October 2021

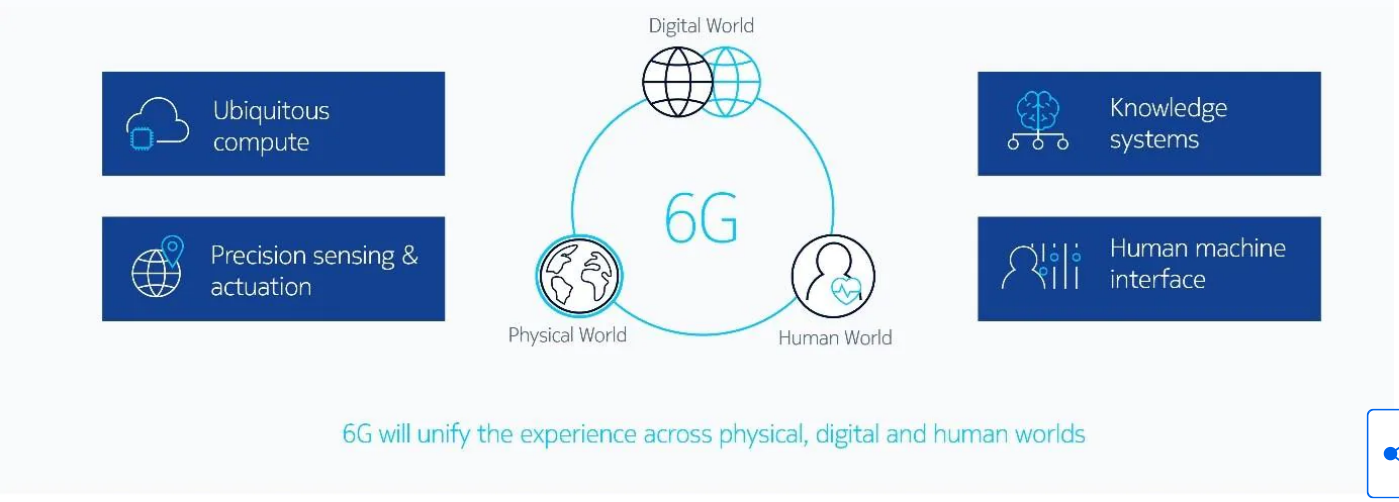
6G explained

With every generation of communications technology, the focus of the network changes. The 2G and 3G eras centered on human-to-human communication through voice and text. 4G heralded a fundamental shift to the massive consumption of data, while the 5G era has turned its focus on connecting the Internet of Things (IoT) and industrial automation systems.

In the 6G era, the digital, physical and human world will seamlessly fuse to trigger extrasensory experiences. Intelligent knowledge systems will be combined with robust computation capabilities to make humans endlessly more efficient and redefine how we live, work and take care of the planet. Even though there is still a lot of innovation in 5G with the 5G-Advanced release of new standards, Nokia Bell Labs has already begun the research work on 6G to make it commercially available by 2030.

“The role of next-generation networks is the unification of our experience across the physical, digital and human world,” says **Harish Viswanathan, Head of Radio Systems Research at Nokia Bell Labs**.

“Just as the applications of today are built on the foundation of multimedia, we envision future applications to use digital worlds as the framework. Dynamic digital twin worlds would be accurate, high-resolution representations of the physical world and/or representations of virtual worlds,” he adds.



6G will unify the experience across physical, digital and human worlds

How will the 6G era benefit us?

Literally, every single improvement in network connectivity that 5G will bring to the end-user will get further perfected with 6G. Whether it's smart cities, farms or factories, and robotics, 6G will take it to the next level. Much of that will be facilitated by 5G-Advanced, the next standard enhancements for 5G. It comes with improved efficiency and extended capabilities and improved user experience.

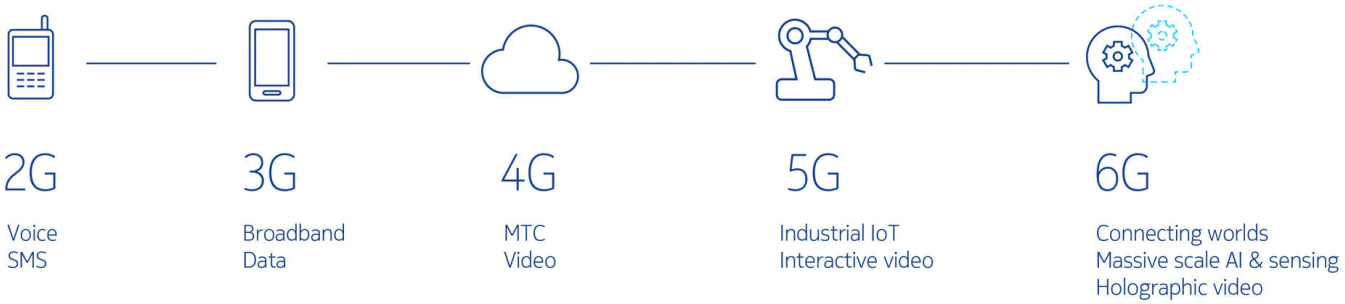
Looking at the past, it's clear that each generation optimizes the use cases of the previous generation and introduces new ones. This will continue to be the case. 6G will build on top of 5G in terms of many of the technological and use case aspects, driving their adoption at scale through optimization and cost-reduction. At the same time, 6G will enable new use cases.

We will connect the physical world to our own human world, thanks to the massive scale deployment of sensors and artificial intelligence and machine learning (AI/ML) with digital twin models and real-time synchronous updates. These digital twin models are crucial because they allow us to analyze what's happening in the physical world, simulate possible outcomes, anticipate needs and then take productive actions back into the physical world.

Digital twin models are already being used with 5G. With 6G, we can expect these technologies to operate at a much larger scale. Digital twins will be found not only in factories but also in wide area networks of cities and even digital twins of humans which will have a major impact on the network architecture.

While the smartphone will remain a key device in the 6G era, new man-machine interfaces will make it more convenient to consume and control information. Touchscreen typing will gradually get replaced by gesture and voice control. Devices will come embedded into clothing and even transform into skin patches. Healthcare will be an important benefactor as wearables facilitate 24/7 monitoring of vital parameters.

The maturing of AI and machine vision and their capacity to recognize people and objects will turn wireless cameras into universal sensors. Radio and other sensing modalities like acoustics will gather information on the environment. Digital cash and keys may become the norm. We may even start relying on brain sensors to actuate machines.



6G will also promote sustainability in a variety of ways. By enabling faster and lower cost per bit connectivity, it would be able to support data collection and closed-loop control of numerous appliances. The data can be analyzed using sophisticated tools to improve energy efficiency in industries. The advanced multi-sensory telepresence that is created with very high data rates will reduce the need for travel through the introduction of multi-modal mixed reality telepresence and remote collaboration.

6G will be significantly more energy-efficient, turning off components and scaling down capacity when the demand is lower. Energy efficiency will be a major design criterion in 6G along with the other metrics such as capacity, peak data rate, latency, and reliability.

The 6G network

6G will call for a change in the way communication networks are designed. Multiple key requirements must be reconciled: serve the massively growing traffic and the exploding numbers of devices and markets, while also accomplishing the highest possible standards regarding performance, energy efficiency and strong security, enabling sustainable growth in a trustworthy way.

“We’ve identified research vectors that will cause disruption for 6G, but each one of these areas will already have early precursors in 5G-Advanced, and there will be important evolutions that we can ride on in terms of network waves,” says **Peter Vetter, President of Bell Labs Core Research, Nokia.**

5G-Advanced is an important stepping stone for some of the capabilities we want to enable at a larger scale in 6G. It will further develop 5G to its fullest capabilities over the coming half-decade. In the 5G-Advanced era, how networks are architected, designed and deployed will require a new level of intelligence, one that can be managed across a disaggregated network and powered by AI and Closed Loop Automation to cope with the traffic growth. The evolution to 5G-Advanced will also require optimal support for critical network applications, be it via communication service providers (CSPs) or as industry grade private wireless networks.

According to Nokia Bell Labs, there are six technology areas that will characterize 6G.

Artificial intelligence and machine learning - AI /ML techniques, especially deep learning, has rapidly advanced over the last decade, and it has already been deployed across several domains involving

image classification and computer vision, ranging from social networks to security. 5G will unleash the true potential of these technologies, and with the approaches in 5G-Advanced, AI/ML will be introduced to many parts of the network at many layers and in many functions. From the optimization of beam forming in the radio layer to scheduling at the cell site with self-optimizing networks, all using AI/ML to achieve better performance at lower complexity.

In 6G, Nokia Bell Labs expects AI/ML will go from an enhancement to a foundation by taking a clean slate approach, where we do away with the complexity, and let AI/ML figure out how to best communicate between two endpoints.

Spectrum bands – Spectrum is a crucial element in providing radio connectivity. Every new mobile generation requires some new pioneer spectrum that helps fully exploit the benefits of a new technology. Refarming of the existing mobile communication spectrum from the legacy technology to the new generation will also become essential. The new pioneer spectrum blocks for 6G are expected to be at mid-bands 7 – 20 GHz for urban outdoor cells enabling higher capacity through extreme MIMO, low bands 460 – 694 MHz for extreme coverage and sub-THz for peak data rates exceeding 100 Gbps.

While 5G-Advanced will expand 5G beyond just data communication and substantially improve positioning accuracy to centimeter-level, especially for indoors and underground facilities where satellite signals are unavailable, 6G will take localization to the next level by taking advantage of wide spectrum and new spectral ranges all the way up to terahertz.

A network that can sense – The most notable aspect of 6G would be its ability to sense the environment, people and objects. The network becomes a source of situational information, gathering signals that are bouncing off objects and determining type and shape, relative location, velocity and perhaps even material properties. Such a mode of sensing can help create a “mirror” or digital twin of the physical world in combination with other sensing modalities, thereby extending our senses to every point the network touches. Combining this information with AI/ML will provide new insights from the physical world, making the network more cognitive.

Extreme connectivity – The Ultra-Reliable Low-Latency Communication (URLLC) service that began with 5G will be refined and improved in 6G to cater to extreme connectivity requirements, including sub-millisecond latency. Network reliability could be amplified through simultaneous transmission, multiple wireless hops, device-to-device connections and AI/ML. Enhanced mobile broadband combined with lower latency and enhanced reliability will improve the experience of real-time video communications, holographic experiences or even digital twin models updated in real-time through the deployment of video sensors.

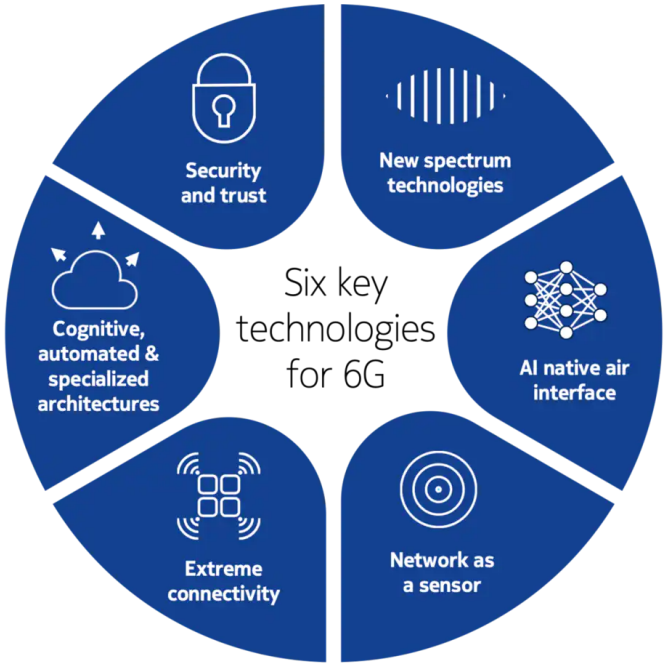
In the 6G era, we can expect use cases with networks that have specific requirements in sub-networks, creating networks of networks with networks as an endpoint. Machine area networks such

as a car area network or a body area network can have hundreds of sensors over an area of less than 100 meters. These sensors will need to communicate within 100 microseconds with extreme high reliability for the operation of that machine system. Making networks within cars or on robots truly wireless will open a new era for the designers of those devices as they would no longer need to install lengthy and bulky cable systems.

New network architectures – 5G is the first system designed to operate in the enterprise/industrial environment, replacing wired connectivity. As the demand and strain on the network rises, industries will require even more advanced architectures that can support increased flexibility and specialization.

5G is introducing services-based architecture in the core and cloud native deployments that will be extended to parts of the RAN, and the network will be deployed in heterogeneous cloud environments involving a mix of private, public and hybrid clouds. In addition, as the core becomes more distributed and the higher layers of the RAN become more centralized, there will be opportunities to reduce cost by converging functions. New network and service orchestration solutions exploiting the advances in AI/ML will result in an unprecedented level of network automation that will reduce operating costs.

Security and trust – Networks of all types are increasingly becoming targets of cyber-attacks. The dynamic nature of the threats makes it imperative to deploy sturdy security mechanisms. 6G networks will be designed to protect against threats like jamming. Privacy issues will need to be considered when new mixed-reality worlds combining digital representations of real and virtual objects are created.



Moving towards Industry 5.0

In recent decades, a range of technological improvements has fueled the rise of smart factories. Connectivity, however, has remained a major issue. 5G jumpstarted the fourth industrial revolution with a host of modern technologies. The march towards Industry 5.0 will receive further momentum with the widespread adoption of 6G.

Communication and control co-design will enable lower cost and higher data rate and increase the number of use cases. 6G network as a sensor will enable joint communication, sensing and localization that will address the needs of industries with a single system, thereby reducing cost.

New zero energy or battery-less devices could be enabled in 6G using backscatter communications that will allow a massive scaling of data gathering for analytics and closed loop control. There will be extensive use of mobile robot swarms and drones in various verticals such as hospitality, hospitals, warehouses and package delivery.

Stepping up to 6G

The rollout of 5G and subsequently 5G-Advanced could not have come at a better time when global resources are stretched thin. Communications technology is going to play a critical role in boosting productivity and help pursue comprehensive green policies. 6G will further build on the successes of 5G by bolstering human well-being and unveiling new possibilities that we cannot yet define or imagine.

Nokia brings 6G forward

Nokia expects 6G systems to launch commercially by 2030, following the typical 10-year cycle between generations. Standardization phase 1 will likely start from 2026 as part of 3GPP Release 20.

Meanwhile, 5G will be enhanced by 5G-Advanced, which will be a key focus for 3GPP in Release 18 onwards and power commercial networks starting 2025 onwards, well before 6G arrives at the end of the decade.

Powered by world-renowned research from Nokia Bell Labs, Nokia has been the forerunner in defining the fundamental technologies for the 5G era and beyond. To make 6G a reality before 2030, Nokia is leading Hexa-X, the European Commission's 6G flagship initiative for research into the next generation of wireless networks. In addition to multiple 6G research projects around the globe, Nokia is also a founding member of the Next G Alliance, an initiative to advance North American mobile technology leadership, and RINGS, an NSF-led initiative in the US that will accelerate research in areas with potentially significant impact on Next-Generation (NextG) networking and computing systems.