INTERNATIONAL JOURNAL OF RESEARCH CULTURE SOCIETY ISSN(O): 2456-6683
Monthly Peer-Reviewed, Refereed, Indexed Journal [Impact Factor: 9.241]
Volume - 9, Issue - 2, February - 2025

DOIs:10.2017/IJRCS/202502018 --:-- Research Paper / Article / Review

Artificial Intelligence Enabled Wireless Networking for Beyond 5G

Ashwini G T
Assistant Professor, Department of Information Science and Engineering, GM University.
Email - ashwinigt.fet.scst@gmu.ac.in

Abstract: *Beyond 5G (B5G) networks are replacing fifth-generation (5G) Wireless networks due to the demand for highly dependable, low-latency, and high-capacity communication systems that can handle advanced applications such as autonomous systems, smart cities, and immersive technologies. B5G networks aim to address the shortcomings of 5G by incorporating state-of-the-art technologies to enhance scalability, coverage, energy efficiency, and security. One of the main factors enabling B5G innovation is the combination of artificial intelligence (AI) and machine learning (ML), which are revolutionary in simplifying network operations, resource management, spectrum utilization, and real-time decision-making. This paper examines the application of AI and ML to B5G network design and operation and covers a variety of topics related to wireless network design and optimization, such as physical layer research, channel measurements, modeling, and estimates, as well as network administration and optimization. An outline of common advancements in the use of AI/ML algorithms to B5G networks follows a discussion of ML algorithms and their applications to B5G networks. Future challenges in applying AI/ML to B5G networks are discussed in our study's conclusion.*

Key Words: *Artificial Intelligence, Machine Learning, B5G, Network.*

1. INTRODUCTION:

In recent years, the number of connecting devices and their users has grown exponentially, forcing cellular carriers to expand their capacity to achieve higher data rates for wireless media [1]. This is where the shift from 1G to 4G-LTE mobile phone generations has been both beneficial and problematic [2]. These days, internet speed is a big concern for both users and service providers; thus, cellular companies are battling for the implementation of fifth-generation (5G) internet to give their customers a lightning-fast and reliable connection [3]. Future developments are expected to provide fifth generation (5G) and beyond 5G (B5G) wireless networks with increased data rates, improved coverage, cost effectiveness, resource usage, security, adaptability, and scalability. [4]. Artificial intelligence (AI) technology can efficiently address unstructured and seemingly insurmountable difficulties with massive amounts of data in the design and optimization of 5G and B5G wireless networks.[5]

Beyond 5G (B5G) wireless networks represent the next frontier in mobile communication technologies, aiming to build on the advancements introduced by 5G while addressing the growing and evolving demands of the modern world. With the rapid growth in the number of connected devices, the rise of the Internet of Things (IoT), and the increasing demand for ultra-reliable, low-latency communications, the need for a next-generation wireless network that goes beyond 5G capabilities has become crucial. B5G is poised to offer higher data rates, more efficient resource management, and enhanced reliability, all while supporting innovative applications such as autonomous systems, immersive virtual reality (VR), and massive machine-type communications. While 5G has made substantial strides in delivering faster internet speeds, lower latency, and greater connectivity, it still faces several limitations that hinder its full potential. One of the primary limitations of 5G lies in its scalability. Despite providing high-speed connectivity, 5G struggles to effectively manage and serve a large number of devices simultaneously in dense environments. Additionally, 5G networks are still not sufficiently optimized to handle the complex demands of emerging applications, such as real-time video processing, autonomous vehicles, and smart cities, which require both ultra-low latency and high reliability. Another significant challenge of 5G is its limited coverage, especially in rural and remote areas. Additionally, security and privacy concerns are growing as 5G opens new avenues for cyberattacks due to its increased exposure to the internet, creating vulnerabilities in critical infrastructure.

Given these limitations, the need for Beyond 5G (B5G) networks is evident. B5G aims to overcome the scalability, coverage, and security issues of 5G by integrating advanced technologies that can provide more intelligent, flexible, and reliable network management. B5G networks are designed to not only enhance the performance of existing systems but also support the burgeoning ecosystem of applications that 5G cannot fully accommodate. These networks are expected to offer massive scalability, ensuring that even in densely populated areas or environments with a high concentration of devices, the network remains efficient and effective. One of the key enablers of B5G is artificial intelligence (AI). AI has a critical role to play in overcoming the limitations of 5G by enabling smarter, more adaptive networks.

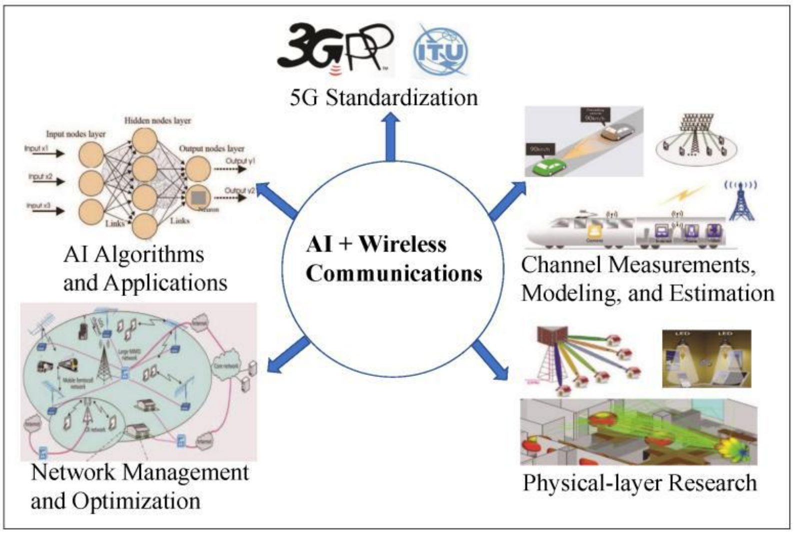

Figure 1: Five aspects propelling AI beyond 5G in wireless networks

Five aspects have been discussed in, as shown in Figure 1, that bring AI technologies beyond 5G wireless networks: physical-layer research, network management and optimization, channel measurements, AI algorithms and applications, and standard developments. The AI and ML can potentially revolutionize the future beyond 5G wireless networks by addressing complex and unstructured challenges. Their ability to adapt, learn from data, and make real-time decisions will help address the complex and evolving challenges that arise in these advanced networks, ultimately leading to more robust, efficient, and user-centric communication systems. AI can also facilitate real-time decision-making in B5G networks, enabling them to adapt to changing conditions and traffic loads. By using AI-driven algorithms, B5G networks can optimize power consumption, enhance spectrum usage, and improve the overall quality of service (QoS), ultimately supporting a vast range of applications that require low latency and high reliability.

2. RELATED WORK

Various types of wireless technology and artificial intelligence have been discussed in numerous publications. Ma et al. [6] discussed AI strategies related to autonomous vehicles (AVs) and their primary uses. They have clarified the potential applications of AI to other state-of-the-art technologies, such as enhanced big data and AR/VR simulation platforms, high-def mapping, high-performance computation, and 5G connectivity for linked AVs. Sheraz et al.'s [7] primary focus was on AI-based caching methods in wireless networks that include machine learning (ML) algorithms such as supervised reinforcement, unsupervised reinforcement, and transfer learning (TL). They have presented the current issues that need to be resolved for upcoming generations. A developing AI paradigm for vehicle-to-everything (V2X) was introduced by Tong et al. [8]. They gave some information about AI methods, including fuzzy logic language processing, logical AI, swarm intelligence, and expert systems heuristics. Another study [9] examined relevant research on the deep integration of fog computing (FC) and artificial intelligence (AI) technologies in future V2X networks. Additionally, the authors provided fog-assisted, AI-enabled V2X use examples that take advantage of AI to facilitate the intended evolution of vehicular networks and accommodate the required FC capabilities. A survey on the function of AI-based resource management was given by Lin and Zhao [10], who also discussed the difficulties and unresolved problems associated with using AI in upcoming wireless networks.

The integration of AI technologies into B5G wireless networks is comprehensively examined in the paper, as shown in Fig. 1. The remainder of the paper is therefore organized as follows. In Section III, we discuss channel estimation, modeling, and measurements for AI-powered B5G networks. AI-powered physical-layer research for B5G networks is examined in Section IV. We provide a summary of AI-based network optimization and management for B5G networks in Section V. AI methods and applications for B5G networks are presented in Section VI. Section VII discusses AI/ML for B5G Networks in Standards and Study Groups. Conclusions and future issues are covered in Section VIII.

3. CHANNEL MEASUREMENTS, MODELING, AND ESTIMATION FOR B5G NETWORKS USING AI TECHNOLOGIES

The design and optimization of Beyond 5G (B5G) wireless communication systems depend heavily on the processing of channel measurement data and channel modeling. The variety of frequency bands, such as millimeter-wave (mmWave), terahertz (THz), sub-6 GHz, and optical bands, makes it extremely difficult to realistically describe channel properties. The distinctive propagation characteristics of various settings must be captured through comprehensive channel measurements, which can be a time-consuming operation, in order to successfully handle these problems. The combination of artificial intelligence (AI) and machine learning (ML) approaches provides a data-driven approach that can improve the accuracy of channel models, whereas older methods frequently rely on simplifying assumptions. Based on channel measurement data and environmental information, machine learning (ML) can be used to forecast channel features, model channel impulse response (CIR), cluster multipath components (MPC), estimate channel parameters, and classify scenarios. A large data-enabled channel model based on both feed-forward neural networks (FNN) and radial basis function neural networks (RBF-NN) was proposed by the authors in [11]. With the input parameters of transmitter (Tx) and receiver (Rx) coordinates, Tx–Rx distance, and carrier frequency, it can forecast the received power, root mean square (RMS) delay spread (DS), and RMS angle spreads (ASs) of the channel. Both synthetic and real channel measurement data were used to properly compare the performances of FNN and RBF-NN. In [12], convolutional neural networks (CNNs) were used to automatically identify different wireless channels and help choose the most relevant wireless channel characteristics. After retrieving and using the MPC parameters—such as amplitude, latency, and Doppler frequency—as input parameters, the CNN's output was the class of the wireless channels.

A. Channel estimation associated with ML

Communications is essential to understanding how messages travel across the environment. Blind methods and pilot-based methods are the two main methods for channel estimation. Blind estimation uses the statistical properties of incoming signals without providing additional information, although it still needs a lot of data to work effectively. Pilot-based estimation involves sending known signals (pilots) to help in channel estimation; however, this can lead to overhead, especially in systems with many antennas (like massive MIMO) or crowded networks. Because some channels, including those used in mmWave systems and visible light communication, are nonlinear, accurate assessment is difficult. Furthermore, in fast-moving scenarios, like high-speed trains, maintaining great service quality requires precise channel estimates. Researchers are employing machine learning (ML) approaches to address these problems. For instance, some techniques employ deep learning to extract channel properties from massive datasets, while others use support vector regression to enhance estimates in quickly changing situations. There are various methods that use the special characteristics of mmWave channels to determine the signal routes. Future research aims to develop generalized machine learning (ML)-based channel estimation techniques that do not require retraining in various scenarios. In order to improve wireless communication systems, this will include leveraging vast volumes of previously gathered data to teach machine learning algorithms how to adjust to different channel circumstances.

4. PHYSICAL-LAYER RESEARCH FOR B5G NETWORKS USING AI TECHNOLOGIES

Physical-layer research for Beyond 5G (B5G) networks employing artificial intelligence (AI) technology seeks to improve the efficiency and performance of wireless communication systems through sophisticated data processing and analysis methods. In the construction of B5G networks, new methods for channel measurements, modeling, and estimations must be developed due to the complexity of the data produced by big antenna arrays, especially in massive MIMO (Multiple Input Multiple Output) systems. Techniques from artificial intelligence (AI) and machine learning (ML) are being used more and more to solve issues like pilot contamination and the accuracy of channel state information (CSI), both of which are essential for preserving dependable communication. Researchers may find useful information in the massive volumes of data generated by using deep learning and other data-driven approaches.[5] This enhances localization accuracy, network management, and the ability to detect dynamic events in real time. In B5G contexts, this move from conventional model-based techniques to data-driven optimization enables more responsive and flexible network operations, which eventually improves service quality and user experience. In addition to resolving current issues, the incorporation of AI technologies into physical-layer research creates new opportunities for wireless communication innovation, which results in networks that are smarter and more effective.

5.NETWORK MANAGEMENT AND OPTIMIZATION FOR B5G NETWORKS USING AI TECHNOLOGIES

Artificial intelligence (AI) technologies are becoming more and more important in the management and optimization of beyond 5G (B5G) networks in order to handle the complexity and changing needs of contemporary wireless communication systems. The majority of traditional network management techniques have been model-based, depending on pre-established models to direct the architecture and implementation of network infrastructure. These models span a wide range of activities, from overall network operations to the design of the physical layer. The limits of model-based approaches, however, become evident when B5G networks develop to accommodate a wide range of applications, ultra-dense deployments, and many and diverse radio access technologies.

A. Limitations of Model-Based Approaches

The complex nature of network environments in the real world is frequently not well represented by model-based optimization. For example, current models might not even exist or might not be appropriate in situations like on-demand network deployments using unmanned aerial vehicles (UAVs) for emergency services. This insufficiency calls for a change to more adaptable and flexible methods that can react to demands and circumstances in real time.

B. The Shift to Data-Driven Optimization

It is essential to go from model-based to data-driven optimization techniques in order to manage and operate B5G networks efficiently. This change makes use of the enormous volumes of data produced by numerous sources, such as sensor readings, wireless channel measurements, and data from mobile devices. Network operators can improve situational awareness and operational efficiency by utilizing AI and machine learning (ML) approaches.

AI systems can optimize a number of tasks, including resource management, fault monitoring, and user tracking, by analyzing real-time data to provide thorough operational maps of the network. These AI-powered systems have the capacity to continuously learn from user behavior and the wireless environment, enabling dynamic modifications and enhancements in network performance.

C. Practical Applications of AI in B5G Networks

- Optimization of threshold-based demodulators in communication systems is one real-world use of AI in B5G network management. Conventional approaches depend on a flawless grasp of the system model to reduce mistake probability in settings such as optical and molecular communications, where inter-symbol interference (ISI) makes modeling more difficult.
- A data-driven strategy, on the other hand, makes use of artificial neural networks (ANNs) to determine the ideal demodulation thresholds without requiring any prior knowledge of the channel model.
- Based on real-time data, ANNs can adaptively choose the optimal demodulation strategy by utilizing supervised learning techniques like Bayesian regularization backpropagation. This feature demonstrates how AI has the potential to completely transform network administration and optimization, facilitating more responsive and smarter decision-making.

6.AI ALGORITHMS AND APPLICATIONS FOR B5G NETWORKS

Beyond 5G (B5G) networks must incorporate distributed machine learning (ML) techniques and artificial intelligence (AI) algorithms to meet the demands and complexity of contemporary wireless communication. The enormous volumes of data created in B5G environments provide unstructured difficulties that AI technologies, in particular machine learning, have the ability to effectively address. Important AI methods that are used in many B5G network applications include supervised learning, unsupervised learning, reinforcement learning, and deep learning. For example, unsupervised learning aids in anomaly identification and clustering, while supervised learning can be applied to defect detection and traffic prediction. While deep learning is superior at tasks like image processing and channel optimization, reinforcement learning is especially well-suited for dynamic situations, helping with resource management and routing.

A. Applications

- The usage of AI in B5G networks also includes traffic analysis, network management and optimization, security, smart resource allocation, and user experience improvement. By keeping surveillance out for odd trends in traffic, these technologies improve security, automate procedures, estimate demand, and customize offerings.

ISSN(O): 2456-6683
[Impact Factor: 9.241]

- Conversely, distributed machine learning techniques are distinguished by their reduced latency, scalability, and data privacy. Large datasets can be processed across several nodes using these techniques, which improve privacy by preserving data localization and facilitating quicker decision-making.
- Two important distributed machine learning techniques are decentralized learning, which enables nodes to share model updates without a central server, increasing robustness in unpredictable network conditions, and federated learning, which enables collaborative model training while protecting data privacy.
- The applications of distributed machine learning in B5G networks are numerous and include enhanced user experiences, cooperative resource management, real-time analytics, and enhanced network security.
- By analyzing data from multiple sources in real-time, these techniques preserve user privacy while enabling quick responses to network changes and cooperative resource allocation.

B. AI use cases in 5G & beyond

According to recent findings and current research, 5G networks allow unified connectivity with nearly everything around us through connections and communications with billions of IoT devices. Nearly everything in our surroundings might become sentient with the help of a learning platform known as artificial intelligence. Numerous machine learning techniques, such as supervised learning, unsupervised learning, and reinforcement learning, employ different models and are tailored to specific 5G applications. Below is a sample of a number of 5G learning courses and associated applications (Ref [13]).

Learning Classes	**Learning Models**	**Applications in 5G**
Supervised Learning	ML and statistical logistic regression techniques Support Vector Machines (SVMs)	Dynamic frequency and bandwidth allocation in self-organized LTE dense small cell deployments Path loss prediction model for urban environments
Unsupervised Learning	K-means clustering, Gaussian Mixture Model (GMM), and Expectation Maximization (EM) Hierarchical Clustering	Cooperative spectrum sensing and Relay node selection in vehicular networks Anomaly/Fault/Intrusion detection in mobile wireless networks
Reinforcement Learning	Reinforcement Learning algorithm based on long short-term memory (RL-LSTM) cells Reinforcement Learning with Network assisted feedback	Proactive resource allocation in LTE-U Networks is formulated as a non-cooperative game, which enables SBSs to learn which unlicensed channel, given the long-term WLAN activity in the channels and LTE-U traffic loads Heterogeneous Radio Access Technologies (RATs) selection

Table 1: Models with Application In 5G

7.AI/ML FOR B5G NETWORKS IN STANDARDS AND STUDY GROUPS

There are currently no defined methods for integrating AI and ML into communication networks due to the complexity of the data volumes and formats in Beyond 5G (B5G) systems. Numerous organizations and research teams are working to address this issue. The International Telecommunication Union (ITU), which is creating papers and standards on use cases, topologies, protocols, and data formats, has set up a focus group on machine learning (ML) for future networks. Similarly, the Third Generation Partnership Project (3GPP) is exploring machine learning (ML) functions for network analytics and monitoring under its NWDAF initiative. Numerous organizations, such as the 5G PPP, Telecom Infra Project (TIP), and others, are researching the use of AI/ML to enhance network administration, planning, and user experience. Together, these efforts aim to improve the performance of upcoming wireless networks, reduce costs, and promote energy and spectrum efficiency.

Leading Organization	Group Name	Starting Time	Purpose	Applications
3GPP	NWDAF	March 2018	Allow 5G operators to monitor the status of a network slice or third-party application performance	5G core network data analytics
5G PPP	CogNet	July 2015	Build an intelligent system of insights and action for 5G network management	Autonomic network management based on machine learning
FuTURE	Wireless big data for smart 5G	November 2017	A white paper that collects pioneering research works on big data for 5G in China	Boost spectrum efficiency and energy efficiency, improve the user experience, and reduce the cost
ITU	ML5G	November 2017	Identify relevant gaps and issues in standardization activities related to ML for future networks	Interfaces, network architectures, protocols, algorithms, and data formats
TIP	AI and applied machine learning	November 2017	Define and share reusable, proven practices, models, and technical requirements for applying AI and ML	ML-based network operations, optimization, and planning; Customer behavior-driven service optimization; Multi-vendor ML-AI data exchange formats

Table 2: A summary of AI/ML for B5G networks in standards

8. CONCLUSIONS AND FUTURE CHALLENGES

In order to address the complex issues related to Beyond 5G (B5G) wireless networks, this paper has looked at how machine learning (ML) and artificial intelligence (AI) can be applied. We discussed the most recent advancements in the application of AI/ML in critical domains such as channel prediction, physical layer research, and network administration. It was also highlighted how standard organizations and research teams are integrating AI/ML into B5G systems. The intelligence and efficiency of B5G networks could be greatly enhanced by AI and ML, but challenges with energy consumption, real-time processing, and data privacy still persist. Overcoming these challenges will be necessary to create reliable and adaptable networks, paving the way for future 6G developments.

REFERENCES

1. Al-samman, A. M., Azmi, M. H., & Rahman, T. A. (2019). A survey of millimeter wave (mm-Wave) communications for 5G: Channel measurement below and above 6 GHz. In Recent Trends in Data Science and Soft Computing: Proceedings of the 3rd International Conference of Reliable Information and Communication Technology (IRICT 2018) (pp. 451-463). Springer International Publishing.
2. Da Silva, M. M., & Guerreiro, J. (2020). On the 5G and Beyond. Applied Sciences, 10(20), 7091. https://doi.org/10.3390/app10207091.
3. Patra, Soumendra Kumar, Bijaya Kumar Sundaray, and Durga Madhab Mahapatra. "Are university teachers ready to use and adopt e-learning system? An empirical substantiation during COVID-19 pandemic." Quality Assurance in Education 29.4 (2021): 509-522.
4. C.-X. Wang et al., “Cellular Architecture and Key Technologies for 5G Wireless Communication Networks,” IEEE Commun. Mag., vol. 52, no. 2, Feb. 2014, pp. 122–30.
5. Wang, C., Di Renzo, M., Stanczak, S., Wang, S., & Larsson, E. G. (2020). Artificial Intelligence Enabled Wireless Networking for 5G and Beyond: Recent Advances and Future Challenges. IEEE Wireless Communications, 27(1), 16–23. https://doi.org/10.1109/mwc.001.1900292.
6. Y.Ma,Z.Wang,H.Yang,andL.Yang,“ Artificial intelligence applications in the development of autonomous vehicles: a survey,” IEEE/CAA Journal of Automatica Sinica, vol. 7, no. 2, pp. 315–329, 2020.
7. M. Sheraz, M. Ahmed, X. Hou et al., “Artifcial intelligence for wireless caching: schemes, performance, and challenges,” IEEE Communications Surveys and Tutorials, vol. 23, no. 1, pp. 631–661, 2021.
8. W. Tong, A. Hussain, W. X. Bo, and S. Maharjan, “Artifcial intelligence for vehicle-to-everything: a survey,” IEEE Access, vol. 7, pp. 10823–10843, 2019.
9. M. Rihan, M. Elwekeil, Y. Yang, L. Huang, C. Xu, and M. M. Selim, “Deep-VFog: when artifcial intelligence meets fog computing in V2X,” IEEE Systems Journal, vol.15, no. 3, pp. 3492–3505, 2021.
10. M. Lin and Y. Zhao, “Artifcial intelligence-empowered resource management for future wireless communications: a survey,” China Communications, vol. 17, no. 3, pp. 58–77, 2020.
11. J. Huang et al., “A Big Data Enabled Channel Model for 5G Wireless Communication Systems,” IEEE Trans. Big Data, vol. 6, no. 1, Mar. 2020.
12. H. Li et al., “Wireless Channel Feature Extraction via GMM and CNN in the Tomographic Channel Model,” J. Commun. Inf.o Net., vol. 2, no. 1, Mar. 2017, pp. 41–51.
13. Haidine, A. et. al, “Artificial Intelligence and Machine Learning in 5G and beyond: A Survey and Perspectives,” in A. Haidine (ed.), Moving Broadband Mobile Communications Forward – Intelligent Technologies for 5G and Beyond, IntechOpen London, 2021, https://doi: 10.5772/intechopen.98517.
14. J. Kang, C. Chun, and I. Kim, “Deep learning based channel estimation for MIMO systems with received SNR feedback,” IEEE Access, vol. 8, pp. 121162–121181, 2020.
15. Abubakar, A.I. et. al, “The role of artificial intelligence-driven 5G networks in COVID-19 outbreak: opportunities, challenges, and future outlook,” Frontiers in Communications and Networks, 11 November 2020, https://doi:10.3389/frcmn.2020/575065.