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Improving Wireless Communications for the Next Generation (6G) via Education and Research

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Abstract— Fifth generation (5G) wireless communication is only getting started, and new iterations will be introduced during the next several years. Telecom researchers are already beginning to think about the next generation of wireless communications, 6G, in light of the limitations of 5G and the growing applications and services with rigorous criteria such as latency, energy/bit, traffic ca- pacity, peak data rate, and dependability. We examine the problems, needs, and developments of 6G here. We also talk about the benefits that AI methods may bring to 6G networks. Through analysis of the problems and their potential answers, we've identified a number of exciting new 6G services and use-cases that 5G just can't handle. Further, we outline several potential avenues of investigation that might pave the way for the development and deployment of 6G.

Index Terms—6G wireless communications, automation, intel- ligence, machine learning.

I. Introduction

The forecast for the mobile industry indicates that the total number of customers and mobile connections will rise in the next years. Some estimates put the total number of mobile connections worldwide at 9.1 billion by 2025 [1] and the number of individual customers at 6.1 billion by that year. South Korea officially deployed the first version of the 5G NR (new radio) standard at the beginning of April 2019. This standard was first issued in June 2018 [2]. By 2025 [1,] it is expected to have taken 15% of the worldwide market.

Unpleasantly, however, both the pace of increase of the number of unique subscribers and the average revenue per user (ARPU) are falling. Figure 1 displays historical trends in the number of subscribers, which increased by 20.5% in 2005, 5% in 2015, and a far more modest 1.45% by 2025. This marked slowing in development is seen as a major crisis for mobile network operators (MNOs), and it has prompted calls for more involvement from academic and business institutions in an effort to rescue the sector by presenting novel, appealing alternatives to broadband.

Given these numbers, and taking into account the fact that the lines between the mobile industry and other sectors have blurred and MNOs are racing to find ways to make money off of 5G, it would appear to be the ideal moment to focus study on this topic.

beyond 5G to investigate untapped commercial potential in a dynamic and more competitive marketplace.

As the quantity and growth rate of IoE devices and connections are experiencing a fantastic growing ratio, it is possible that the Internet of Everything (IoE) might be a viable alternative to compensate for such losses. Figure 2 depicts the forecast growth in consumer use by a factor of 2.5, while industrial usage is expected to rise by a factor of 4.7. IoE is built on the foundation of 5G's specifications and capabilities, which are also shared by huge machine communications (mMTC).

The users also expect some interesting services beyond broadband applications, such as extended reality (XR) (VR, MR, AR), super Hi-vision (8K) video streaming, holographic communications, holoportation/telepresence, tele-surgery, haptics, unmanned aerial vehicles (UAV), connected autonomous vehicles, etc.

Take South Korea's K-city as an example, a "smart city" where all vehicles operate autonomously. In the not-too-distant future, K-city will play home to thousands of autonomous cars. Coordination and cooperation among vehicles requires super-precision location, e.g. near centimeter accuracy, context-awareness to react to changes in the area in which they are operating (including other cars, cyclists, and pedestrians), and near-zero perceived latency. As a result, it's important to cut down on travel time, gas money, and potential mishaps.

With severe requirements including near-zero latency, scalability, connection density, peak data rate and user-experienced data rate, traffic volume density, dependability, and mobility, it is questionable if policy-driven 5G technologies can adequately deliver the aforementioned services. Many factors contributed to this, but one of the first 5G deployments focused mostly on sub-6GHz bands, especially for mobility assistance.

As was the case with the generations of mobile phones that came before it, a decade passes between the beginning of research and the beginning of early plans for the next generation. This means that while MNOs are rushing to make money off of 5G, academics are already hard at work conceptualizing the next generation of wireless technology, 6G.

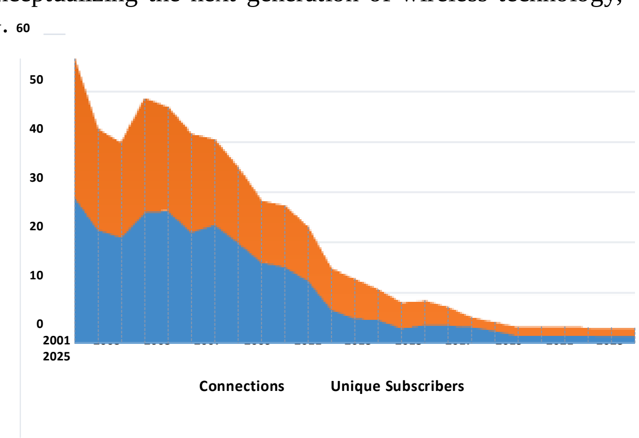

Fig. 1. Growth rate of mobile industry.

II. We outline the forthcoming trends and demanding specifications of mobile networks of the future in this study. Following that, we outline how artificial intelligence and ML approaches may aid in overcoming these obstacles. In particular, we detail how machine learning methods may be used in device processing to facilitate the introduction of new services and reduce the strain on existing networks. Then, we'll talk about the many ways in which ML algorithms aid in network management across its many levels. We then provide some potential 6G services and use-cases in light of the specified needs and solutions. At last, we'll go through some potential next steps for 6G research. The remaining sections of the paper are structured as follows. The second section outlines the specifications for 6G networks and the current industry developments. In the next section, we will go over some of the ways in which artificial intelligence may be used to facilitate smarter network administration and device processing. We detail some of the novel services and applications that will be possible with the advent of 6G networks. In the last section, you'll get some ideas about where to take your study. After all that, we get to the final findings in Section VI.

III. 6G REQUIREMENTS AND TRENDS

The mobile industry needs to shift from the traditional strategy to some new ones, such as operating in shared spectrum bands, inter-operator spectrum sharing, indoor small cell networks, a large number of local network operators, leasing network slice on demand, and many more in order to address the problems that the current generation of mobile networks is facing. Because of this, Figure 3 demonstrates how the demands of 6G are higher than those of 5G. Here we will go over some of the most crucial needs and tendencies of the next generation of mobile networks.

• Large bandwidths: While NR is expected to make use of the sub-6 (3GHz to 6GHz) and mmWave bands (e.g. 24GHz, 28GHz, 37GHz, 39GHz, 47GHz) to support bandwidth-intensive applications, the networks of the future need higher spectrum technologies, such as 73GHz to 140GHz, 1THz to 3THz, or perhaps optical communications.

One of the most prominent developments in recent times is the expected enormous growth in mobile traffic over the next several years, therefore it's crucial to have a data plan that can handle the influx. Achieved by the implementation of

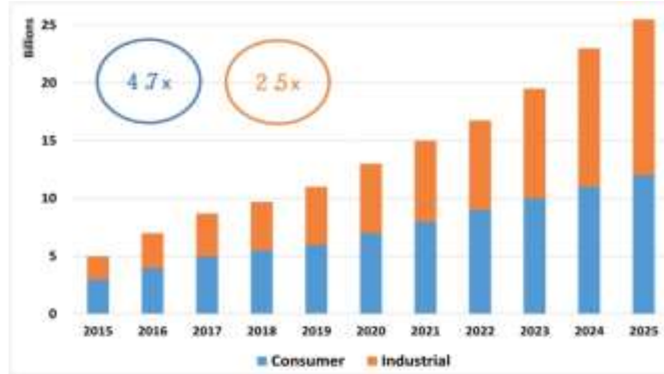

Fig. 2. Growth rate of IoE.

Super-immersive multimedia, XR, holographic 3D video communications, 8K, 4K, etc., are all examples of emerging technologies that are expected to significantly increase the amount of mobile traffic dedicated to video sharing [1]. Taking Samsung as an example again, the company has already begun work on the Exynos9820 smartphone processor, which will allow future devices to capture 8K video. Experts are also keeping an eye on digital cinema (such as 64K) as a potential mega-trend. Such services need an extremely high and opportune peak data rate. Holographic communications need a bandwidth of 4–10Tbps, whereas 360° VR/AR services require up to 500Mbps.

• Opportunistic delay: New 6G services are anticipated to have latency close to zero, for instance, less than 1ms end-to-end delay. Even a 20ms delay in a networked augmented reality application is quite frustrating. The same holds true for the other services, which can only operate with delay measured in milliseconds. Telepresence, for instance, requires latency of only a few milliseconds or less.

According to Statista's 2019 predictions, there will be 50 billion IoE-connected devices by 2030. This translates to a staggeringly high density of connections per square kilometer (km2) for mMTC. In the near-term mMTC

Also known as massive IoE (mIoE), this paradigm shifts the focus from humans to robots. Scalable and efficient connection for the vast number of connected devices, QoS provisioning, managing highly dynamic and erratic mMTC traffic, massive signaling overhead, and network congestion are the primary issues that 6G will encounter in mMTC. Further, 6G is essential for enabling vast area coverage as well as deep inside penetration while keeping costs and energy usage to a minimum.

• Super-reliable mobile telecommunications (sMTC): The majority of 6G use-cases need not just high bandwidth and low latency, but also high availability (99.999 percent). As a result, sMTC—the availability, latency, and reliability of the network—must be prioritized in the network of the future.

Humans won't be able to handle the complexity of the future network, which is why we need the Self-X network. In order to facilitate the autonomy of 6G networks and to capture insights and knowledge of their surroundings, cutting-edge intelligent and adaptable ML techniques are applied. Therefore, in the future, the network will be able to learn, reconfigure, optimize, heal, aggregate, defend, and organize itself, all without the need for human interaction.

• Extremely precise operation: For certain services, such as exact delivery times, it is critical to ensure a high degree of accuracy at all times. High-precision services need more than what conventional statistical multiplexing can provide. Therefore, certain new function components are needed, such as the user-network interface, reservation signaling, new forwarding paradigm, intrinsic and self-monitoring operation, administration, management, and configuration of the network. Some examples of these services are tele-surgery and intelligent transportation systems.

The current localization systems estimate location using a combination of satellites (such as Augmented-Global Positioning System (A-GPS), Glonass, and Galileo) and signal strength and journey time. They are not suitable for most modern services, however, due to their high rate of mistake even when ordering meters. For new applications like telesurgery and the tactile internet, sub-millimeter precise positioning is essential.

• Scalability: It is expected that billions of items, including high-end computers, sensors, actuators, smartphones, tablets, wearables, household appliances, cars, etc. will be connected to the Internet through IoE. Having so many gadgets in one's home all producing data at once is overwhelming. In the hands of the right researchers, these facts may reveal previously unknown information. So, we use AI algorithms and methods to sift through information. User equipment (UE) and edge devices in the Internet of Everything (IoE) that are equipped with artificial intelligence (AI) may analyze data, summarize it, and find new insights before sending them along. By reducing a large data set to a more manageable size, this increases bandwidth usage, dependability, energy efficiency, traffic load on the network, and latency.

6G devices are expected to operate in higher frequency bands, hence they will need much more power than their predecessors. Therefore, the issue of energy efficiency and power consumption is one of the greatest difficulties now facing humanity. Nonetheless, advancements in technology, such as energy harvesting in home automation and smart buildings, will lead to greater energy efficiency and, eventually, battery-free IoE devices.

The expansion of future networks beyond 2D to span seas, atmosphere, and space will enable the seamless incorporation of terrestrial and extraterrestrial components.

1 msec	Latency	0.1 msec
NS	Energy/bit	1 pJ/bit
10 Mbps/m2	Traffic Capacity	10 Gbps/m3
10 cm on 2D	Localization Precision	1 cm on 3D
50 Mbps 2D	User Experience	10 Gbps 3D
20 Gbps	DL Peak Rate	1 Tbps

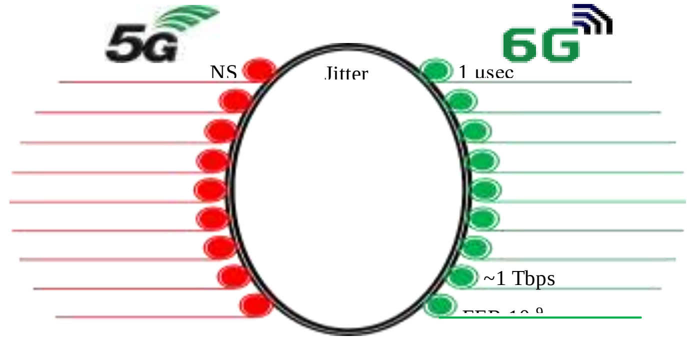

Fig. 3. The requirements of 5G and 6G.

aerial devices. Such type of networks will support various applications including underwater acoustic ad hoc and sensor connections, climate and weather forecasts, and monitoring, etc.

Global coverage will be provided via satellite communication technologies, which will be integrated into the next generation of 6G communications. Localization services, broadcast and Internet access, and weather information will all be made available to cellular customers thanks to the 6G network's integration of telecommunication satellites, earth imaging satellites, and navigation satellites. Having access to fast Internet on fast trains and aircraft is one such example.

Network management for future 6G networks may benefit greatly from the use of software-defined networking (SDN), which allows for dynamic and programmer-efficient network design. Using NFV, network tools may be consolidated onto large servers in data centers, dispersed network devices, or even at the end user's premises. Network slicing provides a cognitive and dynamic network architecture on demand, allowing for several virtual networks to run on top of a single set of physical network components.

After this part, we will talk about how generations of mobile devices might benefit from artificial intelligence and ML algorithms.

4. WIRELESS COMMUNICATIONS DRIVEN BY LEARNING Context-aware, omnipresent, reconfigurable, and intelligent 6G wireless communications will change the Internet of Everything (IoE) and mobile devices and networks in a number of ways. As a result, the networks of the future will be too complicated for humans to manage. Thus, to attain such skills, an AI-enabled and learning-driven network, aided by big data, will be able to provide the users with unique capabilities like learning, reasoning, and decision-making to operate a network with zero human intervention. In 6G, AI is increasingly being used for tasks like network resource management, network planning, and optimization, and even problem detection.

and evaluation. Since IoE "supply data" and AI "analyses data" and "mines knowledge," a combination of IoE and AI enabled by 6G will be all the more fascinating.

We explore the use of AI in network management and device processing to improve operational dependability, real-time predictions, and security in the areas below.

Management of Computer Networks Using Artificial Intelligence

Many facets of network administration, including as monitoring, processing, and decision-making, benefit from the use of artificial intelligence. Machine learning (ML) is a kind of artificial intelligence (AI) that entails training computers to learn how to make decisions based on data in order to carry out activities and functions (act) without any human input. There is a lot of room for growth in the fields of large data analytics, efficient parameter estimation, and interactive decision-making where ML may be used as a supporting technology.

Thereafter, ML algorithms would enable self-x networking, which would be a major advancement in the realm of networking and communications at both the device and network levels (e.g. self-learning, self-reconfiguration, self-optimization, self-healing, self-organization, self-aggregation, and self-protection). For instance, ML can be used to solve the issue of IoE access congestion [3], add intelligence to the PHY to enable smart estimation of parameters, interference mitigation, and resource management- ment [4], use DL for channel estimation and symbol detection [5], and use DL for dynamic radio resource allocation for V2V and V2X [6].

Learn how ML algorithms like supervised learning, unsupervised learning, and reinforcement learning can be implemented in various network layers in the following section [9]. • Supervised learning: is a learning function that maps an input to an output based on the labeled training data, i.e. input-output pairs. Independent component analysis, locally linear embedding, principal component analysis, isometric mapping, K-means clustering, and hierarchical clustering are only few of the numerous approaches developed under supervised learning that may be used for network management. This kind of algorithm may be used in several layers of wireless networks. The aforementioned methods may be used at the physical layer for a variety of purposes, including channel equalization, channel decoding, path-loss and shadow prediction, channel state estimation, beamforming, adaptive signal processing, etc. Caching, traffic classification, anomaly detection, throughput optimization, delay mitigation, etc. are all examples of network-layer use cases for supervised learning.

• Unsupervised learning is a kind of autonomous learning that is used to unearth ill-defined patterns in a dataset without assigning labels in advance. K-nearest neighbors, neural networks, decision trees, random forests, Bayesian learning, linear/logic regression, and support vector machines are only some of the unsupervised learning methods that have been created. All of the aforementioned methods have applications in network management.

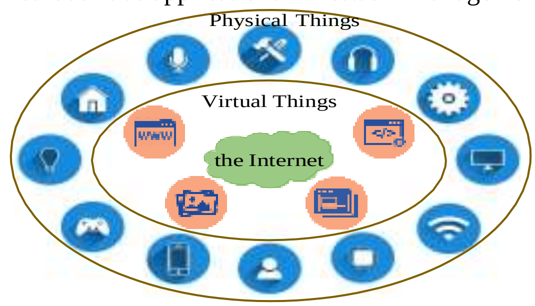

Fig. 4. IoE is composed of physical and virtual things.

routing and traffic control layer parameter prediction resource allocation and RAT selection Management of handoffs and mobility, allocation of network slices, etc. Channel-aware feature extraction, interference cancellation, channel estimation, multiple-input multiple-output (MIMO) pre-coding, node association, beam switching, etc. are all examples of applications of unsupervised learning at the physical layer.

• In reinforcement learning, the agent makes a series of decisions in order to maximize a predefined reward function over time. Multi-arm bandit, temporal-difference learning, the Markov decision process, SARSA learning, Q-learning, and the Monte Carlo Method are just a few of the well-known methods created for network management. In network slicing, these methods may be used for proactive caching, data offloading, error prediction, and data rate allocation at the application layer. Multi-objective routing, packet scheduling, security, traffic prediction and classification, etc., are all examples of network-layer applications that might benefit from reinforcement learning. In the physical layer, reinforcement learning may be used for a wide variety of purposes, including link preservation, channel tracking, on-demand beamforming, energy harvesting, modulation selection, radio identification, and so on.

A. AI-powered Device Processing

The recent introduction of on-device Edge AI, in which AI processing is moved from the centralized computing facilities, e.g. cloud, to every terminal in the network, such as IoE devices, smartphones, BSs, APs, etc., has fueled the growing trend of AI-powered gadgets. Using AI approaches in both hardware and software, such gadgets would have far-reaching consequences for numerous industries, including but not limited to: commerce, healthcare, transportation, industry automation, robots, mobile phones, and many more. Strategy Analytic has predicted that by 2023, 80 percent of all smartphones would use some kind of AI [7]. As can be seen in Figure 4, this has led to an effort on the part of manufacturers to provide an open ecosystem powered by AI that spans all the devices and services needed to construct the IoE. Because of this, IoE apps and services enabled by 6G will be more interesting than those provided by IoE and AI separately.

New artificial intelligence (AI)-based features are available on the newest smartphones. For instance, the camera on modern smartphones use AI methods to improve picture quality and refine the device's attractiveness. Cameras powered by artificial intelligence may also be programmed to snap pictures in response to certain behaviors, such as raising a hand or making a goofy face. Melaud is an AI-powered smart earphone that lets you adjust your workout soundtrack in response to biometric data like your heart rate and motion. Intelligent interfaces like Bixby, Siri, Alexa, and Google Assistant are powered by artificial intelligence (AI) and can do things like compose text messages based on dictation through the voice app, recognize landmarks and translate languages through the device's camera, perform online purchases, control smart home devices, and remind users of upcoming appointments. The Google Call screener automatically picks up incoming calls, speaks to the caller, and then writes a written summary of the discussion.

It is anticipated that in the near future, electronics will be smarter thanks to the advancement of ML algorithms and methodologies. There are a number of services that are expected to become available through mobile devices in the 6G era.

The user's own data may be used to train an AI-based smart gadget equipped with Neural Networks.

Future mobile devices will run on higher frequency bands, have displays with better resolutions, and use other power-intensive applications, therefore optimizing their energy use is seen as a major problem. The devices will be able to prioritize battery power for various apps and services thanks to the future smart battery that employs ML algorithms.

• The chipsets feature neural processing engines capable of doing billions of operations per second. Such robust engines are aiding on-device augmented reality (AR) by processing collected data and uncovering the desired knowledge close to the birthplace of data, thereby reducing network traffic volume and bandwidth consumption. in situations such as navigating congested streets and highways, crowded stadiums, malls, subway stations, etc.

AI and computer vision are used in computational photography to acquire, process, analyze, and comprehend digital images so that multi-dimensional information about the physical world may be uncovered.

With the help of AI, Samsung's next Exynos9820 CPU provides a notable increase in both performance and energy efficiency. Future smartphones will be able to capture 8K video at 30 frames per second (fps) or 4K video at 150 fps thanks to the processor.

IV. 6G Envisioned Services and Use-cases

It is expected that 6G would revolutionize networking by allowing for intelligent communication between machines as well as between humans and machines. Figure 5 depicts the wide variety of cutting-edge services and applications that will debut in the 6G era.

Some services and use cases that existing technology are unable to accommodate are as follows:

Fig. 5. The envisioned services and use-cases for 6G.

• Multisensory XR applications: Virtual reality (VR), augmented reality (AR), and other similar technologies use a wide range of sensors to create a fully immersive environment, including orientation, acceleration, location, temperature, and sound. Such applications need a near-zero perceived latency network environment in which large amounts of data may be transferred quickly and reliably. High-resolution XR (such as 4K and 8K) will be utilized in a wide variety of industries and use cases. These include but are not limited to: broadcasting; teaching; production; advertising; medicine; the automotive industry; healthcare; video games; workplace communications; entertainment; and more.

True immersive communication in 5D of human sense information is made possible by the Internet of holograms, which includes holographic applications like holoportation and telepresence (in- cluding sight, hearing, touch, smell, and taste). Users will be able to have conversations with one another that seem almost as genuine as in-person encounters because to the incorporation of digital holographic presence. Further, by using immersive live models, we may deliver a mix of the environment and many digital avatars from various sources. These kinds of communications need a data rate significantly greater than 1Tbps, making their use with 5G impossible. For instance, a holographic telepresence of a 77x20-inch person needs a data rate of 4.62Tbps.

• In-Vehicle Infotainment (IVI): one of the fascinating services that will be supplied by the future networks is offering high-quality services to drivers and passengers on the move, such as in-vehicle ultra-high-quality terrestrial TV transmission. Through terrestrial digital broadcasting infrastructure, IVI allows the driver to receive not just television channels but also secure firmware upgrades and map updates. Both high bandwidth and strong mobile support are essential for these services.

• Highly precise manufacturing: the complexity of future products is beyond the capabilities of humans (e.g., zero-touch). Systems with this level of importance need dependability on the order of

109 and latencies of 0.1 to 1ms, which are exceedingly low.

• Tactile Internet (TI): TI is the next generation of IoE, and it encompasses real-time connections between humans and machines. Haptics and other tactile applications call for ultra-fast short-range local-cell communications (sRLLC), ultra-reliable mobile telephone communications (MTC), and stringent data encryption. A delay of 40 milliseconds is typical for interactive distant experiences, whereas a response time of less than 5 milliseconds will open the door to innovative multisensory remote tactile control. Tele-robotics, remote inspection and maintenance of anything from factories to airplanes, and so on are just a few of the many uses for TI.

• Smart city: smart urban application that requires pervasive sensing and intelligent decision makers and actuators, such as smart transportation, smart grid (SG), urban infrastructure, resident living environment, transportation management, medical treatment, shopping, security assurance, intelligent transportation system (ITS), intelligent medical diagnosis (IMD), and shopping recommender system (SRS).

• Smart home: intelligent houses of the future will be able to give users detailed services like energy management, patient help, real-time product labeling, and subscription.

• Six degrees of freedom (6 DoF): immersive content is thought of as the next generation of video with spatial mobility for more immersive experiences that allow users to move freely. These services need a compromise between throughput and latency, with a latency of 5 milliseconds and a throughput of up to 5Gbps.

• Event sharing at stadiums and other crowded settings; sometimes, large amounts of footage are shared simultaneously through social media. Upload speeds of up to 12.5 Tbps/km2 may be necessary for such events.

• e-Health: 6G will usher in a new era of healthcare applications with capabilities including real-time haptic feedback, always-on connectivity, ultra-low latency data delivery, rock-solid dependability, and easy portability.

Additionally, 5G will not be able to support the following: super Hi-vision (8K) or ultra-high definition (UHD) video streaming; connected robotics and autonomous systems; self-driving vehicles; unmanned aerial vehicles; wireless brain-machine interactions; distributed ledger technologies; robotic autonomous drone deliveries.

V. SUGGESTIONS FOR FURTHER STUDY

Future 6G will not only focus on the pure communication sector, but also be compatible with other, related disciplines such as electronics and materials, wireless communication, and computer science and engineering [8]. Nanoelectronics for the Internet of Everything, radio frequency (RF) modules and packaging, high-frequency materials, radio transceivers, energy harvesting, Terahertz (THz) imaging, and two- and three-dimensional (2D, 3D) imaging will all play a role in this. However, in the realm of computers

in the areas of science and engineering, such as image and signal analysis, mobile apps, security and privacy, big data analysis, smart sensor analytics, smart environment, and ubiquitous systems, professionals may make significant contributions. Wireless communications experts are crucial to the success of related subfields such as radio frequency (RF) and antennas, fifth-generation (5G) baseband, Internet of Things (IoT) applications, future radio access, network optimization and management, spectrum restrictions and channel modeling, etc.

VI. CONCLUSION

In this article, we looked at the potential of AI to improve the future generation of wireless networking. Therefore, we conclude that 6G is not just a faster version of 5G but rather a convergence of technologies from many different areas, such as communications, automation, control, sensing, and intelligence, that will be motivated by being context-aware, on-demand, self-configuring, and self-aggregating. With the advent of 6G, we will be able to go beyond rate-centric eMBB and into the realms of super-eMBB, huge interconnectedness, and ultra-reliable and low-latency communication (URLLC). Therefore, it is not an exaggeration to say that artificial intelligence will transform and form the foundation of the future generation of mobile devices and network business.

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