IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

Role of AI in 5G and 6G Technologies

Manish Uniyal
Principal Engineer-Wireless, Wireless Operations (Advanced NOC), Dish Wireless, Littleton, Colorado (USA)

Abstract: *Artificial intelligence (AI) is key technology in enabling and enhancing the performance of 5G and 6G networks. AI will be playing a crucial role as a facilitator and catalyst in the advancement of 5G and 6G networks, it has potential to increase network performance, enhance user experience and optimizing costs. AI and 5G/6G combinations are most disruptive technologies that expected to change the entire ecosystem*

Keywords: Artificial intelligence, 5G, 6G, disruptive, catalyst, AI-native

I. INTRODUCTION

Artificial Intelligence (AI) plays a crucial role in optimizing and enhancing the performance of 5G and 6G networks by analysing vast amounts of data to dynamically manage network resources, predict potential issues, automate responses, and improve overall user experience, essentially making the network more intelligent and efficient through real-time adjustments based on changing conditions and user demands; this includes traffic management, signal quality optimization, and proactive maintenance, enabling a seamless high-speed connectivity experience across various applications like autonomous vehicles and smart cities.

II. METHODOLOGY AND LITERATURE REVIEW

What is AI?

Artificial Intelligence (AI) is a broad field encompassing technologies that enable machines to learn, adapt, and perform tasks traditionally requiring human intelligence. As defined by the International Telecommunications Union (ITU), AI systems are "self-learning, adaptive systems."

Main components of AI:

• Machine Learning (ML): As a subset of AI, ML focuses specifically on algorithms that learn from data and improve their performance over time. This involves training models on datasets to recognize patterns, make predictions, or take actions. ML techniques include supervised learning (where data is labelled), unsupervised learning (where data is unlabelled), and reinforcement learning (where agents learn through trial and error).

• Deep Learning (DL): A subset of ML, DL leverages artificial neural networks to recognize patterns in data. DL has excelled in tasks like image and speech recognition, thanks to its ability to process complex data structures.

• Generative AI: This branch of AI focuses on creating new content or data, such as text, images, or audio.

- Foundation Models: These are large-scale, pre-trained AI models trained on massive datasets. Examples include OpenAI's GPT-3 and Google's BERT.
- Large Language Models (LLMs): LLMs are foundation models specifically trained on large amounts of text data. They can generate human-quality text, translate languages, and write different kinds of creative content.

Role and incorporation of AI in 5G:

According to **3GPP(**Third Generation Partnership Project) and **6Gworld**, AI plays a crucial role in both 5G and 6G networks by enabling real-time optimization, intelligent resource allocation, and predictive maintenance, with 6G aiming for a more "AI-native" approach where AI is deeply integrated into the network architecture, allowing for significantly enhanced performance, reliability, and user experience compared to 5G's more targeted AI applications.

As per **6Gworld** - AI was made a part of the first 5G release in 2018. "This involved gathering lots of data to help manage network functions and simplify operations using advanced data analytics. While the 3GPP standard continues to adopt AI/ML methods, how they are implemented is usually up to the network operators."

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

While 5G has started introducing some fundamentals for an AI-enabled network, 5G-Advanced takes that further. 3GPP Release 18, the first for 5G-Advanced, was frozen in March 2024 so there are plenty of capabilities, which have not yet hit the market. A variety of 3GPP working groups who have all been developing new specifications related to AI and ML -

The System and Service Aspects Working Group 1 **(SA1)** has explored methods for sharing AI/ML models across the 5G network, paving the way for a more interconnected and intelligent network fabric.

SA2 looked at architectural support for AI/ML-based services within the 5G system, laying the groundwork for improved service delivery and operational efficiency.

The **SA4** group, which focuses on media services, examined potential uses of AI/ML for 5G media codecs, offering significant improvements in media quality and delivery.

Meanwhile, **SA5** tackled AI/ML management, aiming to harmonise AI/ML functions across 5G systems for easier management, orchestration, and charging.

We will be going through different 3GPP release incorporation and advancement from AI/ML aspect in the later section of this article.

Key aspects of AI in 5G:

Network Optimization:

AI algorithms can analyse network data to identify bottlenecks and dynamically allocate bandwidth, improving network performance and user experience by adjusting parameters based on real-time conditions like user density and location.

Predictive Maintenance:

AI can predict potential network issues before they occur by analysing patterns in data, allowing operators to proactively address maintenance needs and minimize downtime.

Traffic Management:

AI can intelligently route traffic across the network, optimizing data flow and minimizing latency, especially crucial for applications like live streaming and gaming.

Self-Healing Networks:

By continuously monitoring network health, AI can automatically detect and address issues, promoting network resilience and reliability.

Resource Allocation:

AI can efficiently allocate network resources based on user demands, ensuring optimal performance for different applications.

Enhanced Security:

AI can be used to identify and mitigate potential security threats within the 5G network, improving overall network security.

Applications enabled by AI and 5G:

Smart Cities:

Real-time data analysis from sensors can be used to optimize traffic management, energy consumption, and public safety systems.

Autonomous Vehicles:

Low latency and high bandwidth of 5G combined with AI enables real-time communication between vehicles and infrastructure for safer and more efficient autonomous driving.

Industrial Automation:

AI-powered systems on 5G networks can enable advanced automation and real-time decision making in manufacturing environments.

Healthcare:

Remote surgery and real-time patient monitoring can be facilitated by the reliable and high-speed connectivity of 5G with AI-powered data analysis

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

Within line of a white paper published by **5G Americas** - The growing complexity of cellular networks, driven by the proliferation of devices and data-intensive applications, has strained traditional management approaches. Manual processes, heuristics-driven control, and static automation are inadequate for meeting the dynamic demands of modern networks. As networks evolve toward 5G Advanced and beyond, the diverse use cases—such as massive Internet of Things deployments, ultra-reliable low-latency communications, and enhanced mobile broadband—require real-time decision-making and adaptive resource allocation. Artificial intelligence (AI) provides a transformative solution for optimizing network efficiency, performance, security, and user experience and ensuring seamless operations across complex, heterogeneous environments.

In the rapidly evolving landscape of telecommunications and specially 5G, 6G; cellular networks have undergone a profound transformation. The proliferation of connected devices and the escalating demands for data-intensive applications have pushed these networks to their limits. To meet these challenges, a new approach is required. AI, a field that has witnessed remarkable advancements in recent years, offers a promising solution. By leveraging the power of AI, cellular networks can become more efficient, reliable, responsive to the needs of users, and autonomous. AI's ability to analyse vast amounts of data, learn from patterns, and make intelligent decisions in real-time has positioned it as a critical enabler of next-generation communication systems.

AI/ML operational workflow per 3GPP:

Third Generation Partnership Project (3GPP is standard body that creates technical specification for mobile networks) –

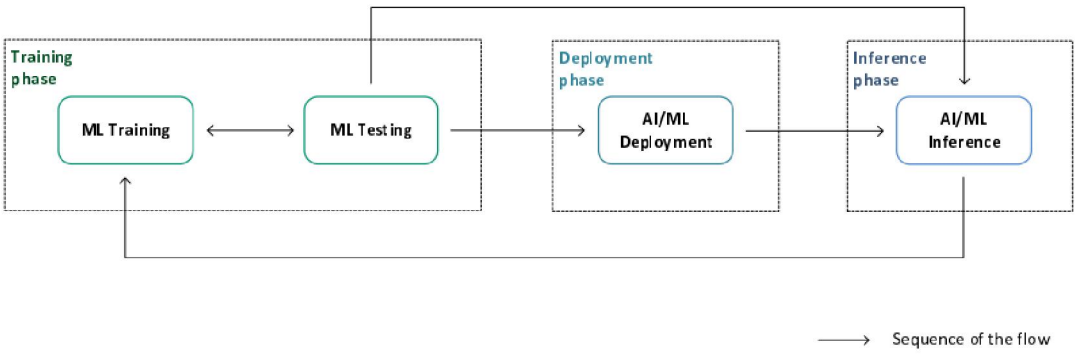

Fig. 1 AI/ML operational workflow, source 3GPP

The workflow involves three main phases; the training, deployment and inference phase, including the main operational tasks for each phase. These are briefly described below:

Training phase:

- ML Training: Learning by the Machine from the training data to generate the (new or updated) ML entity that could be used for inference. The ML Training may also include the validation of the generated ML entity to evaluate the performance variance of the ML entity when performing on the training data and validation data. If the validation result does not meet the expectation (e.g. the variance is not acceptable), the ML entity needs to be re-trained. This is the initial step of the workflow. The ML Training MnS is specified in 3GPP TS 28.105.
- ML Testing: Testing of the validated ML entity with testing data to evaluate the performance of the trained ML entity for selection for inference. When the performance of the trained ML entity meets the expectations on both training data and validation data, the ML entity is finally tested to evaluate the performance on testing data. If the testing result meets the expectation, the ML entity may be counted as a candidate for use towards the intended use case or task, otherwise the ML entity may need to be further (re)trained. In some cases, the ML entity may need to be verified which is the special case of testing to check whether it works in the AI/ML

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

inference function or the target node. In other cases, the verification step may be skipped, for instance in case the input and output data, data types and formats, have been unchanged from the last ML entity.

Deployment phase:

- ML Deployment: Deployment of the trained and tested ML entity to the target inference function, which will use the subject ML entity for inference.

Inference phase:

- AI/ML Inference: Performing inference using the ML entity by the inference function. In telco-grade environments, it is worth noting that the selected learning method can influence on how AI/ML operational workflow executes. In some cases (e.g. when using supervised learning methods), the inference phase cannot start until training phase gets ended. In other cases (e.g. when using reinforcement learning methods), the inference phase can start while training phase is still in progress.

Towards a 5G and ambitious 6G AI-native communications system design within line of 3GPP specs:
Third Generation Partnership Project, (3GPP is standard body that creates technical specification for mobile networks). AI will substantially improve wireless performance starting with 5G advanced feature and 3GPP features brought in 3GPP releases – Rel 16, Rel 17 and Rel 18. The high-level summarization of those are -

3GPP Release 16 AI/ML Related Features:
Machine Learning for Cell Planning and Optimization:

- Leverage AI/ML algorithms to optimize cell site placement, antenna configurations, and frequency planning for improved coverage and capacity.
- Predict future traffic demands and proactively adjust network resources.

AI-based Resource Allocation and Congestion Control:

- Utilize AI/ML to dynamically allocate resources (bandwidth, power) to users and applications based on real-time demand and Quality of Service (QoS) requirements.
- Implement intelligent congestion control mechanisms to prevent network overload and ensure smooth user experience.

Anomaly Detection for Network Security:

- Employ AI/ML techniques to detect anomalies in network traffic patterns, identify potential security threats (e.g., DDoS attacks, intrusions), and trigger appropriate security measures.

Support for Edge Computing and AI Inference at the Edge:

- Enable the deployment of AI/ML models at the network edge (e.g., base stations, edge servers) to reduce latency and improve response times for latency-sensitive applications.

3GPP Release 17 AI/ML Related Features:
Enhanced Machine Learning for Network Slicing:

- Utilize AI/ML to dynamically provision and manage network slices (dedicated network segments) for different applications and services with specific QoS requirements.
- Optimize resource allocation and performance within each network slice.

AI-powered Network Self-Organization and Self-Optimization:

- Enable the network to autonomously configure, optimize, and heal itself using AI/ML algorithms.
- Minimize human intervention and improve network efficiency.

Improved Support for AI/ML at the Edge with Enhanced Edge Computing Capabilities:

- Further, enhance edge-computing capabilities to support more complex AI/ML workloads and applications.
- Improve the performance and reliability of AI/ML inference at the edge.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

AI-based Predictive Maintenance for Network Equipment:

- Utilize AI/ML to predict potential equipment failures and proactively schedule maintenance activities.
- Reduce downtime and improve network reliability.

3GPP Release 18 AI/ML Related Features:

AI-driven Network Virtualization and Orchestration:

- Leverage AI/ML to automate and optimize the management of virtualized network functions (VNFs) and network services.
- Improve the agility and flexibility of network operations.

Advanced Machine Learning for Network Security, including Threat Detection and Mitigation:

- Enhance network security capabilities by employing more sophisticated AI/ML techniques for threat detection, classification, and response.
- Improve the accuracy and effectiveness of intrusion detection and prevention systems.

AI-powered Network Slicing with Improved Performance and Flexibility:

- Further, enhance network slicing capabilities with AI/ML, enabling more dynamic and flexible slice provisioning and management.
- Improve the performance and isolation of network slices.

Integration of AI/ML with 6G Technologies:

- Explore the integration of AI/ML with emerging 6G technologies, such as integrated terrestrial-aerial networks (ITAN) and holographic beamforming, to enhance network performance and enable new use cases.

Key Takeaways of 3GPP specs with respect to AI/ML:

- 3GPP releases have seen a progressive increase in the incorporation of AI/ML technologies.
- Initial releases focused on foundational aspects like cell planning, resource allocation, and security.
- Later releases have expanded to more advanced areas like network slicing, self-organization, and edge computing.
- Release 18 signifies a significant step towards AI-driven network management and the integration of AI/ML with future 6G technologies.

These advancements in AI/ML within 3GPP releases are crucial for realizing the full potential of 5G and future wireless networks, enabling more intelligent, efficient, and user-centric network operations.

III. RESULTS AND DISCUSSIONS

Key 3GPP Release 18 feature alignment with AI:

Latest 3GPP release 18, focuses on three key wireless AI use cases though there will be many more potential use cases for the future –

Channel feedback

- More efficient, predictive Channel State Information (CSI) feedback can improveuser downlink throughput and reduce uplink overhead

Beam management

- Beam prediction in time/spatial domain for overhead and latency reduction, improving beam selection accuracy, especially useful for mm Wave systems

Precise positioning

- Positioning accuracy enhancements for different indoor and outdoor scenarios including, e.g., those with heavy non line-of-sight conditions

Path towards AI-native 6G:

These above mentioned foundational wireless AI feature and innovations would be leading a way towards AI-native 6G. There was (and is) era in 5G with cloud-native vision and possibly, there will be 6G era with AI-native vision.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

3GPP Release 19, while primarily focused on enhancing 5G capabilities, includes several features that lay the groundwork for the AI-native vision of 6G:

Enhanced AI/ML Support for Mobility Management:

- Release 19 refines mobility management techniques, incorporating AI/ML for more intelligent handover decisions.
- This includes predicting user movements and proactively preparing for seamless transitions between cells, crucial for the dynamic and diverse mobility scenarios envisioned for 6G.

Advanced Beam Management with AI/ML:

- Release 19 introduces advancements in beam management techniques, leveraging AI/ML to optimize beam selection and tracking.
- This is essential for maximizing spectral efficiency and user throughput, key requirements for the high data rates expected in 6G.

Network Slicing Enhancements with AI/ML:

- Release 19 further enhances network-slicing capabilities, allowing for more dynamic and flexible slice provisioning.
- AI/ML plays a crucial role in optimizing resource allocation and ensuring QoS within each slice, a fundamental aspect of 6G's envisioned personalized and tailored network experiences.

Foundation for AI/ML-driven Network Slicing:

- Release 19 establishes the foundational framework for AI/ML-driven network slicing, enabling more intelligent and automated management of network resources.
- This paves the way for the highly dynamic and adaptive network slicing capabilities envisioned for 6G.

Key Considerations:

- These features provide a stepping-stone towards the AI-native 6G vision.
- 6G will likely see a much deeper integration of AI/ML, with AI/ML algorithms embedded within the core network functions.
- 3GPP Release 19 serves as a crucial foundation for ongoing research and development in this area.

Note: This information is based on current understanding and may be subject to change as 3GPP Release 19 standardization progresses.

Some possible key areas/functionalities to explore towards AI-native 6G are:

1. AI-Native E2E Communications

Concept: In AI-native 6G, AI is not just a tool used on the network, but is embedded within the communication process itself. This means AI algorithms are integrated at every stage of the communication chain, from the source to the destination.

Implications:

- Intelligent Resource Allocation: AI can dynamically adjust transmission parameters (power, modulation, coding) in real-time based on the specific needs of each data packet and the current network conditions. This leads to optimal resource utilization and enhanced efficiency.
- Predictive and Adaptive Communication: AI can predict and anticipate user demands, network congestion, and interference. This allows the network to proactively adapt and optimize its performance, ensuring smooth and reliable communication even under dynamic and unpredictable conditions.
- Self-Optimizing Networks: AI can enable self-organizing and self-healing networks that can autonomously identify and resolve issues, such as congestion or interference, without human intervention.

2. Scalable Network Architecture

Concept: 6G will need to support a massive surge in connected devices (IoT, sensors, etc.) and the exponential growth of data traffic. An AI-native architecture is crucial to achieve this scalability.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

Implications:

- Decentralized Intelligence: AI/ML models can be distributed across the network, enabling localized decision-making and reducing reliance on centralized control. This improves scalability and resilience.
- Network Slicing with AI: AI can dynamically create and manage network slices tailored to specific applications and user requirements, ensuring optimal resource allocation and QoS for each slice.
- Cognitive Radio Techniques: AI-powered cognitive radio techniques can enable dynamic spectrum access, allowing the network to efficiently utilize available spectrum resources and adapt to changing conditions.

3. Expanding into New Spectrum Bands

Concept: 6G will likely utilize higher frequency bands (e.g., terahertz frequencies) to achieve higher data rates. However, these higher frequencies face challenges such as higher propagation losses and increased susceptibility to interference.

Implications:

- AI-Driven Spectrum Management: AI can help overcome these challenges by:
- Intelligent interference mitigation: Identifying and mitigating interference from other sources, such as radar and other wireless systems.
- Waveform design: Designing and optimizing waveforms that are robust to propagation losses and interference in these new frequency bands.
- Dynamic spectrum access: Enabling flexible and efficient utilization of the available spectrum in these new bands.

4. Air Interface Innovations

Concept: The air interface is the crucial link between the device and the network. AI-native 6G will revolutionize the air interface with:

- Intelligent Waveform Design: AI can design and optimize waveforms that are tailored to specific applications and channel conditions, maximizing spectral efficiency and energy efficiency.
- AI-Driven Beamforming: AI can dynamically adjust beamforming patterns to optimize signal strength and minimize interference, leading to improved coverage and capacity.
- Intelligent Modulation and Coding: AI can select the most appropriate modulation and coding schemes for each transmission, adapting to the dynamic characteristics of the wireless channel.

IV. CONCLUSION

Concluding this article, it is worth to say that AI is not merely a tool for 5G and 6G; it is an integral and transformative force. In 5G, AI is already enhancing network performance through predictive modeling, automated fault detection, and intelligent resource allocation.

In 6G, AI will be further embedded within the network fabric, becoming an "AI-native" system. This will enable:

- Proactive and adaptive networks: Anticipating user needs and dynamically optimizing network performance in real-time.
- Enhanced user experiences: Personalized service delivery, improved QoS, and seamless connectivity.
- Improved network efficiency: Optimized resource utilization, reduced energy consumption, and enhanced security.
- New use cases: Enabling innovative applications in areas such as autonomous vehicles, remote surgery, and the Industrial Internet of Things.

While challenges related to data privacy, explainability, and interoperability remain, ongoing research and development will continue to refine the integration of AI in 5G and 6G, paving the way for a future of intelligent, efficient, and user-centric wireless communication.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 1, February 2025

Key takeaway: AI is no longer an optional extra for 5G and 6G; it is a fundamental enabler for the realization of their full potential. Hope, this concise summary effectively captures the key conclusions regarding the role of AI in 5G and 6G.

V. ACKNOWLEDGMENT

I, Manish Uniyal acknowledge that this research paper is written with best of my knowledge while referencing white papers and specifications publicly available to summarize an idea on role of AI in 5G and 6G technologies and how crucial AI will be.

REFERENCES

[1]. 5G Americas white paper - https://www.5gamericas.org/wp-content/
[2]. 3GPP specs – 3GPP TR 28.908 version 18.0.0 Release 18
[3]. 6Gworld blog - https://www.6gworld.com/exclusives/network-ai-evolution-5g-to-6g/