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Artificial Intelligent-Based Resource Management In 6g Networks: A Review

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Abstract
This paper discusses how the introduction of 6G networks, which provide extremely fast, low-latency, and massive connections, has the potential to revolutionize wireless communication and create new uses for it, such as holographic communication, autonomous systems, and real-time AI-driven services. However, managing the resources in such complex, dynamic, and varied networks presents a number of challenges. Conventional resource management techniques are no longer sufficient to meet the demands of 6G environments. This article explores how AI may be included into resource management for 6G networks, with a focus on how it can enhance scalability, optimize network performance, and improve resource allocation. AI techniques such as machine learning (ML), deep learning (DL), and reinforcement learning (RL) can enable intelligent decision-making processes for dynamic spectrum allocation, energy-efficient resource consumption, load balancing, and quality of service (QoS) provisioning. AI's ability to analyze vast amounts of real-time network data enables networks to predict network activity, adapt to changing conditions autonomously, and optimize resource utilization to enhance user experience and network efficiency.

***Keywords*:** *artificial intelligence, 6G networks, the Internet of Things (IoT), and reinforcement learning.*

1. INTRODUCTION

6G technology is poised to revolutionize the mobile communications sector with its ground-breaking capabilities, which include extremely fast data rates, extremely low latency, and massive device connection. This next-generation wireless technology envisions a hyper-connected future that goes beyond simply faster mobile connectivity. Essentially, 6G aims to allow for continuous, intelligent data interchange across a range of settings by seamlessly integrating billions of Internet of Things (IoT) devices, from wearables and smart appliances to industrial systems and traffic sensors.

The exponential growth of IoT connections will lead to the emergence of intelligent networks that can generate, collect, and analyze massive amounts of real-time data. These abilities are expected to promote innovation in key areas including smart cities, industry, healthcare, and transportation. For instance, networked IoT infrastructures will be used in smart cities to dynamically address urban challenges like energy management and traffic congestion. Autonomous machine-to-machine communication will also benefit industrial systems by enabling predictive maintenance, real-time decision-making, and improved operational efficiency.

6G is expected to be a big step up from 5G, which has download speeds in the gigabits per second (Gbps) range. 6G will have download speeds in the terabits per second (Tbps) range. With this kind of ultra-high-speed networking, it will be possible to stream ultra-high-definition content, like 8K video and higher, without any buffering or delays. Thanks to this, users may be able to see live international events, like concerts and sports games, in real time with unmatched fluidity and clarity. Also, 6G's high speed and low latency are expected to make apps like augmented reality (AR) and virtual reality (VR) much better. Instantaneous transmission of huge amounts of data will make it possible to create virtual worlds that are very similar to or even better than the real world.

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Figure 1: Vision for 6G-Enabled Ecosystem

Beyond entertainment, the unmatched data capacity of 6G will significantly influence scientific and technological advancement. Large datasets may be handled and shared in real time, which will speed up discoveries and encourage multidisciplinary innovation in fields including medicinal research, materials engineering, and artificial intelligence.

For efficient resource management in 6G networks, artificial intelligence (AI) is emerging as a key enabler. Deep reinforcement learning (DRL) and explainable AI (XAI) are two examples of sophisticated AI-driven methodologies being utilized to improve the effectiveness and transparency of resource allocation strategies [1–3]. Particularly helpful are XAI techniques for enhancing system resilience, simplifying complicated model behaviors, and enabling the interpretation of AI conclusions [4].

Even in the absence of real-time channel state information, multi-agent deep reinforcement learning offers a viable solution for intelligent radio resource allocation, allowing systems to make informed decisions using indicators such as the received signal strength indicator (RSSI) [5]. To enhance dynamic resource management, a sophisticated, traffic-aware software-defined radio access network (Soft-RAN) architecture is incorporated. This approach ultimately boosts scalability, adaptability, and performance in future 6G networks by considering factors like data throughput, signaling overhead, and system complexity.

Figure 2: Challenges in 6G Resource Management

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2. REVIEW OF LITERATURE

This part gives a brief overview of relevant studies on managing resources in 6G networks. These studies lower the effects of congestion, make the most of bandwidth use, and cut down on delays by making the best use of resources based on the weather.

Alexander W. Koch and others [1] came up with an AI-based way to manage traffic for 6G Cloud Radio Access Networks (Cloud-RAN) to deal with RAN traffic congestion and lessen its negative effects. The method effectively cuts down on congestion, delays, and bandwidth waste by sorting traffic statuses and dynamically allocating resources. The results show that the model may improve network performance under different traffic conditions by lowering the time it takes to complete tasks by up to 18%.

Xinlu Li, Canguan Ling, and others [2] looked at how explainable and strong AI methods could be used to improve resource management in 6G networks. These methods try to make decision-making processes less complicated and more resilient by making "black-box" AI models easier to understand. The study improves radio resource management in 6G by using explainable AI, which makes AI decisions easier to understand and more useful. The paradigm makes complex algorithms easier to understand, makes resource allocation choices clearer, and makes algorithms work better and make better decisions.

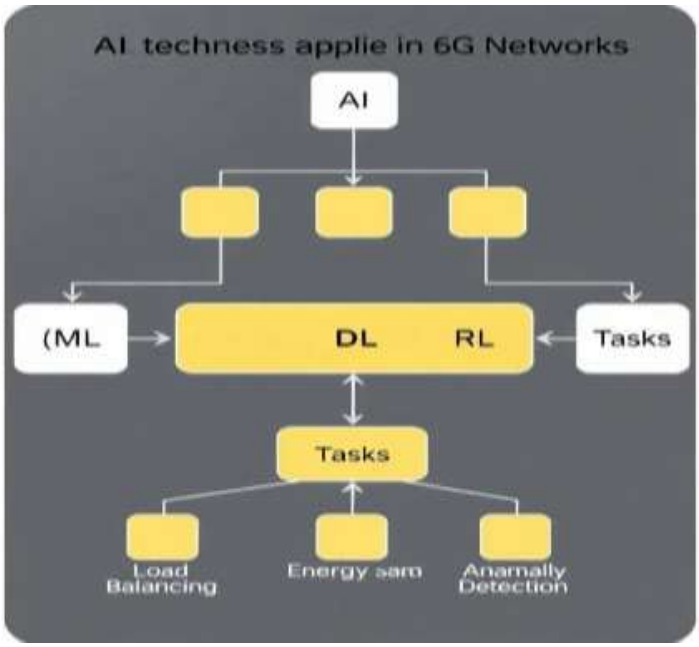

Figure 3: AI Techniques Applied in 6G Networks

Ali Nouruzi et al. [3] suggest a way to manage resources intelligently in dynamic 6G subnetworks using multi-agent reinforcement learning (MARL). Instead of using traditional channel gains, this method uses the Received Signal Strength Indicator (RSSI) as a key metric to improve efficiency. The authors' extensive research shows that the suggested MARL-based strategy works better than current methods on a number of performance metrics. It is a more efficient way to dynamically allocate resources in real-time situations.

Tania et al. [4] presented a sophisticated artificial intelligence-based resource allocation method for the software-defined radio access network (Soft-RAN) architecture of 6G wireless networks. The authors employ deep reinforcement learning (DRL), which allows the network to instantly adapt to changing conditions, to support dynamic decision-making. By using a hierarchical approach to resource distribution, the proposed system provides greater scalability and flexibility compared to traditional fixed-resource allocation systems.

Klaus et al. [5] looked at how to combine expert systems for smart automation and service delivery in 6G networks. The authors present an intelligent architecture that speeds up networks and makes them easier to use by automating decision-making and making resource management more efficient. The idea cuts

down on the need for manual work and makes service delivery across the network more efficient by making 6G more automated.

Xiao Du et al. presented the Artificial Intelligence-Enabled Dingo Optimizer [6] to regulate energy in 6G communication networks. By employing cluster-based routing strategies, the model seeks to improve energy efficiency and prolong the lifespan of IoT devices. Energy efficiency is crucial in settings like low-power Internet of Things networks, and this technique ensures that devices with limited resources may continue to function well for extended periods of time.

For 6G-enabled Cooperative Intelligent Transportation Systems (C-ITS), N. Khan et al. [7] proposed the ReMaAl-AutoNet system, an intelligent resource management solution. The solution uses reinforcement learning (RL) to improve communication between connected cars and infrastructure, optimize network performance, and increase the effectiveness of resource allocation in C-ITS applications. This method ensures dependable and efficient resource management while increasing the overall efficacy of C-ITS networks.

The role of AI in intelligent resource management for 6G networks was examined by Rekha et al. [8], who concentrated on how AI might improve network security and efficiency. 6G networks can automatically identify and reduce security risks while maintaining long-term functionality with the aid of AI. But the report also raises issues with protecting networks from sophisticated AI-driven attacks and preserving privacy. AI is regarded as a key facilitator of 6G network security in spite of these obstacles.

For multidimensional resource management in integrated satellite-terrestrial networks (ISTN), Kaan et al. [9] presented a matching game-based intelligent mission-resource two-sided matching framework. The model optimizes the allocation of resources between the satellite and terrestrial components of the network by applying matching game theory. The framework ensures effective worldwide coverage and improved network efficiency by successfully resolving resource management issues specific to ISTNs in 6G.

AI-native 6G networks, which combine AI with terminal-fog-cloud systems to enable intelligent wireless control, innovative protocols, and enhanced performance, were studied by Quang et al. [10]. The study comes to the conclusion that artificial intelligence will be essential to meeting the various performance requirements of 6G applications. By enabling more complex commercial applications and high performance requirements, AI integration will simplify network administration.

A machine learning-based Intelligent Admission Control (AC) model for 6G networks was proposed by Brandon et al. [11] to enhance resource-efficient connections. This model improves reliability, especially for safety-critical communications with stringent latency requirements. By improving system reliability by 17% over baseline methods, AI integration provides a workable answer to the problems presented by high-performance communication networks.

For multi-domain 6G networks, H. Yang et al. [12] developed an autonomous network management system using Graph Neural Networks (GNNs). It allows for intelligent decision-making and performance analysis, which addresses the issues with traditional network management solutions. The research concludes with a proposal for a GNN-based autonomous network management system that combines multiple domains and enhances network performance via autonomous management.

For Beyond 5G (B5G) networks, A. Nouruzi et al. introduced NEMI (Network Management Intelligence), an AI-enabled autonomous network management solution [13]. By reducing the need for manual interventions and automating network management operations, NEMI improves dependability and resilience. In order to ensure more robust and scalable operations, the study demonstrates how AI-powered autonomous systems may enhance the overall resilience and dependability of 6G networks.

In their analysis of AI's application in open programmable virtualized networks, W. Yulei et al. [14] emphasized the significance of the technology in overseeing and coordinating network operations. According to the study's findings, artificial intelligence (AI) is critical to the success of open programmable virtualized networks in 6G because it makes it possible for network automation and dynamic reconfiguration, both of which are necessary to satisfy the diverse needs of 6G applications.

In order to handle the particular resource management issues in 6G networks, Xiao Du emphasized the necessity of AI and machine learning (AI/ML) solutions [15]. Among other important resource

management issues, the project explores how AI/ML might enhance 6G speed, scalability, and flexibility. The authors come to the conclusion that AI/ML technologies, which provide intelligent resource management and optimization, will significantly aid in the development of 6G.

AI-powered methods for signal processing, traffic flow management, and dynamic resource allocation in 6G networks are proposed by H. Zhang et al. [16]. The study focuses on how artificial intelligence (AI) and machine learning (ML) can enhance network performance by facilitating real-time, automated changes that increase responsiveness and efficiency. The conclusion demonstrates how AI and ML have revolutionized 6G network management.

Network slicing is an essential part of effective resource management in 6G networks, and F. Debbabi et al. [17] investigated it using AI-based techniques. Combining edge computing and quantum computing to improve network slicing efficiency is covered in the study. It is thought that using AI techniques will be essential to enhancing B5G and 6G networks' capacity for resource management.

In order to manage network slices in B5G/6G networks, Kamruzzaman et al. [18] proposed an AI-driven engine. This engine improves resource utilization, enables data processing at the edge cloud, and satisfies a variety of service needs. The study's conclusions show that AI-enabled engines are crucial for effectively managing network slices and provide a scalable solution for 6G resource management.

Kyung et al. [19] looked at the application of AI in cybersecurity management for 6G wireless communication networks. The study investigates the potential integration of AI into security standards to enhance energy efficiency while protecting privacy and communications. AI is crucial for enhancing the security and efficiency of 6G networks, particularly in high-risk environments, the study's conclusions indicate.

In 6G subnetworks, L. Yang [20] introduced a Multi-Agent Reinforcement Learning (MARL) method based on a GA-Net architecture for intelligent radio resource management. The RSSI is used in the model instead of channel gains to improve the efficiency of resource allocation and interference control. The results show that the recommended method outperforms traditional MARL models and offers a more efficient resource management solution in dynamic 6G environments.

According to M. Corici et al. [21], the application of AI to 6G HetNets' dynamic network configuration, load forecasting, resource optimization, and security enhancement was examined. The authors propose an optimized allocation of machine learning tasks in a layer-based HetNet design for enhanced energy efficiency. This architecture enhances energy efficiency and enables dynamic network management in 6G HetNets, according to the study's findings.

The application of Generative Adversarial Networks (GANs) to 6G wireless networks for trust management was discussed by M. Rasti et al. [22]. To enhance security and service quality, the article recommends using GANs to optimize secure communication and resource management. According to the study's conclusions, 6G networks can be effectively protected by integrating GANs into trust management systems.

F. Granelli et al. [23] suggested a smart software-defined RAN (SD-RAN) architecture for 6G networks that dynamically optimizes resource allocation through deep reinforcement learning. The authors present a hierarchical resource allocation model and demonstrate how the Soft Actor-Critic technique enhances scalability and reliability in SD-RAN networks. The results of the study show that the proposed algorithm offers more dynamic and flexible resource management and performs better than fixed schemes.

In their discussion of AI-driven orchestration in 6G networks, C. Qiu et al. [24] highlighted the significance of machine learning in optimizing resource management. Hexa-X, a project that focuses on machine learning-driven network operation, is one significant endeavor that addresses the challenge of maintaining 6G networks. According to the study's findings, machine learning enhances the efficiency of 6G network orchestration and management.

H. Cao and colleagues [25] looked at the role of AI in 6G network resource management, particularly in spectrum prediction and dynamic resource allocation. The results of the study show that AI-enabled networks are critical for spectrum optimization, efficient 6G resource management, and enhanced network performance overall.

A knowledge-driven explainable AI architecture was presented by Xinru et al. [26] for network automation in intricate 6G networks. The framework is intended to offer AI agents for tasks like resource management that are understandable to humans. The study highlights the difficulties in applying explainable AI and makes recommendations for future research directions to increase network automation's efficacy and transparency.

An adaptive AI framework for resource management in 6G networks was examined by P. Singh et al. [27] with an emphasis on connected automobiles. Feature selection is used in the suggested approach to lower computing complexity without sacrificing resource allocation accuracy. The framework increases performance and lowers system overhead in cyber twin-driven 6G networks by improving resource management, according to the study's findings.

Jesus et al. emphasized the significance of customized AI models for 6G Network Intelligence (NI) [28]. In order for NI-native systems to effectively manage resources, these ideas are necessary. The study concludes that NI-driven functionality can be used for network capacity projections and that AI models need to be tailored for specific network levels.

Priyanka et al. [29], who talked about AI-driven resource management in 6G networks, said local domains are crucial for the optimal resource allocation. The study's findings suggest that artificial intelligence (AI) and machine learning will play a crucial role in network management in the future since they will facilitate resource efficiency and enhance overall network performance.

Albert et al. [30] used decentralized machine learning and wireless communication to effectively manage resources in their study on the integration of Edge AI in 6G networks. The potential advantages of Edge AI for network security, privacy, and performance are highlighted in the paper. According to the study's findings, Edge AI will revolutionize 6G networks by providing reliable and scalable decentralized resource management solutions.

S.No.	Authors	Title	Key Issues Tackled	Techniques Used	Major Contributions
1	Alexander W. Koch (Jan 2023)	AI-Native 6G Intelligent Network	Integration of AI with 6G for high-performance applications	AI-Native architecture, redefined protocol stack	Proposed AI-native design with a new fog-cloud-terminal management system
2	Xinlu Li, Canguan Ling (Jan 2023)	AI-Based 6G Network Security	AI as a double-edged sword in security and privacy	Analytical study of AI's role in 6G security	Offered solutions to AI-related security concerns
3	Ali Nouruzi et al. (Feb 2023)	AI-Driven Smart Resource Allocation in SD-6G	Inflexibility of traditional allocation in complex networks	Hierarchical ML with DRL-based model	Introduced TOC metric and DRL for resource decisions
4	Tania Chauhan, Renjith P. N. (Feb 2023)	Expert Systems for 6G Transformation	Challenges in latency, coverage, UX, and AI processing load	Expert system-based intelligent network design	Suggested improved architecture and future research areas
5	Klaus et al. (Mar 2023)	6G Fabric Using Micro Domains	Need for scalable and intelligent service delivery	Integration of AI, ML, quantum in 6G fabrics	Highlighted AI/ML as enablers in 6G management
6	Xiao Du et al. (Mar 2023)	MARL for Dynamic Resource Management	Subnetwork interference and missing channel data	MARL with GA-Net, RSSI-driven management	Introduced RSSI-based MARL and new training algorithm

7	N. Khan et al. (Apr 2023)	Explainable AI for Trustworthy 6G Resource Management	High model complexity and lack of transparency	Explainable AI framework	Case studies showcasing robust, interpretable models
8	Rekha Smruti et al. (June 2023)	AI-Based Traffic Management in 6G C-RAN	Traffic congestion, bandwidth inefficiency	Cloud-based resource scheduling using traffic states	Proposed traffic-aware C-RAN model with dynamic classification
9	Kaan Aykurt, Wolfgang Keller (June 2023)	GNN for Autonomous 6G Network Management	Cross-domain scalability issues in networks	GNN-based framework for self-managed networks	Demonstrated multi-domain network integration via GNN
10	Quang Ngoc Nguyen et al. (Jan 2023)	Survey on 6G HetNet Resource Management	Spectrum sharing and interference in HetNets	Power control, association, spectrum allocation	Identified current limitations and proposed future directions
11	Brandon D.L. Marshall (Jan 2022)	AI-Enabled 6G Resource Optimization	Resource challenges in dense environments	ML-based spectrum prediction and allocation	Showcased dynamic resource handling via AI methods
12	Helin Yang et al. (Jan 2022)	AI-Driven 6G Network Intelligence	Resource handling in heterogeneous networks	ML-focused architecture	Advocated AI-based adaptive spectrum allocation
13	Alireza et al. (Feb 2022)	Smart AI-Based Allocation in 6G	Poor performance of fixed resource models	DRL with SDN control and soft-RAN integration	Introduced TOC metric and traffic-aware decision model
14	Yulei Wu et al. (May 2022)	Explainable AI for 6G Automation	DL models' lack of transparency	Knowledge-based XAI for automation	Feasibility demonstrated through path selection case study
15	Xiao Du et al. (May 2022)	MARL in 6G in-X Subnetworks	Inter-subnetwork interference	GA-Net and RSSI-based MARL framework	Modeled subnetwork interactions using graph attention
16	Haijun Zhang et al. (May 2022)	AI-Engine for 6G Management	Need for dynamic slice management	Distributed AI engine with ML models	Enabled multi-use AI engine for 6G orchestration
17	Fadoua Debbabi et al. (May 2022)	AI Algorithms for B5G/6G Slicing	5G limitations and emerging demands	Literature review on AI-driven slicing	Studied training models and AI for resource allocation
18	M. M. Kamruzzaman (Jun 2022)	AI-Enhanced Security via Cloud Edge	Weak security and data integrity in IoT	DNN-based secure communication model	Designed energy-efficient, AI-enabled security framework
19	Kyung-Keun Kim (Jun 2022)	Energy-Efficient Edge AI for HetNets	High computation demand in ML tasks	Layered HetNet with D2D and ML task division	Proposed energy-efficient edge AI with distributed learning

20	Liuqing Yang et al. (Jul 2022)	Adversarial Learning for Trust in 6G	Ensuring trust in sensor networks	Adversarial learning + fuzzy logic	Introduced secure trust management with GAN-based model
21	Marius Corici et al. (Dec 2022)	NEMI: AI Autonomic Management for 6G	Legacy systems are slow and error-prone	AI-enabled autonomic system for open networks	Validated system for reliability across fixed and 5G
22	Mehdi Rasti et al. (Aug 2022)	6G Multi-Band Resource Strategy	AI/ML for optimization and spectrum management	DRL with Dueling DQN for channel assignment	Mapped transformation of optimization to AI-based solutions
23	Fabrizio Granelli et al. (Oct 2022)	AI in Virtualized 6G Networks	Diverse demands increase network complexity	Editorial review on AI in programmable networks	Summarized AI contributions in network orchestration
24	Chenxi Qiu et al. (Dec 2022)	AI-Empowered Net-RCA for 6G	High operational cost in 6G	AI-driven Net-RCA model	Outperformed existing RCA tools in 6G networks
25	Haotong Cao et al. (Dec 2022)	Autonomous Resource Allocation in 6G ITS	Challenges in 6G-enabled ITS	RL-based ReMaAl-AutoNet architecture	Designed intelligent and autonomous ITS resource system
26	Xinru Mi et al. (Dec 2022)	Intelligent Resource Management for Satellite-Terrestrial Networks	Satellite integration complexity	Matching game theory with MRTM framework	Formulated resource strategy for ISTN environments
27	P. Singh et al. (Dec 2022)	AI-Based Dingo Optimizer in 6G	Spectrum scarcity and energy usage	Cluster routing with AIDO-EM method	Maximized IoT device lifetime via energy-aware routing
28	Jesús Pérez et al. (Dec 2022)	AI-Orchestration for 6G	Management complexity in diverse networks	Hexa-X project and ML-driven orchestration	Outlined ML's role in advanced orchestration practices
29	Priyanka J. et al. (Dec 2022)	Intelligent Admission Control for 6G	Overprovisioning in 5G	LASSO-based ML for resource prediction	Enabled efficient and reliable connectivity control
30	Albert Banchs et al. (Oct 2021)	Network Intelligence in 6G	One-size-fits-all AI models are ineffective	NI-native architecture tailored per network layer	Advocated for end-to-end network intelligence
31	Shuaiqi Shen et al. (Nov 2021)	Adaptive AI for Connected Vehicles	Generic AI too heavy for vehicles	Lightweight AI with feature selection	Balanced accuracy and efficiency in AI models

32	Khaled Letaief et al. (Nov 2021)	Edge AI for 6G	Latency, energy, congestion, and privacy issues	Decentralized learning at network edge	Hierarchical DRL for slicing and resource distribution
33	Ying Loong Lee et al. (Jan 2021)	6G RAN: Applications & Challenges	Dense networks, energy harvesting complexity	Flexible and sustainable RAN approaches	Emphasized RAN flexibility and energy efficiency

3. CONCLUSION

The secret to releasing 6G networks' full potential lies in AI-based resource management, which offers a scalable, flexible, and perceptive method of network administration. AI will be essential to the effective, dependable, and long-term functioning of next-generation wireless networks as 6G technology develops.

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