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Toward Artificial Intelligence-Native 6G Services

Various industry and academic viewpoints and perspectives on 6G services are being merged. 6G services are expected to improve current mobile networks' traditional communication features and include several new beyond-communication features, such as sensing, network intelligence, artificial intelligence (AI)-native features, etc. Today, we are living in an age of AI, where logical reasoning, perception, knowledge representation, language processing, and navigation are intelligently provided by machines. Various AI-native services are expected to be provided through the 6G mobile system, and then 6G will be called the real intelligent mobile network.

6G Use Cases

From 8 to 10 May 2024, a 3rd generation partnership project (3GPP) workshop was held in Rotterdam, The Netherlands [1]. In this workshop, various communities, including operators, verticals, regional alliances, and the International Telecommunication Union (ITU), shared their views on 6G/information management technology (IMT) 2030 use cases. This gathering aimed to delve into the perspectives and priorities of operators, regional 6G research alliances, 3GPP partners, and other innovators regarding IMT2030 use cases, laying the groundwork for formal 6G standardization activities within 3GPP. The trigger was the finalization of the ITU Radiocommunication Sector (ITU-R) vision framework document, which enlists six overarching 6G Usage Scenarios: Immersive Communication, Massive Communication, Hyperreliable and Low-Latency Communication, Ubiquitous Connectivity, AI and Communication, and Integrated Sensing and Communication.

The ITU-R addressed the idea that IMT2030 is expected to support enriched/immersive experiences, enhanced ubiquitous coverage, and new forms of collaboration. Furthermore, it is envisaged to support expanded and new usage scenarios compared to those of IMT2030 while providing improved and new capabilities. The first 3GPP Technical Specification Group-wide 6G workshop is expected to be held on 10–11 March 2025.

Operators' Views on 6G Use Cases

The Global System for Mobile Communications Association (GSMA) proposed high-level principles for 6G in the 3GPP workshop. The GSMA proposed that the objectives that 6G standardization needs to meet should serve both direct and indirect stakeholder groups. For example, technical requirements such as faster enhanced mobile broadband (eMBB), user density, operator handover time, support for lowest possible user equipment (UE) power consumption for the Internet of Things (IoT), etc., are for the direct stakeholder groups. By contrast, technical requirements such as 6G core as a harmonized integration point for non-3GPP networks, reduced operational requirements in support of population reductions, support for other environmental points—sustainable human/power usage, circular economy, etc.—are for the indirect stakeholder groups. In particular, the GSMA emphasized the sustainability issue for 6G research.

The Next Generation Mobile Networks (NGMN) Alliance addressed the topic that 5G was forward looking and flexible, able to support new applications that demand critical key performance indicators and capabilities. The NGMN Alliance's expected 6G use cases beyond 2030 are challenging, provisional, and speculative, even though there will be significant overlap between many use cases identified for 6G and those proposed for 5G and 5G advanced. The NGMN Alliance highlighted the idea that 6G must support the ability of mobile and fixed networks to continue to scale in a sustainable, energy-efficient, and cost-effective way to address growth in data demand. The NGMN Alliance considered the following examples as prominent 6G use cases: immersive holographic telepresence communications; multimodal communication for teleoperation; intelligent interaction and sharing of sensations, skills, and thoughts; robot network fabric and interacting collaborative robots (cobots); 3D hyperaccurate positioning, localization, and tracking; interactive mapping; digital health care;

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automatic detection, recognition, and inspection; smart industry; trusted composition of services; native trusted AI; coverage expansion; and autonomous systems for energy efficiency.

Research Alliances' Views on 6G Use Cases

The Next G Alliance (NGA) considered the societal and economic needs of 6G, including quality of life, digital equity, privacy and trust, economic growth, and sustainability. The NGA summarized the following use cases for 6G: multisensory extended reality (XR), fixed wireless access (FWA), intelligent transportation systems/connected vehicles, smart factories, low-power wide-area (LPWA) networks, personalized user experiences, robots, digital twins, and short-range massive sensors (ambient IoT). For 6G use cases, the following vertical industries were considered: agriculture, the automotive industry, education, gaming and entertainment, e-health, industry, mining, public safety, smart cities, etc.

The European views on 6G use cases were summarized as immersive experiences, a fully connected world, digital twins, cobots, physical awareness, and trusted environments. An immersive experience includes seamless immersive reality, immersive enterprise and industry, immersive education, immersive gaming, and live and interactive immersive content creation. A fully connected world includes Earth monitors, sustainable food production, resilient communication for safety-critical applications, autonomous supply chains, and virtualization of device functionalities. Digital twin topics include smart continua, smart maintenance, digital twins with building models, and public protection and disaster relief with digital twins. Cobots include autonomous embodied agents within flexible manufacturing and mesh embodied intelligence. Physical awareness includes environmental radio sensing, wide-area surveillance, smart crowd monitoring, and network physical data exposure. Trusted environments include an industrial sensor network for safe production and manufacturing, a wireless in-vehicle network, and a virtual control room.

The 6G Forum of South Korea considered the following usage scenarios for 6G: the hyperrealistic metaverse, remote multisensory telepresence, and remote health care as examples of immersive communication, industrial automation and monitoring, and intelligent manufacturing and logistics; precision agriculture as an example of massive communication; fully autonomous driving and cobots as examples of hyperreliable and low-latency communication; aerial node connectivity, environmental monitoring, and smart agriculture as examples of ubiquitous connectivity; autonomous collaboration among AI robots and 6G-assisted automated driving as examples of integrated AI and communication; and 6G-assisted navigation and object detection and tracking as examples of integrated sensing and communications (ISAC).

The IMT2030 promotion group of China proposed the following use cases as prominent services for 6G: holographic communications, immersive XR, and multimodal interconnection as examples of immersive communication; wide area environmental monitoring, smart agriculture IoT, automatic asset management and global tracking, and digital twins as examples of massive communication; cobots, machine vision, and AI/machine learning (ML) for defect detection; industrial sensors and smart grids as examples of higher reliable and low-latency communication; ubiquitous broadband access and ubiquitous IoT as examples of ubiquitous connectivity; collaborative and distributed inference, multinode distributed learning, data and model management, and network optimization and automation as examples of integrated AI and communication; and localization and tracking, human activity recognition, environmental object reconstruction, and monitoring tasks as examples of ISAC.

The Beyond 5G Promotion Consortium of Japan proposed the following prominent use cases of 6G: ultrawide communication, ubiquitous sensing, mission-critical communication, intelligent connection, ultramassive connection, and universal coverage.

The Bharat 6G Alliance of India proposed the following services as prominent 6G use cases: enhanced voice, immersive communication, LPWA networks, integrated network-based sensing/service exposure, AI and compute as services, etc.

Manufacturers' Views on 6G Use Cases

At a high level, Qualcomm addressed the key goals and drivers for the 6G innovation platform to achieve in the next decade and beyond, which include economic growth, technology advancement, cost efficiency, societal equity, environmental sustainability, and trust and reliability. With technology advances, Qualcomm anticipates that 6G will integrate AI, advanced computing, and system resilience features alongside innovative green technologies as well as ISAC, marking a new converging era of the physical–digital–virtual worlds. On 28 June 2024, Qualcomm summarized the prominent use cases discussed and envisioned in the 3GPP workshop in 2024 May, including immersive experiences, digital twins, smart industry and robotics, FWA, the next-generation IoT, connected transportation, critical communications, and other emerging deployments, including terrestrial and nonterrestrial communications.

Samsung noted that it is expected that a variety of new use cases would be enabled by 6G. By grouping many different anticipated use cases,

Samsung summarized the following representative user and application trends for 6G: ubiquitous intelligence, ubiquitous computing, immersive multimedia and multisensory interactions, digital twins and virtual worlds, smart industrial applications, digital health and well-being, ubiquitous connectivity, integration of sensing and communication, and sustainability. In addition, Samsung expects that 6G will enhance communication performance and extend its utilization to various directions by integrating sensing/AI with communication.

Nokia is the designated project leader of Hexa-X-II, the flagship 6G initiative of the Smart Network and Services Joint Undertaking. Its goal is to design an end-to-end system-enabling platform that delivers novel capabilities for next-generation networks. Nokia's view on 6G use cases seems to align with the European view discussed earlier.

Ericsson addressed the topic of 6G being realized on a network platform that is trustworthy, sustainable, and cognitive and provides limitless connectivity. Another key challenge will be combining the many components, from cloud systems to applications, diverse devices, and industrial systems. In particular, Ericsson's view on 6G use cases includes critical communication to support sensitive needs in society and industry, immersive communication to encompass intense human and machine interaction, and massive communication to cover the future of large-scale digital twins. Ericsson emphasizes that the future network platform delivering 6G will provide applications with auxiliary services, extending current offerings of exposed services (e.g., positioning) with novel services beyond communication, such as navigation and spatial awareness. These new services exposed by the network platform require an architecture with functions capable of collecting and distributing data through localization, sensing, mapping, and time synchronization.

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Huawei proposed that 6G, a more advanced next-generation mobile communication system, will go far beyond just communications. It will serve as a distributed neural network that provides links with integrated communication, sensing, and computing capabilities to fuse the physical, biological, and cyber worlds, ushering in an era of true "intelligence of everything." Huawei's view on 6G use cases is summarized as follows: eMBB for human-centric communication use cases, such as highly immersive experiences and multisensory interactions in XR applications; the continuous evolution of ultrareliable low-latency communications for critical machine-type communication (MTC) for robots, unmanned aerial vehicles, and new human–machine interfaces in manufacturing, public service, autonomous driving, and household management; the continuous evolution of massive MTC for the massive number of lightly connected devices with sporadic traffic in smart cities, health care, buildings, transportation, manufacturing, and agriculture; networked sensing as a new type of usage scenario beyond communication for localization, imaging, environment reconstruction and monitoring, and gesture/activity recognition; and intelligent connection of distributed intelligent agents to proliferate large-scale deployment of AI in all industries.

AI for 6G

The ITU has proposed that the new 6G air interface be AI native and use AI/ML to enhance the performance of radio interface functions, such as symbol detection/decoding and channel estimation. From a standardization perspective, 3GPP is operationalizing the ITU proposal for the AI-native air interface. In Release 18, 3GPP conducted a first-of-its-kind study on AI/ML for a 5G New Radio air interface to investigate a general framework for AI/ML as well as selected use cases, including channel state information (CSI) feedback, beam management, and positioning. Release 19 will expand on these topics on at least three fronts. Specifically, the study will investigate AI/ML-based radio resource management prediction for both the UE-sided model and network-sided model as well as the prediction of events (such as handover failure, radio link failure, and measurement events) for the UE-sided model.

The integration of AI in 6G technology can potentially revolutionize various industries. With AI-powered networks, we can expect

- significantly improved capacity, coverage, and automation
- faster and more reliable connections
- enhanced data processing capabilities
- the ability to support a wide range of new applications and services.

The AI-Radio Access Network (AI-RAN) Alliance is an organization that revitalizes the convergence of AI and wireless communication and leads technology innovation through cooperation with related companies [2]. This new alliance will collaborate on the development of innovative new technologies as well as the application of these technologies to commercial products in preparation for the upcoming 6G era. Senior Vice President of Samsung Research America, Charlie Zhang, said, "Emerging services in the 6 G era will revolutionize the way people interact with technology, and AI will be an integral part of this trend." The AI-RAN Alliance aims to combine AI and wireless communication technologies for application in various fields, create an ecosystem,

and ultimately expand opportunities for new businesses. To this end, it has established three working groups that carry out technical research: AI for RAN, AI and RAN, and AI on RAN.

The Open RAN (O-RAN) Alliance is also conducting an AI-focused transformation toward an open and interoperable architecture that is natively intelligent. Using AI/ML-based technologies, O-RAN aims to integrate intelligence into every layer of the O-RAN architecture. The introduction of the RAN intelligent controller (RIC) in the O-RAN architecture has been a significant development, making it possible to introduce AI/ML-based solutions to various use cases.

The O-RAN Alliance's Next Generation Research Group is driving research efforts on enabling AI-native architecture and features for next-generation O-RAN. This also includes cross-domain AI between RAN and other domains of physical networks or even beyond the realm of physical network boundaries between physical and digital twin network domains.

On 24 July 2024, Alex Jinsung Choi, Chair of the O-RAN Alliance, presented "AI-Native Open RAN for 6 G" in the ITU-T SG13 IMT2030 workshop. In this presentation, he said that O-RAN's core principles are intelligence and openness. In addition, he noted that the O-RAN RIC is the most practical enabler for AI-native RAN for 6G.

In February 2024, Samsung Electronics announced that it is participating in the AI-RAN Alliance as a founding member to promote 6G innovation by combining AI technology and wireless communication technology. Samsung Research has continuously evolved its 6G technology strategies to adapt to the changing telecom industry landscape. In particular, regarding the AI-RAN Alliance, Samsung Research envisions AI native as a key attribute of future 6G networks. Samsung Research believes that, with AI being a natural part of the 6G system functionality, the network will have significantly improved capacity and coverage and become fully automated and highly energy efficient. Samsung Research continues to lead innovations to successfully launch and commercialize next-generation communication systems in the future.

On 12 September 2024, Qualcomm announced an inspiring concept, adaptive intelligence, which operates autonomously between the device and network across all protocols and layers, incorporating AI. At the device, adaptive intelligence applies AI and contextual awareness to determine how to improve the user experience based on real-time application requirements and local conditions. At the network level, adaptive intelligence includes the convergence of AI and the continuous integration and delivery paradigm to manage networks more smartly under unique circumstances in real time. 6G will be a true fusion of connectivity and AI, not just for its technical merits but also for its economics. A 6G network will be designed to be adaptive, allowing it to perceive, learn, and respond to its environment in real time. This will enable new performance, efficiency, and reliability levels essential for various applications. Qualcomm addressed the topic that adaptive intelligence will be a crucial enabler of 6G's innovative capabilities, including efficient resource utilization, robust service delivery, user-specific and application-aware adaptivity, and fault-resilient network operation. These capabilities collectively elevate 6G technology to an AI-native platform, significantly improving flexibility, efficiency, and performance. The network intelligence embedded in 6G ensures it can adapt to the varying needs of modern and future applications and services.

In July 2024, Huawei announced that the core carrier of 6G services and applications will shift from mobile Internet and smartphone apps to AI agents across various sectors in the age of AI. This means AI will serve as a bridge to 6G. Among various use-case candidates, integrating AI with communications focuses mainly on how 6G can be designed to support massive AI services and applications in the future natively. Huawei noted that, over the next five to 10 years, 99% of all development, design, and administrative tasks are expected to be done by AI. In addition, Huawei expects that foundation models will soon replace manual architecture design chips. This trend will overlap with the window for 6G deployment. AI agents can sense and proactively act. Capable of sensing, learning, and acquiring knowledge, they can set action objectives based on the environment and constantly improve their capabilities. The recent success of foundation models has taken AI agent capabilities to a new level, going beyond just generative AI to creating interactive AI capable of complex dialogs and decision making. Therefore, in the 6G era, networks will control AI agents and artificial general intelligence.

On 6 June 2024, Ericsson announced that the AI-NET-ANIARA project officially concluded on 30 April 2024. The project, led by Ericsson, contributes novel AI concepts and carrier-grade AI technologies for telecom edge automation, a dynamic computation offloading solution, and demonstrations of edge node data centers featuring new cooling solutions. To make future mobile networks ready in terms of performance and functionality for use-case scenarios like smart cities and intelligent manufacturing, new enablers must be provided to transform these networks into a platform that offers services beyond pure communication, including computing and AI. Ericsson emphasized that AI-NET-ANIARA successfully delivered its project promises of accelerating digital transformation by efficiently using a highly integrated and flexible edge infrastructure that is programmable across all of its components.

On 18 March 2024, Nvidia unveiled its 6G Research Cloud platform to advance wireless communications

with AI. This open, flexible, and interconnected platform offers researchers a comprehensive suite to advance AI for RAN technology. The platform allows organizations to accelerate the development of 6G technologies that will connect trillions of devices with cloud infrastructures, laying the foundation for a hyperintelligent world supported by autonomous vehicles, smart spaces, a wide range of XR and immersive education experiences, and cobots. Ronnie Vasishta, senior vice president of telecom at Nvidia, said, "The massive increase in connected devices and host of new applications in 6G will require a vast leap in wireless spectral efficiency in radio communications. Key to achieving this will be the use of AI, a software-defined, full-RAN reference stack and next-generation digital twin technology."

The Nvidia 6G Research Cloud platform has three foundational elements: the Nvidia Aerial Omniverse Digital Twin for 6G, the Nvidia Aerial CUDA-Accelerated RAN, and the Nvidia Sionna Neural Radio Framework. Testing and simulation are essential in developing the next generation of wireless technology. Nvidia stated that the Nvidia 6G Research Cloud platform combines these powerful foundational tools to let telcos unlock the full potential of 6G and pave the way for the future of wireless technology.

The Nvidia 6G Developer Program provides access to all of the platforms, documentation, and early access to software releases to facilitate cutting-edge 6G research. It includes a software-defined and accelerated RAN platform, AI and ML frameworks that are interlinked with the RAN software, and a network digital twin with a deterministic ray-tracing channel model with a photorealistic scene creation and rendering component based on Nvidia Omniverse. Nvidia believes that these platforms democratize 6G research, empowering developers and researchers with the essential tools, software, and hardware to drive rapid innovation for the 6G era.

On 19 July 2024, Nvidia also announced that it was working with its partners and the wider telecommunications ecosystem [including the AI-RAN Alliance (https://ai-ran.org/), 3GPP (https://www.3gpp.org/), and O-RAN (https://www.o-ran.org/)] to drive AI/ML-enabled innovations that will shape the requirements and opportunities for the 6G era. Nvidia noted that it is not only delivering AI native 6G tools but is also working with partners and industry groups to accelerate innovation.

The RAN is the most computationally intensive part of the cellular network. AI/ML methodologies are proving effective in addressing its increasing complexity. Nvidia seems to focus on many of the tangible new features and capabilities of 6G to improve performance and enable new use cases and applications that can only be accomplished by using AI/ML natively in the RAN.

On 24 June 2024, Rohde & Schwarz announced that it joined the AI-RAN Alliance and leveraged its test and measurement expertise to unlock the potential of AI for wireless communications. Rohde & Schwarz addressed that it would aim to integrate AI into wireless communications to advance RAN performance and mobile networks. In fact, before joining the alliance, Rohde & Schwarz had already collaborated with Nvidia's research team on 6G research, pioneering a testbed for exploring neural receiver implementations that promise to revolutionize the air interface by improving performance and network efficiency. In particular, Andreas Pauly, CTO at Rohde & Schwarz, said: "Collaboration is critical to unlocking the full potential of 6G technology components, such as an AI-native air interface. By partnering with leading industry players and joining the AI-RAN Alliance, we ensure that we remain at the forefront of wireless communications innovation. In this way, the ecosystem benefits from our extensive experience in creating holistic test solutions for the wireless industry."

White Papers on AI for 6G

On 16 April 2024, Nokia released a white paper titled "AI Opportunities in 6 G Layer 2," which explores the frontiers of ML to improve features beyond the physical layer and further enhance the native AI air interface (AI–AI) envisioned for 6G [3]. The authors surveyed recent research on AI-driven functions, such as resource allocation, random access, adaptive modulation and coding, power control, protocol learning, CSI reporting, hybrid automatic repeat request, and multiple radio access technology spectrum sharing.

With advances in end-user devices and other technologies, the demand for immersive experiences that seamlessly blend the digital and physical worlds will be significant by the end of the decade. To support this, 6G networks must deliver unprecedented capacity, low latency, energy efficiency, and cognitive capabilities to manage vast radio resources. This article contended that, while the fundamental duties of the 6G wireless medium access control (MAC) will remain consistent with prior generations, the integration of ML methodologies will instigate transformative changes across multiple MAC domains.

Recently, the AI-RAN Alliance released a white paper titled "Integrating AI/ML in Open-RAN: Overcoming Challenges and Seizing Opportunities," which summarizes and explores the unique challenges and opportunities associated with deploying AI/ML in O-RAN, with a focus on the three AI RAN domains driven by the AI-RAN Alliance: AI for RAN, AI and RAN, and AI on RAN (i.e., RAN for AI) [4].

The advent of O-RAN represents a paradigm shift in telecommunications, promising enhanced flexibility, interoperability, and cost-efficiency. Central to the success of O-RAN is the integration of AI and ML technologies. These advanced computational techniques offer unprecedented capabilities for optimizing network performance, automating management tasks, and enhancing the overall user experience.

Integrating AI/ML into O-RAN presents significant challenges and exciting opportunities. Overcoming issues related to data quality, standardization, resource requirements, and contextual understanding is essential for unlocking the full potential of AI in telecom networks. With domain-specific training and adaptation, AI models can effectively address telecom-specific needs, driving the future of intelligent networking. The convergence of AI capabilities with traditional telecom services, supported by a robust and scalable infrastructure, promises enhanced network performance, new revenue streams, and improved user experiences. As the industry evolves, AI-driven intelligence will be crucial in optimizing network operations and supporting the next generation of telecom innovations.

In July 2024, Ericsson released a white paper titled "Cocreating a Cyberphysical World," which proposed that the 6G platform would aim to deliver advanced telecommunication networks that offer enhanced optimization and efficiency for communication service providers (CSPs). Ericsson anticipated that AI would have a central role in realizing the 6G system, both as an enabler to increase the efficiency of existing network features and also to introduce new features previously impossible to implement using non-AI technologies. Ericsson introduced the concept of "AI native aspects in the 6G architecture," defined as "the concept of having intrinsic trustworthy AI capabilities, where AI is a natural part of the functionality, in terms of design, deployment, operation, and maintenance." In particular, Ericsson addressed the crucial role that generative AI, among other AI technologies, will play in automating network management and operations.

Generative AI and 6G

The proliferation of mobile devices and the continuously increasing demands for user services have stimulated an explosive surge of data in wireless networks. Recently, mobile AI-generated content, an emerging paradigm for mobile data generation, manipulation, and modification, has been applied to a variety of applications, such as ChatGPT and DALL-E.

Generative AI is a type of AI that creates entirely new content based on the characteristics or patterns of the data from which it was trained. In the past, there existed a lot of predictive AI uses (that is, AI algorithms that, when trained on a series of previous data, will tell you what they expect to come next)—a forecast or prediction of the likely outcomes based on a set of values. Generative AI tends to be more innovative and capable of creating unique new content seemingly from scratch.

On 12 September 2024, Magnus Frodigh, vice president and head of R&D at Ericsson, said, "Artificial intelligence (AI) will be essential for enabling the commercial operation of 6 G networks expected around 2030." He anticipated a new wave of advances in generative AI over the next two years, focusing on capabilities related to mapping and analyzing physical spaces. He also said, "Generative AI will understand physical spaces, identify objects in a room, and create digital representations of what you are actually seeing. It will recognize, for instance, that this is a chair and that it can be rotated; this is a table, and so on." As he noted, research into 6G is in the prestandardization phase, where companies select and refine the fundamental technologies to make the service commercially viable.

On 7 November 2023, Ericsson presented "Four ways generative AI is set to transform the telecom industry," where four main avenues through which generative AI can (and likely will) deliver significant value are listed for CSPs, end users, and other players in the telecommunications sector: digital twins, machine-readable contents, semantic communication, and human-readable contents. Ericsson also addressed many key application areas in telecom where generative AI can be leveraged, including wireless channel modeling, spectrum sensing, channel quality estimation, hybrid beamforming, network traffic generation, network traffic analysis, anomaly detection, etc.

For a specific example of generative AI techniques for 6G, on 10 June 2024, authors from the University of Oulu won the Best Paper Award at the 2024 IEEE Wireless Communications and Networking Conference Resource Allocation and Machine Learning track. Their paper, titled "Denoising Diffusion Probabilistic Models for Hardware-Impaired Communications," presented a novel approach to address the challenges imposed by transceivers' residual impairments in communication systems by using advanced generative AI techniques.

On 9 April 2024, Qualcomm expected that on-device generative AI would be used to create more intuitive, user-centric features and automate tasks that were previously time-consuming or impossible for mobile devices. Qualcomm addressed the idea that, by intelligently utilizing a suitable processor alongside a neural processing unit, the heterogeneous computing approach would optimize smartphone application performance, thermal efficiency, and battery life, enabling new and improved generative AI experiences on devices.

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