality, and the integration of artificial intelligence (AI) on a massive scale, the potential risks to privacy and cybersecurity are magnified (e.g. mass data collection). Another critical aspect is its environmental footprint. While 6G aims for energy efficiency, the increasing demand for data and connectivity may still pose challenges related to energy consumption. Balancing technological progress with environmental considerations remains a key objective for the development of 6G.

Countries and companies that lead in 6G development and deployment are expected to gain a competitive edge in terms of technological innovation, economic growth, and influence in shaping global standards. The global race to 6G has already begun.

IN THIS BRIEFING

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Author: Stefano De Luca
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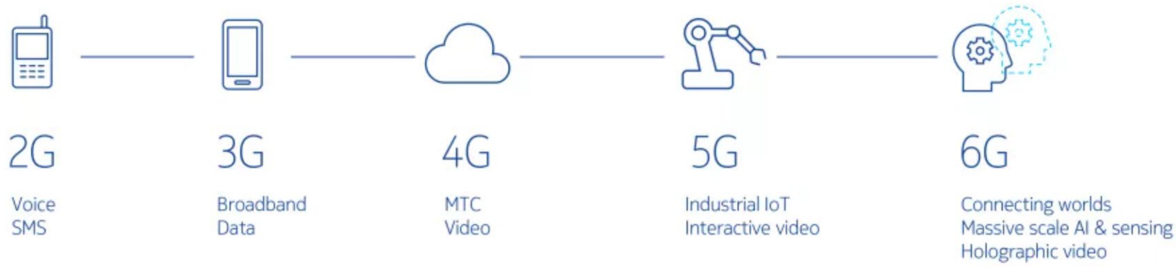
Introduction

High-speed and reliable connectivity is at the root of digital transition. The EU has set 'digital decade' targets, including providing all EU households with access to a fixed gigabit network (1 Gbps) and all populated areas with 5G coverage by 2030. As far as mobile technology is concerned, however, the EU is still far from achieving the latter target. According to the European Commission's state of the digital decade report of September 2023, 5G is available to 81 % of the EU population but the figure drops to 51 % in rural areas. In addition, the deployment of 5G stand-alone networks (also called 'true' 5G) – which solely use 5G both at radio access and core network level, without relying partially on 4G infrastructure – is lagging (56 % of the EU population).

Nonetheless, a new hyper-connected 6G world might begin to see the light in 2030. Thanks to technological advances towards faster and more reliable connectivity, vertical applications such as autonomous vehicles, 8K virtual reality headsets, hologram devices, the metaverse and remote surgery (e.g. eHealth), might become part of our daily life. According to the Radio Spectrum Policy Group's report of June 2023, the evolution of 6G technology is well under way. The start of standardisation work for 6G is expected by 2025, and its commercialisation around 2030.

Figure 1 – Evolution in legacy mobile networks



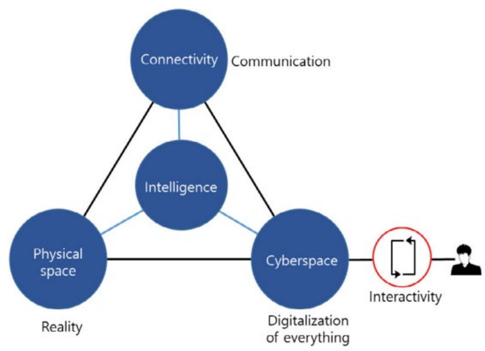
Source: Nokia – 6G explained.

New mobile communications systems have appeared about every 10 years, evolving from 2G to 5G generations (Figure 1). Bringing significantly clearer digital voice calls, 2G allowed users to send text messages (SMS) for the first time. Connecting mobile phone to the internet was then possible thanks to the upgrade to 3G. High-quality video streaming (e.g. helping the proliferation of social media platforms such as Facebook and TikTok) and machine-type-communications (MTC) followed with 4G, whereas 5G is associated with the Internet of Things (IoT).[1]

The next generation mobile system, 6G, is described as a distributed intelligent network (underpinned by AI and machine learning), which creates 'interactions between the **physical** world, **digital** world, and **biological** (human) world, especially emphasising the real-time integration of cyber and physical spaces' (Figure 2).[2] It is considered that 6G will improve applications of previous mobile generations and introduce new ones, such as truly immersive extended reality (XR), high-fidelity mobile hologram and digital twins of real-world objects.

Combining virtual reality (VR), augmented reality (AR) and mixed reality (MR), XR might have potentially interesting impacts in medicine (e.g. providing care outside hospitals),[3] entertainment (e.g. online gaming), education and manufacturing industries (e.g. experimenting new designs without creating prototypes from scratch). According to an industry report, the current user-experienced data rate for 5G is not sufficient for XR seamless streaming to flourish.

Figure 2 – Concept of 6G and its components



Source: The Korean Institute of Communications and Information Sciences.

Hologram technology will allow people to take part in a teleconference by representing their gestures or facial expressions and allowing remote technicians to perform remote troubleshooting or repairs. However, one study reports that 4G and 5G data rates may not enable such a holographic future because 'holographic images will need transmission from multiple viewpoints to account for variation in tilts, angles, and observer positions relative to the hologram'. Nevertheless, 6G might indeed allow the technology to succeed.[4]

Advanced sensors, AI and high-speed connectivity ensuring low-latency (e.g. the time data takes to transfer across the network),[5] would allow replication of physical entities (including people, devices, objects, systems, and even places) in a virtual world. This digital replica of a physical entity is called a digital twin. Among the various use cases, digital twins might be used in medicine to build human immune systems, or in factories to simulate the deployment of specific complex deployed assets such as jet engines and large mining trucks, to 'monitor and evaluate wear and tear and specific kinds of stress as the asset is used in the field'. One think tank stresses how 6G performance (e.g. speed and latency) will better enable digital twin technology by providing real-time monitoring and control of physical objects and environments.

Higher performance than 5G

Figure 3 below shows important dimensions related to the performance of a mobile network. Peak/user-experienced data rate relates to the capacity of a network or other communication channel for transferring data, measured in 'bits per second' (bps). Latency refers to the time it takes for data to travel from one point of the network to another. Connection density/coverage refers to the total number of connected devices per unit area (per square kilometre). Energy efficiency is both the capability to minimise the network energy consumption in relation to the traffic capacity provided as well as the capability to minimise the power consumed by the device modem in relation to the traffic characteristics.

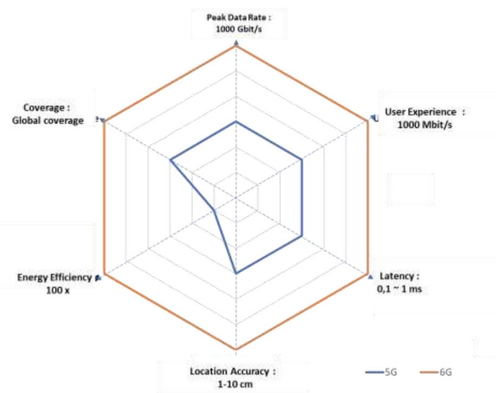
Peak/user-experienced data rate. Connectivity speed with 6G could be between 10, 50 and 100 times faster than 5G. The industry expects to reach a peak data rate (e.g. maximum achievable data rate under ideal conditions per user/device) of 1 000 Gbps and a user experienced data rate (e.g. achievable data rate that is available across the coverage area to a mobile user/device) of 1 Gbps.[6] These much higher data rates would help to make available advanced multimedia services, such as XR, holograms, and digital twins.

Latency. Remote surgery, industrial automation and self-driving cars are latency-sensitive services requiring high connectivity reliability (e.g. real-time decision-making).[7] One study points out that 6G might improve reliability 100 times compared to 5G.[8]

Connection density/coverage. According to one industry forecast, 500 billion devices are expected to be connected to the internet by 2030, which represents a number 59 times greater than the expected world population by that time. A report from the industry stresses how this growth in the number of connected machines 'will require 6G to support about 107 devices per square kilometre. This is 10 times larger than the connection density requirement of 5G'.

Energy efficiency. Considering the enormous future number of connected devices and users' expectations, the same report underlines how the industry intends to develop a 6G technology for networks and devices that would be twice as energy efficient than 5G.

Figure 3 – Enhancement of key requirements from 5G to 6G



Source: IDATE DigiWorld.

Environment, security and privacy as key 6G goals

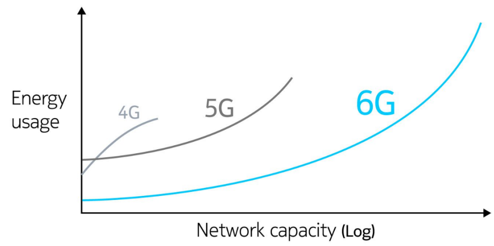
Experts suggest 6G should be developed to be sustainable from the outset and that energy efficiency – along with the other metrics such as speed and latency – may become a design criterion for this new technology, alongside other metrics such as capacity, peak data rate, latency, and reliability.

The information and communications technology (ICT) sector is already responsible for 5-9 % of global electricity use[9] and for around 2-2.5 % of global greenhouse gas (GHG) emissions. This figure might tend to grow, considering that the number of people without access to the internet is steadily declining (even though a third of the global population is still offline), and that there is ever-growing demand for new and enhanced connectivity services (e.g. increase of sensors, smart grids and connected devices). Although the increased use of ICTs is 'undoubtedly part of the cause of global warming' according to the International Telecommunication Union, it can at the same time also be a part of the solution to GHGs because it has the potential to assist in reducing emissions from other sectors of the economy.[10] A study done for the European Commission reflects this dichotomy by stressing that 'while several studies in the recent past have highlighted the role of the information and communication technologies in mitigating climate change, various studies have also indicated that ICT's own footprint is expected to increase significantly over the next few years'.

In terms of electricity consumption, the study forecasts that networks could become more efficient, but also that they will be more intensively used (more subscribers, higher bandwidth, more data traffic). Various reports argue that 6G networks could minimise their environmental impacts due to a set of design strategies such as smart solutions (e.g. integrating AI to achieve network optimisation), resource allocation algorithms for IoT devices, use of renewable energy and harvesting technologies.[11] The latter is a promising technology, which might be incorporated in 6G, able to capture energy from the environment for reuse by IoT devices and sensors, improving battery life (e.g. by rubbing your hands together, and using the friction-generated thermal energy to power small, simple zero-energy IoT devices such as a smart-watch).

According to the World Economic Forum, in combination with digitalisation, 5G is expected to help reduce GHG emissions by up to 15 % by 2030. Successive generations of mobile technologies (e.g. 2G to 3G and 3G to 4G) have been **more energy efficient** than those preceding (Figure 4), but there are indications that the huge energy efficiency gains achieved by technology developments are at least balanced by the surge in data traffic.[12] An industry blog reports that 'the target for 6G should be cutting the average power consumption of 6G networks in half compared to 5G, while still supporting peak capacities 10 times higher than today's 5G networks'.

Figure 4 – Network capacity vs energy usage in 4G, 5G and 6G



Source: Nokia Bell Labs.

In 6G use case scenarios, such as (i) high-precision remote surgery, (ii) medical condition monitoring apps (6G biosensing), and (iii) smart factories relying on industrial IoT,[13] ensuring protection from cyber-attacks and unauthorised access to data becomes paramount. According to experts, 6G would be developed to be secure by design, and its standardisation process would keep in mind mechanisms to preserve privacy. For security concerns, a new approach for 6G networks might be using quantum key distribution techniques[14] that, if correctly implemented, establish a secure encryption key at both ends of a communications line.[15]

For privacy concerns, a preservation scheme based on blockchain technology might tackle potential issues regarding the massive data volume exchange expected from this new mobile generation (e.g. having a common communication channel in the form of blockchain can allow network users to use pseudonyms instead of their actual personal identities).[16] In addition, AI-based threat detection and response solutions – continuously learning and adapting to new threats and vulnerabilities – can be used to detect and prevent cyber-attacks on 6G-connected technologies.[17]

Quantum technology

Quantum technology is increasingly considered globally as an emerging, highly strategic technology that could play an important role in safeguarding critical infrastructure and ensuring personal data security. A 2022 Joint Research Centre report stressed how deploying quantum communication infrastructure would strengthen the cybersecurity protection of European telecoms networks, as well as the transmission of very sensitive information, by using robust cryptography systems.

Quantum mechanics for cybersecurity is still in its infancy but could be developed within the 6G development timescales. The aim would be to build a secure 6G network for interactive sessions as well as file transfers and streaming. It would be based on an architecture that should include a system of quantum key distribution for the encryption keys.

Among its goals, the 'Digital Decade', Europe's overarching digital transformation strategy, envisages Europe 'being on the cutting edge of quantum capabilities by 2030'. To achieve this goal, the EU is promoting several programmes, including the deployment of a secure quantum communication infrastructure. Such infrastructure will include a terrestrial segment that relies on fibre networks and a space segment based on satellites.

Global race to 6G

The global race to 6G has begun and the stakes are high, as 5G and 6G-enabled activity are estimated to generate €3 trillion in growth by 2030 worldwide. Businesses and countries are competing to build the next level of 6G mobile networks. The competition for 6G is also motivated by the need to ensure leadership in the technology and ensure the EU's digital sovereignty.

Early 5G frontrunners in Asia, such as South Korea, China and Japan, have started to define their vision on 6G. India and Brazil have announced investments in 6G research and development projects (R&D). In the United States, the private sector is mainly leading the 6G debate through an industry initiative aimed at advancing North American mobile technology.

South Korea's ambition to secure the world's best 6G

Having led the development of 5G technology, South Korea is striving to position itself as a global leader in 6G technology by gaining dominance in international standards and patents. In February 2023, South Korea's Ministry of Science and ICT announced its K-Network 2030 strategy, with the goal to secure the best 6G technology in the world. Under this plan, the ministry will invest KRW625.3 billion (around €440 million) in R&D projects. South Korea will host the 'Pre-6G Vision Fest' in 2026, aiming to demonstrate the outcomes of the country's research in 6G and become a model country for global cooperation on 6G.

China to pursue major standard-setting role

China's 14th Five-Year Plan (2021-2025) aims at strengthening research on new 6G network infrastructure as well as clarifying its technology requirements. In addition, the government selected 6G as a 2023 top priority in its annual state-of-the-year work conference and will speed up the R&D for this technology.[18] Some sources claim that China accounts for nearly half of 6G-related patent applications in the world. In the recently published 'Three-Year Action Plan for the Industrial Innovation and Development of the Metaverse (2023-2025)', 6G is mentioned as one of the key technologies needed for the creation of a Chinese metaverse. China's IMT-2030 (6G) Promotion Group, representing the flagship platform in China promoting 6G and international cooperation, published a report according to which 6G will also provide efficient support for AI services as well as for large-scale AI deployments in various industries.

Japan's 'Beyond 5G Promotion Strategy'

Japan issued its roadmap to 6G in June 2020, aiming to ensure its future international competitiveness in the sector. The 'Beyond 5G Promotion Strategy' provides funding for 6G research through three programmes for a total budget of US$555 million (around €520 million). Japan and the US agreed to jointly invest US$4.5 billion (€4.2 billion) for the development of 6G technology. The Beyond 5G Promotion Consortium brings together representatives of Japanese industries and academic institutions to carry out research and development initiatives as well as advocating for 6G.

India's vision for ubiquitous 6G coverage

India released its 'Bharat 6G Vision' in March 2023. The government envisages India as a front-line contributor in design, development and deployment of 6G technology by 2030. The proposal aims to 'design, develop and deploy 6G network technologies that provide ubiquitous, intelligent and secure connectivity for high quality living experience for the world'. According to the proposal, a total pool of INR10 000 crore (€1.1 billion – raised through instruments such as loans, grants and venture capital funds) is expected to be invested over the next 10 years in R&D projects developing India's 6G ecosystem. India has already secured around 200 patents on 6G technology through industrial and academic collaboration with the support of the Department of Telecommunications.

6G Development in Brazil

The Brazil 6G Project – an initiative supported by the National Institute of Telecommunications (INATEL), the Ministry of Technology and Innovation (MCTI), and the Brazilian network for education and research (RNP) – issued an action plan for Brazil's future 6G network development. In May 2023, Brazil announced investment of BRL60 million (€11.4 million) in the competence centre responsible for the development of 5G and 6G (INATEL). According to a report, Brazil is growiing ties with China on new technologies, including cooperation in research and also seeking investment in upcoming 6G telecommunications infrastructure.

Next G Alliance and strategic alliances in the United States

The US government is building its position in the 6G race by making strategic alliances with other countries and regions (e.g. Europe, India, South Korea, Japan and the United Kingdom). However, a considerable part of the US 6G debate and its roadmap development relies heavily on a private sector-led effort. The Next G Alliance, a private sector partnership to advance North American 6G technology, comprises organisations and experts from industry, government and academia dealing with 6G (e.g. Apple, Google, Verizon, Nokia, Samsung). The alliance issues publications and reports on 6G, and among its goals is to 'develop a roadmap that will promote a vibrant marketplace for 6G introduction, adoption and commercialisation with North American innovation in mind'.

What is the EU doing

Like the above-mentioned countries, the EU is also providing support for 6G research and innovation to ensure it gains a leadership position in the sector. The European Smart Networks and Services Joint Undertaking (SNS JU) was established in 2021. The SNS JU is jointly funded by the EU budget and industry. As far as industry is concerned, the 6G Smart Networks and Services Industry Association (6G-IA) works in partnership with the European Commission on the SNS JU projects. It represents the voice of European industry and research actors on 6G, bringing together operators, manufacturers, academics, small and medium-sized enterprises and ICT associations.

The SNS JU has a fund of at least €1.8 billion for 2021 to 2027. Industry will, at least, match an EU contribution of €900 million. The SNS JU provides financial support to participants, through research and innovation (R&I) grants, following open and competitive calls to foster Europe's 6G technology sovereignty, as well as boosting 5G deployment. The SNS JU recently adopted its third

R&I work programme for 2024 to advance 6G research in Europe, earmarking €129 million in public funding for collaborative projects to advance 6G systems and prepare for standardisation activities.

The 6G-IA reports on the activities promoted by Member States on the development of 5G towards 6G. Some EU Member States have already launched their own initiatives and programmes on 6G (e.g. Finland with its 6G Flagship and 6G Finland).

Under the EU Recovery and Resilience Facility, providing a total of over €700 billion in loans and grants, Member States must allocate at least 20 % of the expenditure under their national recovery and resilience plan to support the digital transition, including 5G and 6G networks/projects.

In October 2022, the European Commission announced the creation of Hexa-X-II, a research initiative to develop the foundation of 6G technology and contribute to industry consensus leading to 6G. The Commission awarded the Hexa-X-II project funding as part of the SNS JU. It will expand the previous Hexa-X partner list to 44 organisations, tasked with creating the pre-standardised platform and system view that will form the basis for many inputs into future 6G standardisation.

International collaboration is key to achieving a globally accepted 6G standard. The EU is strengthening partnerships with other countries such as the US and Japan. The EU-US Trade Technology Council (TTC), established in June 2021, serves as a forum for research and cooperation on new technologies between Europe and the US, including 6G. Both parties have accelerated their cooperation towards a common vision and industry roadmap on 6G wireless communication systems and issued a 6G outlook in May 2023. The outlook sets out guiding principles and next steps to develop this critical technology (e.g. 6G should be developed with security-by-design and energy efficiency standards). In May 2022, the also EU signed a Digital Partnership with Japan to improve joint work on digital technologies in the area: 'Beyond 5G/6G technologies'.

Conclusion

Considering 6G standards and specifications are still under development, the question remains whether 6G will be the enabler of the next wave of digital disruption. It is legitimate to query whether 6G applications – able to sense our surroundings by integrating the digital and physical realms – will turn the network into our 'sixth sense', or whether the step from 5G to 6G will be just an improved version of 5G, with no profound change.

As far as 6G's environmental impact is concerned, the arrival of newer cellular generations (e.g. 4G and 5G) have brought huge energy efficiency from a technology development point of view. However, studies suggest that such energy efficiency gains have at least been compensated by the increase in data traffic.[19] The question remains whether this will be also the case for 6G.

Quantum key distribution and blockchain seem promising technologies, which will be integrated in future 6G networks to ensure device cybersecurity and communication privacy.[20] Considering the massive (e.g. digital twins) and sensitive (e.g. remote surgery) data exchanges potentially triggered by 6G, the success of such promising technologies in blocking hackers from hijacking the promised hyper-connected 6G world will be crucial.

Which country will be likely to take the lead in the 6G race? In the 1990s, Europe led the world in 2G deployment by adopting a single digital standard (GSM) and common spectrum bands to establish a broad base of networks. This did not happen for the newer generations of mobile technologies (3G, 4G and 5G), led by other countries. Will the funds and projects supported by the EU on 6G research give Europe the chance to regain its lead on 6G? To push this global 6G race further, mobile technology dependency needs to be taken into account. In a 2023 communication, the European Commission stressed that Chinese vendors Huawei and ZTE represent a materially higher risk than other 5G suppliers. It thereby recognised some Member States' decision to restrict or exclude Huawei and ZTE from 5G networks as justified and compliant with the EU toolbox on 5G cybersecurity. How to best deal with 6G security, however, remains an open question.

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