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ScienceDirect

Procedia Computer Science 218 (2023) 310–317

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Machine Learning and Data Engineering

6G: The Next Giant Leap for AI and ML

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Abstract

The technologies like Artificial Intelligence (AI), Machine Learning (ML) and sixth generation (6G) echo systems have the potential to generate breakthrough results in the near future. The merger of these technologies will surely give rise to novel services that will improve the quality of user-centric applications. Accordingly, in the article, we discuss the potential of 6G technology to assist and impact AI and ML. We put forward some key technology transformations that these technologies will witness in the future. Along with this, we also discuss certain key performance indicators and technology requirements in making up the 6G communication ecosystem. In the end, we also provide some open problems and future research directions that will help researchers working in this domain.

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Peer-review under responsibility of the scientific committee of the International Conference on Machine Learning and Data Engineering

Keywords: 6G; Artificial Intelligence (AI); Machine Learning (ML)

1. Introduction

Various user-centric services depending on the Internet of Everything (IoE) are likely to grow in popularity in the future, necessitating the development of next-generation wireless networks. In spite of the fact that fifth-generation (5G) wireless technology have yet to be explored entirely, many researchers have already started futuristic research on the sixth-generation (6G) echo systems [1], [2]. Although the present 5G networks are capable of satisfying the need of a variety of IoE services, they may not be capable of catering for the needs of emerging applications. Wireless technologies in the 6G are expected to overcome the constraints of 5G networks. In this article, we look at some of the recent advancements that have been made towards making 6G systems a reality. We also explore the evolution of the 6G communication technology and its effects on the future of Artificial Intelligence (AI) and Machine Learning (ML) [3].

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Peer-review under responsibility of the scientific committee of the International Conference on Machine Learning and Data Engineering
10.1016/j.procs.2023.01.013

Researchers and Industry experts have switched their attention to 6G as the rate of deployment of 5G technology accelerate and standards continue to stabilize [4]. The 6G communication networks are targeted to provide one Tbps data rate, one ms end-to-end latency, and up to twenty years of battery life [1], [5]. All these sound fictitious for now. However, researchers have gained notable success in achieving these goals. Along with it, technologies like quantum communications, big data analytics, pervasive AI, and ML are expected to boom [6].

This research focuses on pervasive AI and ML, which have the potential to have a significant impact on the future 6G network. AI and ML will play a significant role in enabling optimized 6G networks and developing new waveforms [6].

We summarize the contributions of our work as follows:

- We provide a brief about the 6G technology and its evolution.
- We highlight a few major research problems and system-level implementation issues in AI, ML and 6G.
- We exhibit the 6G communication technology requirement.
- We discuss how 6G technology will empower AI/ML.
- We also provide future research directions and challenges in this domain.

The rest of this paper is structured as follows. Section 2 provides a brief of 6G and its evolution. We provide some of its Key Performance Indicators (KPIs) in the same section. Section 3 explains how 6G can effect the present AI and ML. In Section 4, we provide some open research challenges. Section 5 concluded the paper.

2. 6G and Related Work

In this section, we focus on the history and evolution of the 6G network. Next to that, we provide a brief about the related work, 6G and its various performance indicators.

2.1. Countries Involved in 6G Development

The "International Telecommunication Union (ITU)" was launched in July 2018 to investigate communication technologies for 2030 and beyond. Accordingly, holographic media and next-generation network architecture are the major principles in 6G development. Academy of Finland has established its flagship programme, "6G-Enabled Wireless Smart Society and Ecosystem (6Genesis)" [7], in 2018. This academy focused on the study and development of 6G communication technology. The United States also announced its 6G ambitions during the 2018 Mobile World Congress [8]. According to March 2018 interview with China's Minister of Industry and Information Technology, research on 6G has already begun [9]. Other countries, including Japan, Russia, European Union, South Korea, and others, have begun their work on similar issues. India is also preparing to be 6G ready by 2030.

2.2. History and Evolution

Various schemes such as "Time Division Multiple Access (TDMA)", "Frequency Division Multiple Access (FDMA)", "Code Division Multiple Access (CDMA)" and "Orthogonal Frequency Division Multiple Access (OFDMA)" are common in previous generations of mobile communications, especially at the physical layer [10], [11], [12]. With the emergence of electronic and photonic materials, microelectronic fabrication and air interface designs the communication technologies got new dimensions and vivid use cases.

Technology advancements in circuit digitization, for example, permit shift-keying signals and channel coding, allowing TDMA-based 2G systems to vastly outperform 1G systems which utilized FDMA in terms of voice capacity. The move from "Digital Signal Processor (DSP)" to "Application Specific Integrated Circuit (ASIC)" considerably enhances the processing power and density of the base-band in base stations, which enhances 4G systems' capacity gains over 3G systems.

Extremely cohesive circuits in the base-band, radio frequency, and optical fibre domains gave rise to active antennas. This allows massive Multiple-Input / Multiple-Out (MIMO) to become a reality in 5G. Given the early stages of

6G research, openness concerning technology, along with use cases, deployment scenarios, and performance objectives, should be encouraged. All the 6G related technologies are in varying levels of development, with some still in the early stages of scientific research. AI and ML will likely play a significant role in 6G and they can be used in a wide number of technical fields.

2.3. Related Works

Our research led us to some well-known studies. We brief them one by one here. The authors in [13] describe the modern IoT and its usages. Miao et al. [9] discuss the utility of 6G technology in real-world scenarios. Han et al. [14] presented issues regarding futuristic communication technologies. Letaief et al. [15] briefed about AI and its utility in 6G networks. Hu et al. [16] explained satellite-based communication. Other work like [1] presented recent advancements in 6G technology and also notified about some research challenges. Giordani et al. [2] explained the use cases and future benefits of 6G technology. Other works like [3], [4] discuss uses of AI/ML in 6G and wireless communications.

2.4. 6G Vision and Performance Indicators

By the beginning of the next decade, new user-centric applications and greatly enlarged wireless network technologies will give rise to 6G communication. This will considerably upgrade the current 5G network and cover nearly the entire planet and near outer space.

5G and future 6G networks will significantly rely on millimeter-wave technologies to accomplish the required network performance and communication obligations. As a result of the increased application needs, 6G will need to propose new technical standards and performance measures. The maximum data rate for 5G networks is twenty GB/s, whereas 6G networks can reach one to ten TB/s because of the use of terahertz and optical wireless bands. When compared to 5G, using AI to improve network management can increase spectrum efficiency by three to five times and energy efficiency by ten times. The utilization of extremely “Heterogeneous Networks (HetNets)”, a variety of communication scenarios, and wide bandwidths in high-frequency bands will lead the significant increase in connection density (by ten to hundred times). Due to the motions of ultra-HST and satellites, mobility at speeds greater than thousand km/hr will be possible. The accepted latency would be less than one millisecond.

Other essential performance indicators, like cost effectiveness, safety, coverage and level of intelligence, should be developed in order to comprehensively investigate 6G networks [17]. 6G communication networks will need to make significant paradigm shifts and focus on new enabling technologies to satisfy these application requirements and performance goals. Global coverage, use of complete spectrum, and strong endogenous security are among the most recent paradigm shifts. To provide global coverage, 6G wireless communication networks will expand from terrestrial to space–air–ground–sea integrated networks. These networks will include the usages of satellites, “Unmanned Aerial Vehicles (UAVs)”, terrestrial “Ultra-Dense Networks (UDNs)”, underground and underwater communications [18], [19]. To improve data rates, all spectral bands ought to be thoroughly investigated, including sub-six GHz, millimeter-wave, terahertz, and wireless optical bands [20]. To enable comprehensive applications, key technologies and next-generation application will be highly integrated with the use of AI and data science methodologies. Furthermore, AI can boost network performance by allowing dynamic and optimal usage of networking and computing resources. Comprehensive or built-in network security, including physical layer and network layer security, will become increasingly popular while developing 6G networks [20]. This is in contrary to 1G–5G development plans, which prioritize having networks up and running before addressing network security and how to improve network security [13].

3. 6G the Next Frontier for AI and ML

In this section, we discuss the role of AI and ML in shaping the next-generation communication networks.

Various user-centric applications, voluminous data and a wide variety of use cases will all drive the need for 6G technologies. 6G technology will be a step forward for providing immersive connectivity with continual data sharing [21]. AI and ML will play a critical role in the creation of the 6G network. This is due to the fact that these technologies can swiftly optimise between conflicting priorities such as Quality of Service (QoS) and connection security [21]. 6G technology will have a huge influence on all of our government stakeholders. As a consequence, study into both basic research problems and system-level implementation issues is required.

In Table 1 we summarize few primary areas where we should begin at a high level.

Table 1. Primary Focus Areas

Focus Areas / Problem Areas	**Technology**	**Resultant Outcomes**
Optimizing Network, Creating New Wavefromes	AI and ML for Optimization	New Waveform as Essential Enablers of 6G Technology
Data Comprehension, Comprehensive Usages of Radio Frequency (RF)	Data Library and AI/ML based Algorithms	Improved Data Compresion
Cross-layer optimization of Wireless Networks	Algorithm for Data Sharing Using AI/ML Technology	Enable Machine-to-Machine Connections, Enable Connectivity to Multiple Function Device
Techniques to Diagnose and Monitor Radio Frequency (RF) Networks	AI/ML Based Monitoring Algorithm	Proper Monitoring of RF
Contribute to Global Standards Bodies	6G and Other Prominent Technology	Rapid Development and Standerization of 6G Based Networks

3.1. 6G Wireless Communication Requirements and Technologies

Several demands from end users and technologies will influence the 6G system. A detailed understanding of these demands and technology is essential to enhance the quality of communications over 6G networks. There will be various new technologies in 6G communications [22]. Our work looks at these technologies from the aspect of demand. These higher-level requirements, of course, entail more creative technological assistance.

- ***Dynamic Spectrum Allocation:*** In 6G networks, great efficiency necessitates tremendous flexibility. Dynamic spectrum allocation may necessitate the flexible use of perceptual context information [16].
- ***Network Slicing:*** Network operators in new-generation communication network employ dynamic network slicing technology to enable dedicated virtual networks. This helps to facilitate the efficient delivery of any service to a diverse set of customers, cars, equipment, and industries [23].
- ***Smart Antenna Systems:*** Because of the growing frequency, massive utilization of numerous antenna systems is required. MIMO technique is capable of sending and receiving signals using multiple antennas [24]. Another major antenna technique is holographic beamforming [25]. As it uses software-defined antennas it is different from MIMO systems. In 6G, holographic beamforming might be a highly effective way [26].
- ***Big Data Analytics:*** Large-scale data collection and processing need both advanced technology and in-depth understanding. The volume of data in 6G will be massive and there will be a wide variety of data types [26]. Big data processing requires an understanding of the underlying patterns and hidden linkages inside data.
- ***High-Capacity Backhaul:*** For efficient communications, high-capacity backhaul networks are particularly appealing. High-speed optical fibre and "Free Space Optical (FSO)" systems are absolutely fascinating options in the context of excessive backhaul traffic [1], [27].
- ***Integrating Radar Technology with Mobile Technologies:*** To ensure high precision of geolocation in the field of communication and to make radar communications more easy, the radar system will be linked with 6G wireless communications [28].
- ***Integration of Energy Transfer with Wireless Information :*** Wireless charging of battery devices will be possible with 6G networks. This may facilitate the transfer of information and energy together. Wireless energy transmission necessitates that tiny devices, such as cellphones, or big devices, such as automobiles, be charged wirelessly, which not only ensures battery life but also allows charging to occur at any time and in any location [29], [30]. One of the most revolutionary technologies in 6G will be wireless energy transmission.
- ***Integration of Sensing and Communication:*** Continuously observation of the wireless environment and transferring information between multiple nodes along with making dynamic changes would be required in 6G [31].

This will make cognitive wireless communication more adaptive to highly dynamic, complicated electromagnetic settings [31].

- ***Softwarezation and Virtualization:*** Flexibility, reconfigurability, and programmability are all ensured via softening and virtualization. Furthermore, they will enable the sharing of billions of devices via a common physical infrastructure [31].
- ***Artificial Intelligence:*** Wireless communications will be revolutionized in the future as a result of substantial developments in AI in numerous domains. AI uses intensive analysis to analyse complicated targets, increasing efficiency and lowering communication latency [28], [29].
- ***Quantum Communications (QC):*** QC have enormous processing capacity. In a huge tensor product space, QC may do parallel processing of multidimensional big data. In future 6G communications, QC will achieve extraordinarily high data rates and connection security [28], [29], [30].
- ***Terahertz Communications:*** This is related to high-rate short-distance transmission employing a huge frequency range beyond 100 GHz, transferring long-distance communications to the freed lower frequency band [28]. Terahertz has the benefit of being thinner and having better directionality, making it ideal for MIMO. However, there are concerns with large-scale fading, power usage, and other factors.
- ***Optical Wireless Technology:*** It is based on optical frequency bands, such as Visible Light Communication (VLC), light fidelity, and Free Space Optical (FSO) communication. In both outdoor and indoor situations, optical wireless communication can offer high data throughput and low latency [28], [29], [30].
- ***Accurate Indoor Localization:*** Indoor localization will become more important in 6G communications. Many promising solutions, such as distributed models, will require highly accurate positioning systems to aid model efficiency [29], [30]. Accuracy is a need for efficiency. The interior communication environment will become increasingly complicated as the number of mobile devices and users grows. Indoor localization with high accuracy is required, and high-precision wireless indoor localization will aid virtual reality (VR) and other related systems [29], [30].

3.2. AI / ML Empowerment and 6G

AI and ML will play a key role in optimizing networks and creating new waveforms in the 6G technology. Furthermore, 6G technology will enable further advancements in AI and ML by utilizing data stored locally on the 6G sensor. In the below discussion, we point out some key points that we feel will empower AI/ML usage in 6G communication technology.

- ***AI and 6G Technology:*** Even in 6G networks, the importance of the physical layer and networking layer will remain the same. The borders between these layers will grow less tight as a result. Furthermore, AI and ML algorithms are likely to play a big part in this technological development. This might result in increased throughput and network capabilities [29], [30].
- ***Configuration and Optimization:*** Model-based and algorithm-based methods for network setup and optimization might fail to capture the intricate relationships between physical systems and behaviours. This may result in suboptimal solutions that may not completely fulfil end-to-end network needs. Due to its scale, density, and heterogeneity, modelling dynamic and complicated 6G networks using the same methods would be unfeasible. AI will be crucial in optimizing future 6G networks by tackling difficulties that are difficult to handle with closed-form models [30].
- ***Resource Allocation:*** Massive IoT deployments utilizing 6G communication technology may be addressed with AI, and ML-based predictive resource allocation algorithms that focus on challenges related to unpredictable network performance issues [30].
- ***Reinforcement Learning:*** These techniques are widely employed to address challenges with adaptive network access scheduling [30]. Deep reinforcement learning, on the other hand, employs neural network models as a function approximator to acquire rewards in a feedback mechanism. This allows the decision-maker to repeatedly adjust its behaviour depending on the input from the system. Hence, this learning may be used for adaptive modulation, selection of coding scheme, optimal utilization of power, and beamforming [29], [30].

- ***Development of Collaborative and Distributive Environment:*** The exponential proliferation of mobile devices has resulted in a transition from cloud computing to mobile edge computing [29], [30]. IoT technology, which is quickly developing and projected to dominate 6G networks. We foresee that this technology will also follow a similar path and speed up AI adoption at the network edge devices [30].
- ***Shared Learning Model :*** This ML approach allows users to work together to create a shared learning model. This will facilitate preservation of all training data on the network nodes, ensuring data privacy [29], [30].
- ***Open Radio Access Network (RAN) for AI and ML:*** The RAN is a new network design that uses infrastructure virtualization, flexibility, and embedded intelligence to provide end-users with more agile services and enhanced capabilities [32]. Open RAN strategy will enable a heterogeneous system of commercialized hardware and software to improve and self-organize in order to satisfy the overall goals, and Key Performance Indicators (KPIs) of the ecosystem [32].
- ***Potential Impact on Cellular Business:*** The mobile cellular business is still in the early phases of 6G technology. And all manufacturers and service providers are in the early phase of research. Private players and government stakeholders will undoubtedly be affected by this upcoming and novel technology. Accordingly, THz communication, edge computing, quantum computing, security models, and ubiquitous AI and ML have the potential to revolutionize network interaction and offer new use cases.

4. Opportunities and Challenges for 6G and Beyond

In this section, we present future research challenges and open problems in the 6G communication, AI and ML domains. ***Collection and Availability of Rich Real-World Datasets:*** According to researchers, the bulk of futurist wireless communications applications will be based on AI/ML technology. These models require a vast quantity of data during the training phase. However, such publicly available datasets for wireless communication are still in the works. [29], [30]. Moreover, making such data sets freely accessible may give rise to issues like users' data protection and privacy. ***Holographic Type Communication (HTC):*** True holograms, as a contrast to standard 3D films that use binocular parallax, may meet all visual signals of perceiving 3D things with the naked eye as naturally as feasible. In recent years there have been considerable advancements in this technology. Microsoft's HoloLens [33] is one of the best examples of this. However, the use of HTC requires wider bandwidth in the order of terabits per second [34]. It also needs ultra-low latency and high-precision synchronization. ***Extended Reality (ER):*** This technology is a combination of augmented and virtual reality and is in its adolescent stage in the era of 5G communication technology. In order to achieve a similar visual quality like 2D video streaming, ER devices with a 360-degree field vision will require a substantially higher data capacity. A bandwidth requirement of over 1.6 Gbps per device is predicted by some reports [35]. ***Multi Sense Experience:*** Although humans have five senses, contemporary communications rely solely on optical (text, image, and video) and sonic (audio, voice, and music) mediums to detect their surroundings. Using smell and taste to create a genuinely immersive experience might lead to new products in the food and textile sectors. [15],[14]. ***Digital Twin:*** is used to create an exact virtual reproduction of a physical (or real) thing. The softwarized clone includes many of the original item's features, information, and properties. The twin is then used to automatically and intelligently duplicate an object. Early digital twin implementations caught the curiosity of a number of vertical businesses and manufacturers. However, with the introduction of 6G networks, it is expected to be completely deployed [14]. ***Pervasive Intelligence:*** The introduction of smart mobile devices along with modern communication techniques like UAVs, virtual reality glasses; over-the-air intelligent services are predicted to expand in popularity. However, the majority of these sophisticated innovations are carried out using traditional means and is accepted to have rapid changes in future. ***Computation-intensive AI technologies:*** To address the problems like effective usages of computation, power and storage in resource constraint mobile device, 6G network will have to used new technologies. These technologies will include using distributed computing resources and mobile-edge devices to promote efficient ML training and interference strategies [36]. Moreover, we force the use of "Simultaneous Localization and Mapping (SLAM)", computer vision, and face and speech recognition. A humanoid robot like Atlas from "Boston Dynamics" [37] may be considered as a future prototype of this technology. ***Privacy and Security:*** Quantum cryptography and physical layer security have developed in recent years. However, all these developments require proper research to justify their utility in the 6G communication networks. Moreover, issues regarding privacy protection have gained huge consideration in using ML and AI in wireless communications. Privacy protection during the model training process is a difficult issue [14]. More work in this regard can be done.

5. Conclusion

This article mainly aims to understand the proliferation of 6G communication technology and its impact on future AI/ML-based applications. We also highlight some of the key performance indicators of the 6G technology and discuss how AI/ML will empower the future 6G ecosystem. Further, to boost research in this domain, we also put forward some crucial and open research problems. The information and challenges listed in this article will give researchers and industry experts some new directions to move forward in this domain.

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