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Original scientific paper

STRATEGIC GOALS FOR FUTURE MOBILE GENERATION 6G

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Abstract: 5G is in the middle of its decade, 2020-2030. Based on the experience from previous mobile generations, the mid-decade point of the previous mobile generation is the starting point of work on frameworks and standards for the future mobile generation that should mark the next decade, 2030-2040, and that is 6G. Starting with 3G, the ITU defines requirements for any mobile generation as part of its framework recommendations. Similar to IMT-2000 for 3G, IMT-Advanced for 4G, IMT-2020 for 5G, ITU Radiocommunication Sector will prepare the framework for 6G called IMT-2030, where IMT stands for international mobile telecommunications. A lot of research has been done about the look of the future of 6G, and more will come in the next years, by 2030 and beyond. Considering that the only deployed 5G standard is the one from 3GPP, unlike mobile generations until 4G which had deployments of standards from multiple standard organizations in different regions across the globe, it is expected that 3GPP will also provide the main unified standard for 6G, the next mobile generation. 3GPP standardization process on 6G networks is expected to start in mid-year 2025 and worldwide commercialization around 2029–2030. This paper highlights the most promising research areas in recent literature on overall 6G trends. It discusses development and analysis of 6G mobile technology, including the benefits and challenges associated with its development.

Keywords: 6G, Artificial Intelligence (AI), Internet of Things (IoT), mobile networks

СТРАТЕШКИ ЦЕЛИ ЗА ИДНАТА МОБИЛНА ГЕНЕРАЦИЈА 6G

Апстракт: 5G е во средината на својата деценија, 2020-2030 год. Врз основа на искуството од претходните мобилни генерации, средината на деценијата од претходната мобилна генерација е почетна точка за работа на рамките и стандардите за идната мобилна генерација што треба да ја означи следната деценија, 2030-2040 год., а тоа е 6G. Почнувајќи од 3G, ITU ги дефинира барањата за дадена мобилна генерација во своите препораки за рамката. Слично на IMT-2000 за 3G, IMT-Advanced за 4G, IMT-2020 за 5G, секторот за радиокомуникации при ITU ќе ја подготви рамката за 6G наречена IMT-2030, каде IMT е кратенка за меѓународни мобилни телекомуникации. Направени се многу истражувања за изгледот на иднината на 6G и уште повеќе ќе следуваат во следните години, до 2030 година и понатаму. Со оглед на тоа што единствениот распореден стандард за 5G е оној од 3GPP, за разлика од мобилните генерации до 4G кои имаа распоредувања на стандарди од повеќе организации за стандардизација во различни региони низ целиот свет, се очекува дека 3GPP ќе го обезбеди и главниот унифициран стандард за 6G како следната мобилна генерација. Процесот на стандардизација на 3GPP на 6G мрежите се очекува да започне кон средината на 2025 година, а светската комерцијализација да почне во 2029-2030 год. Овој труд ги истакнува најперспективните истражувачки области од неодамнешната литература во севкупните 6G трендови. Во него се дискутира развојот и анализата на 6G, вклучувајќи ги придобивките и предизвиците поврзани со идната мобилна технологија.

Клучни зборови: 6G, вештачка интелигенција (AI), Интернет на нешта, (IoT), мобилни мрежи

I. INTRODUCTION

As the telecommunications sector advances toward sixth generation (6G) mobile networks, new strategic objectives are beginning to take shape - objectives that are expected to dramatically reshape digital communication as we know it. This thesis investigates those emerging goals, focusing not only on technological improvements over 5G, but also on the wider social, economic and environmental impacts that 6G could bring about. By analyzing current trends and developments in communication technology, the study outlines key aims of 6G, such as delivering extremely high data speeds, enabling broad-scale IoT integration, expanding global connectivity, and supporting cutting-edge applications in areas like healthcare, cybersecurity, and immersive media.

Global mobile data traffic has experienced substantial growth in recent years. Recent statistics compiled by the

International Telecommunication Union (ITU) project that global mobile data traffic will reach 607 Exabytes (EBs) per month by 2025 and 5016 EB by 2030. Furthermore, almost 70% of the population is expected to subscribe to mobile services by 2025 [1]. Furthermore, 60% out of this 70% are estimated to use mobile Internet. The huge data traffic demands have been accompanied by increasing requirements for heterogeneous services, full coverage, ultra high-speed wireless communications with ultra-high reliability and ultra-low latency. The main drivers of the dramatic growth in data traffic are personal computers (PCs), laptops, tablets, smartphones, sensors and Internet of Everything (IoE) devices/applications. These devices are typically consuming data capacity (mainly video) rather than voice traffic. In addition, the number of Internet users, mobile subscribers, machine-to-machine (M2M) connections and connected devices worldwide are also expected to considerably increase in the next few years.

Although the 5G network offers support for many broadband applications and services, it may not be able to meet the rapid growth in traffic demands. Moreover, as a result of the ever-increasing growth in deployment of Internet of Things (IoT) devices and future Internet of Everything (IoE) devices, it will be necessary to further improve connectivity density and coverage of 5G-enabled IoT networks. In addition, future mobile networks are expected to be ultra-large, highly dynamic, and incredibly complex systems. Hence, manual optimization and configuration tasks used in existing mobile networks would no longer be appropriate for next-generation mobile networks [2]. Finally, emerging Internet of Everything (IoE) services, such as extended reality (XR), telemedicine systems, and flying cars, will require high data rates, high reliability, and low latency, significantly exceeding the initial goals of 5G networks. Therefore, with the onset of global deployment, as well as with the global commercialization of 5G mobile networks, 6G network research initiatives have attracted significant attention in both academia and industry. 6G mobile and wireless networks will provide extensive coverage, enabling subscribers to communicate with each other anywhere at high data rates due to unconventional technologies such as extremely large bandwidth due to THz waves and Artificial Intelligence. AI will be a driving force in the design and optimization of 6G architectures, protocols, and operations. These networks would drastically reshape the wireless evolution from "connected things" to "connected intelligence" [3]. In particular, 6G will support ubiquitous and mobile AI services from the core to the edge of the network, surpassing the mobile Internet in use today. In the 6G era, we can further envision an even richer structure of digital services, including expansion of human senses and ambient data that blend the virtual and physical worlds.
Consequently, the current generation of wireless communication is unlikely to sustain the ongoing traffic explosion and emerging applications. To address this challenge, the next generation of wireless communication systems, known as sixth generation (6G) networks, is being introduced. The remainder of this paper is structured as follows: Section II explains the wireless communication technology generation. Section III provides details about the 6G development process. The 6G vision and fundamental elements of 6G are elaborated in Section IV. Section V describes key use cases for 6G. Section VI discusses AI/ML for future 6G networks, and Section VII concludes the paper, addressing challenges in the 6G network and offering directions for future work.

II. Wireless Communication Technology Generation

Wireless communication was first introduced around 1895 by sending Morse code using EM waves using radiotelegraphy. In modern wireless communication, the method of transmitting and receiving the signal uses a similar phenomenon of EM wave transmission. Wireless transmission has developed over time, followed by radio telephones and mobile networks called cellular networks. There has been an exponential growth in the field of wireless communication over the years.

A. First Generation (1G)

The first generation (1G) cellular systems were introduced in 1980, for voice transmission. The access technique used in the radio access network (RAN) of 1G systems was FDMA (Frequency Division Multiple Access). FDMA requires a large channel spacing to avoid interference and each channel can only serve one user. Main service in the first generation was voice using analog transmission and circuit switching. Over time, the number of users increased and, as a result, the 1G system had the disadvantages of limited capacity, poor voice quality, and scalability problems. The operating frequencies were ~ 800–900 MHz, and the channel capacity was limited to 30 KHz. It had limited capacity, poor reception, lacked performance due to interference from battery and background noise, etc.

B. Second Generation (2G)

To overcome these shortcomings, in the early 1990s, 2G mobile technologies (i.e. GSM in Europe, D-AMPS in North America, and PDC in Japan) were developed, all based on TDMA (Time Division Multiple Access). Although TDMA allows multiple users to be served simultaneously on the same frequency channel, where each frequency carrier has one TDMA frame with 8 time-distributed channels (called time slots), it still requires large frequency spacing between channels to avoid interference. The basic service in second generation systems is voice, but there are also additional services such as short messages (SMS – Short Message Service), data services via modem connections, fax services, as well as additional voice services (calling line identification, call forwarding, etc.).

The next development, before moving to 3G, is represented by GPRS (also called 2.5G) and EDGE (known as 2.75G), where packet switching (for data transmission) appears as a novelty and higher bit rates are enabled.

C. Third Generation (3G)

Characteristically, 3G was developed to improve voice services, data throughput, high QoS (Quality of Service) and information security. 3G mobile technology was introduced in 2000 by ITU (International

Telecommunication Union) called IMT-2000. In 3G, data rates of 144 Kbps for mobile users, 384 Kbps for pedestrians and 2 Mbps for indoor users were successfully achieved.

Digital integrity and data security have been upgraded in 3G mobile technology. Similar to broadband Internet service, data rates have been radically improved from 144 Kbps to 2Mbps. Services such as voice, SMS, MMS, video, high-speed data, and video conferencing have been introduced accordingly. Two key variants of 3G technology are 3.5G (HSDPA), which improves downlink data transfer speeds from 8Mbps to 10Mbps downlink, and 3.75G (HSUPA), which improves uplink speeds to 5.8 Mbps by reducing the latency between the uplink and downlink.

D. Fourth Generation (4G)

In 2010, 4G mobile technology was launched with several important changes to its predecessors, such as ITU-IMT, which incorporated a capacity of up to 40 MHz and set its top speed requirement at 100 Mbps during the handover phase from one cell to another. Key developments in 4G compared to its predecessors are the type of switching and its underlying network, i.e. the entire IP network is used as a switched type, and the underlying network is the Internet (3G used packet network, 2G used PSTN). Features such as high speed and real-time data transfer take the 4G revolution to the next level. With ultra-broadband Internet service, data speeds range from 100 Mbps to 1.0 Gbps. High-speed transmission, MIMO technology, and global mobility are some of the most important achievements of 4G compared to the previous generation [4].

A 4G user can enjoy the following services: HD voice, SMS, MMS, mobile TV, wearables, HD streaming, global roaming, gaming services, etc.

E. Fifth Generation (5G)

5G is a fifth-generation mobile network. The 5G network architecture consists of two parts: radio access network (NG-RAN) and core network. Compared to previous generations of mobile networks, in 5G the core network changes drastically with introduction of the service-based architecture (SBA).

The evolution and development of the 5G mobile network is improved with each successive release. In Release 15, scenarios for a standalone 5G network and a 5G network connected to EPC are defined, functionalities of a large number of network functions, services they exchange, improved security and reliability, higher data rates and new user scenarios [5]. In addition, Release 15 also defines the concepts of Network Slicing, Machine Learning and Artificial Intelligence, 5G private networks, improved functionalities of existing protocols in previous generations of mobile networks, as well as introduction of new ones (e.g., SCTP, 5GSM, 5GMM, etc.). The main difference between 5G and 4G is that 4G was only focused on enhanced Mobile Broadband (eMBB), i.e. increasing bit rates and network capacity, while 5G not only improves eMBB but will also offer two completely new user scenarios, thus opening up opportunities for better quality of service and improved user experience, development of new business models and inclusion of a large number of industries in the 5G platform itself. Simply put, 5G will be the basis (technical platform) for future industrial revolution (Industry 4.0 – Fourth Industrial Revolution). 5G is created as an all-IP network, with end-to-end IP connectivity that is completely based on Internet technologies. IP connectivity has been present since 4G as the first all IP network, and 5G continues the evolution. In addition, 5G also enables additional separation of network functionalities (both in control and user planes) based on virtualization of networks.

III. 6G Development Process

Generally, ITU-R and 3GPP are vital consortia in 6G standardization, gathering together a large number of stakeholders to develop consistent, interoperable, and global 6G standards. Estimated timeframe for the development process of 6G is summarized in Figure 1.

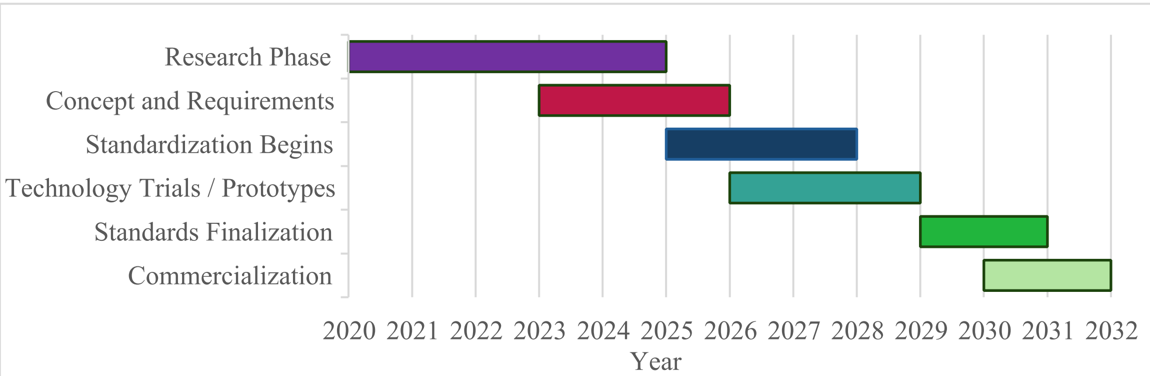

Fig. 1. Estimated timeline for 6G development process

The development of 6G follows a process similar to that of 5G. In short, the mobile network industry carries out the process from research and development to testing and implementation. Academia also participates in research and development work, often cooperating with the industry, which is of great importance.

Standardization and regulations are handled by the international and national standardization bodies and regulatory organizations. In these consortia, there are a vast variety of cooperating stakeholders involved, ranging from companies and universities to alliances and associations. Mobile network operators, service providers, and network vendors carry out the deployment and commercialization phases.

A. Role of ITU-R

ITU (International Telecommunication Union) is a United Nations specialized agency for information and communication technologies (ICTs) [6]. Its slogan “committed to connecting the world"’ reflects the aim of advancing global connectivity and access to digital technologies. ITU consists of three sectors: Standardization (ITU-T), Radiocommunication (ITU-R) and Development (ITU-D) [6]. ITU-R is responsible for worldwide management of radiocommunication and satellite systems. ITU-T standardizes international ICT systems through its study groups comprised of experts around the world. ITU-D aims to close the digital divide by providing digital services for the least developed countries. Among these three sectors, ITU-R plays a key role in 6G standardization.

Specifically, the role of ITU-R includes three main phases [7]:

- phase 1: build a vision of IMT-2030 (2020–2023);
- phase 2: define performance/service requirements and evaluation methodology/criteria (2024–2026);
- phase 3: evaluate candidate RITs and select the IMT-2030 compliant (i.e., 6G) ones by the end of 2030 (2027–2030).

ITU-R began its phase 1 visioning work on IMT-2030 in early 2020 and completed it by the end of 2023. The developed IMT-2030 vision was based on two ITU-R documents. In November 2023, the visioning phase culminated in publication of the Recommendation ITU-R M.2160-0 titled “Framework and overall objectives of the future development of IMT for 2030 and beyond”. The phase 2 of IMT-2030 development process began in early 2024 and is expected to be finalized by the end of 2026. Phase 2 is two-fold. First, ITU-R defines performance and service requirements that IMT-2030 systems need to meet. These requirements will be presented in a report titled “Technical Performance Requirements”. Second, ITU-R develops a comprehensive framework for evaluation of candidate IMT-2030 systems by defining the evaluation criteria and methodology. This evaluation framework will be introduced in a report called “Evaluation Methodology”. Phase 2 will also produce a third report, “Submission Template”, for candidate RIT proposals. Phase 3 is planned to begin in early 2027 and be completed by the end of 2030. In phase 3, ITU-R evaluates candidate RITs developed by 3GPP and other organizations against IMT-2030 requirements, relying on the evaluation framework defined in phase 2. Finally, ITU-R selects and approves RITs that meet IMT-2030 requirements. In addition to mid-band frequencies, the International Telecommunications Union-R (ITU-R) defined five spectrum bands above 100 GHz frequencies for preliminary studies towards potential approval at the World Radio Conference (WRC) in 2031.

B. Role of 3GPP

3GPP, a prominent global consortium, is responsible for development of international standards for mobile telecommunication networks. Formed in 1998, 3GPP has established standards for 3G, 4G, and 5G networks, with ongoing efforts to define standards for 6G. The consortium includes seven organizational partners that oversee policy and hold authority to publish official standards. It also comprises of 26 market representation partners such as industry alliances and forums that provide commercial and strategic guidance. Furthermore, over 850 companies and institutions are involved as individual members, contributing directly to development of 3GPP specifications [8].

Organizational partners include seven SDOs globally, including the Alliance for Telecommunications Industry Solutions (ATIS) from North America, the European Telecommunications Standards Institute (ETSI) from Europe, the China Communications Standards Association (CCSA) from China, the Telecommunications Technology Association (TTA) from South Korea, the Association of Radio Industries and Businesses (ARIB) from Japan, the Telecommunication Technology Committee (TTC) from Japan, and the Telecommunications Standards Development Society - India (TSDSI) from India. These SDOs play a pivotal role in development of 3GPP and 6G standards. 3GPP cellular standards are formulated through releases, each of which encompasses a comprehensive package of novel technological advancements for mobile networks [9]. These releases encompass the core network, radio access, terminal, and service capabilities. Each mobile generation comprises a series of releases, each representing an evolutionary step forward.

For instance, 3G and its subsequent evolution were defined through five releases (4 to 7), 4G through seven releases (8 to 14), and 5G will include six releases (15 to 20). It is noteworthy to mention there is some overlap in releases as the transition between generations occurs, given that current and new/old generation features are developed concurrently. Within each release, new technological features are scrutinized and defined in Technical Reports (TRs) and Technical Specifications (TSs).

As 5G evolution approaches its limitations, the standardization efforts shift towards 6G. The 6G standardization process is anticipated to commence in 2025. If Release 19 is completed by mid-2025, as planned, preparation of Release 20 will commence in July 2025. Release 20 is intended to initiate the 6G standardization process by being the inaugural release to investigate 6G features [10]. Assuming the customary 18 months preparation time for a release, Release 20 is projected to be finalized by the end of 2026, with preparation of Release 21 commencing in early 2027. Release 21 is expected to be the inaugural release to define 6G technologies, thereby becoming the first official 6G standard. Most likely, Release 21 will be included in 3GPP submission to ITU-R as potential 6G radio interface candidate to meet IMT-2030 requirements. If Release 21 is completed by mid-2028, as assumed, the inaugural commercial 6G networks could be launched around late 2028 to early 2029. Consequently, the global commercialization phase of 6G networks could approximately commence in 2029-2030.

IV. 6G VISION

Based on current trends, we anticipate that the next significant disruption in mobile communications will be the emergence of 6G-enabled mobile intelligence. Mobile intelligence encompasses the fusion of wireless, Artificial Intelligence (AI) and the Internet of Things (IoT) technologies at all societal levels [11]. Mobile intelligence possesses the potential to transform any connected, intelligent device into entities that are acutely aware of their surroundings. We envisage that 6G will evolve toward the Intelligent Network of Everything, while serving as fruitful platform for mobile intelligence to grow toward its potential. The 6G-enabled mobile intelligence will create a smart wireless world, where there are unprecedented opportunities to produce great value for the benefit of people, society, and the world in general. Eventually, mobile intelligence will penetrate all walks of life and become an essential part of the future society.

A. Fundamental Elements of 6G

To deliver significant disruption, 6G must be underpinned by three fundamental elements (Figure 2):

- Wireless: 6G necessitates seamless integration of wireless mobile communication, sensing, and energy management capabilities;
- Artificial Intelligence (AI): extensive application of AI across all tiers of the 6G ecosystem, encompassing the network core, network edges, air interfaces, devices, services, and applications, is crucial;
- Internet of Everything (IoE): proliferation of network-connected objects, such as sensors, devices, machines, vehicles, drones, robots, and others, is a hallmark of IoE.

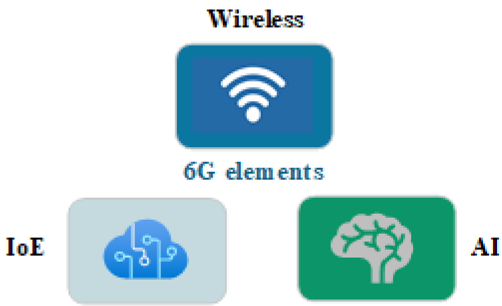

Fig. 2. Fundamental elements of 6G

B. Disruptive Applications

6G is poised to support a diverse range of transformative applications. These applications are categorized into three main areas: human-machine interactions, smart environments, and connected autonomous systems. Human-machine interactions encompass diverse ways in which humans interact with machines, devices, and intelligent entities. Five key interactions are defined: metaverse, virtual reality (XR), holographic communications, digital twins, and tactile Internet. Smart environments are entities that leverage wireless, Artificial Intelligence (AI) and Internet of Things (IoT) technologies to generate enhanced value. Four primary environments are identified: smart society, smart city, smart factory, and smart home. Connected autonomous systems refer to entities capable of operating independently without human intervention, utilizing versatile technologies such as AI, control, sensing, positioning, and connectivity. Three systems are defined: connected autonomous vehicle systems, connected autonomous aerial vehicle systems, and connected autonomous robotic systems.

C. Key Use Cases

Since 6G is expected to significantly expand the capabilities of mobile networks, we introduce five communication-oriented and three beyond communication-oriented use cases accordingly. In the communication domain, there are six main performance dimensions that must be optimized for 6G, those being capacity, latency, reliability, density, coverage, and mobility [12]. The corresponding use cases encompass ultra-broadband multimedia communications, extremely time-sensitive and mission-critical communications, ultra-massive communications, global-scale communications, and hyper-mobility communications. In addition to enhanced communication capabilities, 6G aspires to extend its functionalities beyond communication. The corresponding use cases include network intelligence, network sensing, and network energy.

D. Performance Requirements

Supporting diverse use cases and applications, to cater to a wide range of use cases and applications, 6G performance requirements need to be pushed to their extremes. The International Telecommunications Union - Recommendations (ITU-R) has introduced illustrative target values for nine key performance metrics: peak rate (50/100/200 Gbit/s), user experienced rate (300/500 Mbit/s), spectral efficiency (1.5X/3X), area traffic capacity (30/50 Mbit/s/m^2), latency (0.1–1ms), reliability (1-10^{-5}–1-10^{-7}), connection density (10^6–10^8/km^2), mobility (500–1000 km/h), and positioning accuracy (1–10 cm). Compared to targets proposed in 6G literature, the values established by ITU-R are generally considered to be rather moderate.

E. Potential Technologies

A comprehensive set of advanced 6G technologies is essential to meet anticipated requirements, use cases, and applications. This comprehensive analysis encompasses ten distinct network categories, including spectrum, antenna systems, transmission schemes, network architectures, network intelligence, beyond-communication, energy awareness, end-devices, services, and security. At the core of spectrum-level technologies lies THz communications, which offer exceptionally high data rates. Furthermore, extreme antenna systems, such as ultra-massive MIMO and RISs, provide high spectral efficiency and extended coverage. An ultra-flexible transmission scheme based on a multi-waveform design, with flexible numerology, and fast grant-free access will form the foundation for the 6G air interface.

In the field of network intelligence, Artificial Intelligence (AI) and Machine Learning (ML) are essential technologies that enhance functionality across the core network, edge nodes, and wireless interfaces.

TABLE I
SUMMARY OF KEY USE CASES

Use Cases	Target	Environment	Requirements	Challenges	Enablers	Application
Ultra-Broadband Multimedia Communications	Immersive multimedia	Hotspot to rural	Extreme rates & ultra-low latency	Extreme requirements	THz & UDNs	XR & HTC

Use Cases	Target	Environment	Requirements	Challenges	Enablers	Application
Extreme Time Sensitive Mission Critical Commun.	Applications with tight constrains	Industrial & vehicular	Extreme reliability & ultra-low latency	Conflicting requirements	Fast/robust network processes	Smart factory & CAVs & tele-surgery
Ultra-Massive Communications	Ultra-massive IoT/IoE	Industrial & urban & wide-area	Ultra-dense connections	Network flexibility	Flexible network mechanism	Smart factory & smart city
Global-Scale Communications	Global coverage	Land & air & sea	Super- coverage	Cost efficiency & 3D network	NTNs	Global IoT & remote Internet
Hyper-Mobility Communications	Connectivity at high device velocities	Urban to rural	Extreme mobility	Mobility management	Lower spectrum & fast handovers	Ultra-high-speed trains
Network Intelligence	Intelligence as a service	Industrial & organizational	High level of intelligence	Powerful computing infrastructure	Pervasive AI/ML	Smart environments
Network Sensing	Ubiquitous sensing	Industrial & healthcare	Sensing capabilities	Accurate sensing	ISAC	Detection & tracking
Network Energy	Wireless energy services	Industrial & private	WET capabilities	Efficiency & distances	Energy beamforming	Powering IoT devices

V. Key Use Cases for 6G

6G is anticipated to significantly enhance the capabilities of mobile networks by augmenting conventional communication features and introducing novel beyond-communication functionalities [13] [14].

Following this transformation, we present five communication-centric and three beyond communication-centric use cases, thereby supporting a diverse spectrum of novel 6G-level application scenarios. These use cases are succinctly summarized in Table I.

Communication-oriented use cases: 6G is expected to push the communication performance to its limits. The corresponding performance dimensions are capacity, latency, reliability, density, coverage, and mobility. We identify five communication-oriented use cases to cover all of these dimensions.

Ultra-Broadband Multimedia Communications: This use case aims to deliver comprehensive support for immersive and high-bandwidth multimedia experiences across a variety of settings, ranging from densely populated urban zones to remote rural regions. Representative examples of such data-intensive applications include wireless multi-sensory extended reality (XR), holographic communication systems, immersive information delivery, and ultra-high-speed mobile Internet services.

Key enablers for achieving these requirements include substantial radio resources for capacity (increased spectrum, cells, and antennas), rapid network mechanisms for minimizing latency, and robust communication methods for ensuring reliability [15]. It is important to note that simultaneously satisfying all these requirements constitutes an application-specific trade-off, as each one of them presents varying degrees of conflict. Furthermore, this use case can be regarded as extension of 5G eMBB.

Extreme Time-Sensitive and Mission-Critical: This use case is designed to support time-sensitive and mission-critical applications in diverse environments, including smart factories, smart hospitals, autonomous vehicle systems, and emergency operations [16]. Extreme reliability and ultra-low latency are imperative due to the absence of room for significant errors. Key enablers for extreme reliability include network- and link-level diversity methods, high channel coding rates, robust modulation orders, and advanced retransmission mechanisms. It is important to note that reliability and low latency are conflicting requirements, necessitating a trade-off. This use case can be considered an extension of 5G URLLC.

Ultra-Massive Communications: This use case aims to support an ultra-massive number of different types of devices in diverse application scenarios. The range of devices is wide, including IoT sensors, devices, robots, vehicles, wearables, machines, drones, etc.

Application scenarios vary from smart environments (e.g., cities, factories, hospitals, buildings, warehouses, etc.) to wide-area IoT (e.g., environmental/industrial monitoring) and low-power sensor networks. Due to versatile devices and applications, many performance dimensions need to be considered, such as connection density, coverage, mobility, capacity, and reliability [17]. Key enablers for massive connectivity include flexible spectrum operation, fine-grained frame structure, massive grant-free network access, robust transmission techniques, and efficient resource management. The challenge is to build such a flexible network. This use case is an extension of 5G mMTC.

Global-Scale Communications: The goal of this use case is to provide worldwide super-coverage, including remote areas on the land, at the sea, and in the air. This use case supports diverse global-level application areas, including remote Internet, global IoT, environmental monitoring, industrial tracking, and maritime/aerial communications, to mention a few. In alignment with the United Nations Sustainable Development Goals, provision of Internet access to remote and developing regions worldwide can contribute to alleviation of the digital divide.

Furthermore, the capabilities of this technology enable us to combat climate change effectively through global environmental monitoring. The seamless integration of terrestrial and non-terrestrial networks, utilizing satellite, aerial, and mobile communications, facilitates this global coverage.

Network Sensing: This use case aims to expand capabilities of cellular networks to sensing and positioning. Example applications include object identification, shape recognition, activity detection, range estimation, velocity evaluation, and movement tracking. Typical application environments include industrial and healthcare settings.

For instance, network sensing can be employed to identify gas leaks in a factory or detect a person falling at elderly care facility, triggering an automatic call for assistance. This use case is enabled by integration of communication and sensing. The main challenge is to obtain high accuracy in sensing.

VI. AI AND ML FOR FUTURE 6G NETWORKS

AI (Artificial Intelligence) and ML (Machine Learning) are expected to play a crucial role in future 6G networks. In general, AI makes machines behave like humans. It also enables machines to make appropriate decisions and achieve specific goals. ML, in particular, is considered a part of AI, which enables computer agents to evaluate, acquire knowledge, reason, and make intelligent decisions based on collected data. Typically, machine learning learns essential information either from datasets or through interactions with existing environments [18] to [20].

AI and ML techniques are expected to be integrated into optimization, planning, and design of future 6G wireless communication networks. Furthermore, AI and ML techniques will be the core technology for future 6G wireless communication systems, which have the ability to achieve intelligent resource management, intelligence decision-making, smart assessment and detection, smart routing, automatic maintenance, automated network operations, and management. AI and ML can also be used to improve communication system performance, process huge amounts of data, reduce energy consumption, and reduce end-to-end network latency. AI and ML algorithms have the potential to address challenges associated with network complexity and maintaining quality of service.

AI and ML can be used in the design of future autonomous wireless systems. AI and ML algorithms can also be useful for satellite communication systems. These algorithms are also essential for interference mitigation, time tracking, spectrum and energy resource management, sensor fusion for navigation, large constellation management, and optimizing the performance of satellite networks. Deep Learning techniques are classified into supervised, unsupervised, and reinforcement learning [21], as shown in Figure 3.

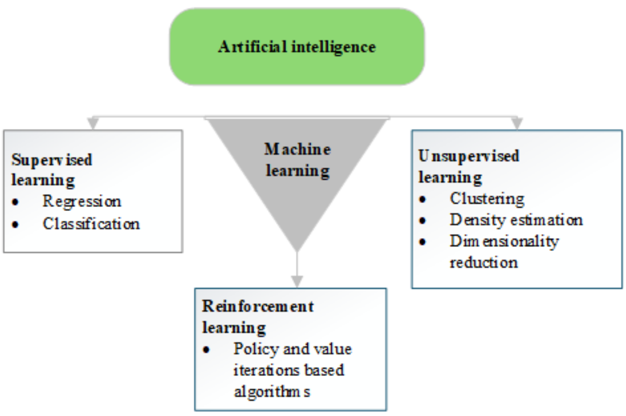

Fig. 3. Artificial Intelligence and Machine Learning techniques, together with their classifications

Each of these techniques has its own unique characteristics. For example, supervised learning requires labeled training data sets, which need to be known in advance. Typically, supervised learning needs to be trained on a large number of datasets (pairs of input and desired output). In contrast, unsupervised learning does not require labeled datasets, which aims to infer features in datasets. Finally, datasets obtained from implementations rather than historical data are required in reinforcement learning, which allows learning agents to learn from experience. ML technology can be effectively used in telemedicine systems. Additionally, ML techniques can be used with intelligent programmable meta surfaces to achieve high energy efficiency, reduce system costs, and enable high-accuracy object recognition. Finally, ML techniques can be effectively used in interference management for UAV communication systems [22].

Deep Learning (DL) is also a promising method to address many technical challenges related to wireless AR, MR, and VR. DL technique is expected to play a crucial role in the design of caching and computing approaches at the mobile edge. DL has the potential to automatically encode data by jointly learning implementations of the transmitter and receiver. These tasks can be accomplished without prior knowledge [23].

Adaptation of AI and ML algorithms in future 6G networks is essentially necessary to reveal their full potential benefits in wireless communication systems, [24]. In particular, to guarantee the quality-of-service requirements [25] which are standard in the design of wireless communication systems, a detailed understanding of fundamental performance limitations of AI and ML applications is required. Therefore, further investigation is needed to find efficient ML algorithms with fast convergence times. Furthermore, wireless networks are subject to highly dynamic mobility and traffic conditions. Federated Learning is considered a promising 6G technique that can be applied to improve learning efficiency. However, the application of Federated Learning in future 6G networks needs to be further investigated. Further research is also needed to explore use of AI and ML techniques for channel estimation in high-mobility environments and mmWave channels.

VII. CONSLUSION

5G systems are characterized by diverse applications and requirements. 6G is anticipated to progress in the same trajectory, with further enhancement of the application ecosystem. Considering network management and orchestration, signal processing and coding at the physical layer, manipulation of smart network structures and data, and device-driven communications, we can conclude that Artificial Intelligence will drive future end-to-end communication, including smart core, slices, smart network, CPE, network terminal, handsets, and applications.

An intelligent 6G network architecture enabled by AI will be implemented to realize knowledge, smart resource management, automatic network adaptation, and intelligent service provisioning. Collective AI is an advanced form of current AI techniques that involve coexistence of multiple distributed mobile radio agents to learn for different benefits. 6G deployment is expected to begin around 2030. This network would be highly energy- and bandwidth-efficient. New dimensions such as quantum communication, satellite integration, and maritime wireless electromagnetic communication are expected to find a place in 6G. In addition, terahertz, visible light communication and technologies such as compressed sensor theory, new channel coding, large-scale antenna, flexible spectrum utilization, AI-based wireless communication and special features such as integrated Space-Air-Land-Sea communication and wireless network are some of the innovations expected to become the common network standard of 6G. The key driver for 6G is expected to be convergence of all past features such as high throughput, low power consumption, high reliability and mass connectivity.

Future services will include AI, smart wearables, autonomous vehicles, augmented reality computing, 3D mapping, sensors, augmented and virtual reality, holographic telepresence, massively integrated smart cities on IoT, automation in manufacturing and much more. Self-assessment at any level such as availability effectiveness, security, efficiency, scalability, portability, flexibility will be driven by Artificial Intelligence.

5G/5G-Advanced has laid the foundation, and 6G will carry it over from 2030 to 2040,

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