A Technical Review and Analysis of Intelligent Autonomous Network Management Mechanisms in 6G Communication Networks

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Abstract: Sixth Generation (6G) communication is the upcoming wireless standard that is expected to perform better than the existing 1G to 5G network based on its integrated sensing, ultra-low latency, Artificial Intelligence (AI)-native services, massive connectivity and ultra-high data rate. While comparing with the present generations, 6G networks aimed to support the microsecond-level latency, real-time intelligence, immersive holographic experiences and terabit-per-second speeds for applications like smart cities, digital twin, Industry 4.0 and autonomous systems. This advancement led to dynamic behaviour and unprecedented complexity, which tends the system to efficiently maintain the heterogeneous infrastructure, including the satellite, terrestrial and aerial systems. Such heterogeneity introduces significant challenges in coordination, interoperability, and resource allocation across multiple network domains. In order to manage these issues, the Autonomous Network Management (ANM) are introduced as a major enabler for efficient network operation. This ANM incorporates machine learning, AI, a closed-loop control mechanism and reinforcement learning to generate self-optimization, self-protection, self-healing, and self-configuration. This tends the system to effectively adapt to different service requirements, environmental condition and changing traffic by ensuring the optimal performance without human intervention. Hence, this review systematically evaluates the intelligent SNM mechanism in 6G networks by surveying the existing corresponding literature. It determines the emerging trends such as blockchain-enabled security, distributed intelligence, and edge computing to assess their impact on maximizing the trust, resilience and autonomy in 6G networks. In addition, this review ensures a comprehensive understanding of the present trends, research challenges anf future direction for the intelligent ANM in 6G network. The actionable insights provided by these findings help the researchers to work on the intelligent and efficient 6G network infrastructure.

Keywords: Sixth Generation Networks, Autonomous Network Management Systems, Artificial Intelligence, Emerging Trends, Research Gaps and Challenges

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Nomenclature

Abbreviation	Description
ANM	Autonomous Network Management
SNM	Self Network Management
AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
RL	Reinforcement Learning
DRL	Deep Reinforcement Learning
DNN	Deep Neural Network
GNN	Graph Neural Network
GAN	Generative Adversarial Network
LSTM	Long Short-Term Memory
DT	Digital Twin
IoT	Internet of Things
V2V	Vehicle-to-Vehicle Communication
UAV	Unmanned Aerial Vehicle
SDN	Software-Defined Networking
NFV	Network Function Virtualization
SON	Self-Organizing Network
SNMP	Simple Network Management Protocol
QoS	Quality of Service
SLA	Service Level Agreement
RAN	Radio Access Network
MIMO	Multiple-Input Multiple-Output
THz	Terahertz Communication
V2X	Vehicle-to-Everything Communication
HAP	High Altitude Platform
DDoS	Distributed Denial of Service
CPU	Central Processing Unit
GPU	Graphics Processing Unit
MEC	Multi-access Edge Computing

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1. Introduction

The rapid development of the wireless communication network leverage path to the 6G network, which has the promising unprecedented capabilities in intelligence, speed, latency and connectivity. This evolution is driven by the increasing demand for data-intensive applications and the need for seamless global connectivity across diverse environments. This heterogeneous and complex network needed an intelligent mechanism to achieve the self-optimization performance in making real-time decisions, even for changing network conditions. For the 6G system, the intelligent ANM become the significant enabler, which includes the AI-driven analytics, reinforcement learning, closed-loop control system and machine learning to facilitate self-optimization, self-configuration and self-protection. This mechanism aimed to ensure the efficient network operation without human intervention. Consequently, it supports the realization of zero-touch network management and automation. Other than its advancements, the involvement of intelligent ANM mechanisms in 6G causes various limitations. The heterogeneity and massive scale 6G is combined based on the satellite, terrestrial and aerial components, which effectively performs the coordination, decision making and real-time monitoring.

However, ensuring the high reliability and ultra-low latency is essential in managing the huge data volume imposes algorithmic and computational constraints. This creates a trade-off between performance optimization and resource utilization. Moreover, the network orchestration becomes complicated by the involvement of different technologies like distributed AI, blockchain and edge computing. In addition, the design of ANM generalizes across service level agreements, network slices and heterogeneous applications. This generalization demands flexible frameworks capable of adapting to diverse quality-of-service requirements. To mitigate these drawbacks, several researchers developed a wide range of solutions using deep reinforcement learning and machine learning models. Moreover, the hybrid AI models have also been developed to enhance the fault-tolerant and self-healing capabilities. Such models combine multiple learning paradigms to achieve improved robustness and reliability. In order to systematically review the existing models, this research work analyzed the traditional frameworks related to the 6G communication network to determine the emerging trends, challenges and future direction, which helps in developing the efficient and robust 6G network infrastructure. This developed article made the following significant contribution:

- To present a systematic review of intelligent ANM mechanisms developed for emerging 6G communication networks. Here, the recent research papers corresponding to the related topic published between 2021 and 2026 are investigated. This review also highlighted the utilization of AI-driven learning models to ensure the autonomous functionalities in managing the heterogeneous and complex 6G infrastructure. Additionally, it categorizes the reviewed works based on methodologies, performance metrics, and application domains.
- To provide the architectural and application scenario of 6G communication network, along with the comparative analysis of the previous literature. Moreover, the integration of emerging technologies like blockchain, edge computing, and advanced security mechanism are discussed to improve the efficiency, trust and resilience in intelligent ANM for 6G systems. Furthermore, the study outlines practical implications for deploying these technologies in real-world scenarios.

Remaining section of the work is as follows: Section 2 presents the overview of the 6G system with its application. Section 3 elucidates the existing literature works and their resolved limitations. Section 4 provides the different network functionalities, comparative details among the existing work and the integrated techniques in the 6G networks. Section 5 concludes the work.

2. Overview of 6G Communication Network and Its Usage for Different Applications

2.1 System Model of 6G Communication Network

The system model of the 6G communication network defines the operational component and structural framework that ensures the next-generation communication system. It provides a holistic representation of how different network entities interact to deliver intelligent services. When comparing with the earlier network generation, the 6G works as an intelligent distributed

system that is capable of supporting massive connectivity, ultra-low latency, and high data rate [1]. The heterogeneous infrastructure, combined with this architecture, which involved the satellite, terrestrial and aerial networks, provides seamless connectivity. Such integration enables continuous service delivery even in geographically challenging environments. There are multiple layers in the network architecture to maintain the large-scale system and to deliver autonomous network management.

2.1.1 User layer

The endpoint of 6G communication is represented in this layer, which performs the data generation. It acts as the primary interface between human users and the network ecosystem. This layer integrates different smart and connected devices within the network to perform the data transmission, services, request analysis and also receives information. The devices in the 6G environment support the intelligent sensing capability, advanced communication technology and extremely high data rate. These devices are often equipped with embedded AI for local decision-making. Here, the heterogeneous and dynamic traffic pattern is generated through this user layer based on the diversity of applications and the number of connected devices.

2.1.2 Access network layer

This layer acts as the communication bridge between the core network and user devices. It ensures seamless connectivity and efficient signal transmission across wireless interfaces. Access network is highly responsible for ensuring the reliable transmission of data, managing the radio resource and wireless connectivity [2]. The access network in the 6G system combines advanced wireless technologies like MIMO systems, cell-free infrastructure, terahertz communication and small cell deployment. These technologies collectively enhance network flexibility and scalability. These technologies highly improve the coverage, spectral efficiency and capacity in making the intelligent resource allocation for optimal performance.

2.1.3 Edge computing layer

This layer plays a significant role in enhancing the real-time service and network latency. It brings computation closer to data sources, reducing dependency on centralized systems. To process the data locally, the edge nodes are deployed closer to the user, rather than relying on centralized cloud system. This distributed computing model ensures less communication delay and faster decision-making. For the latency sensitive application like remote medical procedures and autonomous vehicles, edge computing is particularly important. Such applications require millisecond-level responsiveness. In addition, this edge layer minimizes the computational loads by enhancing the efficiency and responsiveness of the system.

2.1.4 Core network layer

In the 6G communication system, the core network layer performs as the central control component [3]. It manages overall network intelligence and policy enforcement. The main function of this layer is to coordinate the communication among the several network segments by ensuring security through authentication. This programmable and flexible network maintains the overall network operation. Software-defined networking (SDN) principles are often applied in this layer. The advancement in this technology tends to enable the network function to provide efficient resource utilization and dynamic network configuration. The automated orchestration is supported by the integration of AI in the core network.

2.1.5 Space-Air-Ground network layer

Within the satellite and aerial communication platform, the distinctive characteristics of the 6G system were incorporated. This layer extends connectivity beyond terrestrial limitations. This framework is also known as the Space-Air-Ground Integrated network. The seamless communication coverage is ensured by the terrestrial, aerial and high-altitude platforms. The network scalability, global accessibility and reliability are enhanced through these integrated domains.

2.1.6 Autonomous network management layers

This layer is initiated to optimize and control the operation in the 6G environment [4]. It serves as the intelligence backbone of the network. This layer acts as the intelligence engine, which is important for the continuous monitoring condition to make an automated decision based on analyzing the operational data to enhance the performance. The network parameters are

dynamically adjusted by leveraging reinforcement learning, AI and machine learning, and it is useful in fault recovery, traffic routing and resource allocation. This enables proactive network optimization and resilience.

Overall, the system model of the 6G communication network shows the intelligent and highly integrated framework that is constructed to support the digital services and applications [5]. It reflects the convergence of communication, computation, and intelligence into a unified ecosystem. Through these multiple integrated network layers, advanced technologies efficiently manage the complex communication environment, thus ensures the scalability and reliability. The system diagram for the 6G communication network is shown in Fig. 1

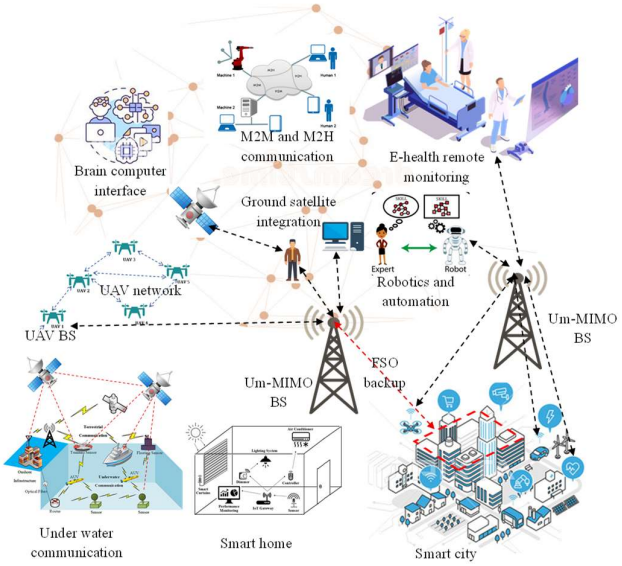

Fig. 1. Illustration of 6G communication network

2.2 Different Application Scenarios

The 6G communication network is expected to support several advanced applications that need intelligent network management, ultra-low latency, massive connectivity and ultra-high data rate. These applications are characterized by their demand for real-time responsiveness and high reliability. In contrast to previous generations, the 6G mainly give attention towards mobile broadband services. Unlike existing generations, 6G networks mainly give attention towards mobile broadband services combined with a digital ecosystem that encompasses intelligent environments and cyber-physical systems. Different application scenarios of the 6G communication are detailed below.

2.2.1 Smart cities and intelligent infrastructure

The development of smart cities is a significant application in 6G communication. The numerous interconnected devices used in the smart city environment help in monitoring the public services, transportation system, environmental conditions, and urban infrastructure. These systems rely heavily on real-time data analytics. The massive amount of data generated in this system requires real-time processing and transmission [6]. The seamless communication enabled by the 6G communication connects the data analytics, sensors and control system to optimize environmental monitoring. The stable connectivity is maintained by the ANM even for varying traffic demand.

2.2.2 Autonomous transportation system

In 6G networks, one of the key applications is intelligent transportation systems and autonomous vehicles. The future transportation systems highly depend on real-time communication between the cloud-based control system, road infrastructure and vehicles. Vehicle-to-everything (V2X) communication is a key component. These models needed highly reliable communication with extremely low latency [7]. This 6G communication technology enables instant decision through ultra-fast data exchange, which helps in traffic coordination, collision avoidance and navigation. This dynamic allocation of the network resource ensures consistent communication in ANM.

2.2.3 Industry 4.0 and smart manufacturing

In industrial environment, the digital transformation is facilitated by the 6G networks through the adoption of Industry 4.0 technology. It enables intelligent automation and smart production processes. The present manufacturing system highly depends on the intelligent control system, industrial robots and connected machines. Automated remote monitoring, predictive maintenance, and production process are facilitated by control systems, sensors and machines within the 6G networks [8]. Continuous network availability maintained by the ANM optimizes the resource allocation and availability to solve potential network failures.

2.2.4 Immersive communication and extended reality

The extended reality technologies like mixed reality, virtual reality and augmented reality facilitates immersive communication. These technologies transform user interaction into highly engaging experiences. In order to deliver a high-quality interactive experience, this technology requires extremely high data transmission. In general, the high-speed and reliable network enables immersive gaming, remote collaboration, holographic communication and virtual education [9]. These immersive services get support from the 6G network to ensure smooth service delivery based on demand.

2.2.5 Remote Healthcare and Telemedicine

In the healthcare service, the 6G communication plays a crucial role, especially in telemedicine and remote healthcare. Real-time patient monitoring and remote diagnosis performed by the medical professionals rely on low-latency and ultra-reliable communication. High reliability is essential for critical healthcare operations. For patient monitoring and analysis, the wearable devices and medical sensors are utilized through the collection and transmission of medical data. The system maintains service reliability by proactively detecting network anomalies with the help of ANM.

2.2.6 Space and Remote Area Connectivity

The communication services extended by the 6G network are based on the integration of serial and satellite communication platforms. It bridges the digital divide in underserved regions. This capability is especially significant for rural connectivity, maritime communication and remote exploration [10]. These heterogeneous communication platforms coordinate the SNM to manage the reliable and stable network coverage.

The 6G communication system is expected to support several application scenarios that needs the high-performance and intelligent communication infrastructure. These applications highlight the transformative potential of 6G technologies across multiple domains. The 6G network is enabled by the integration of ANM, which dynamically adapts to different applicational requirement.

3. Existing Works of Network Management and their Motivation with Limitations

3.1 Related Works

In 2021, Chen *et al.* [11] have trained a deep neural network for the real-time investigation of the 6G-supported transportation system by determining the Vehicle-to-vehicle (V2V) communications with the channel access technology. This approach focused on improving communication reliability in highly dynamic vehicular environments.This framework was applied in an autonomous driving platform to ensure safety and efficiency. In 2021, Serugunda *et al.* [12] have examined the atomic network function and multi-agent service decomposition for the autonomous agent in performing the network traffic management. Their work emphasized modularity and scalability in autonomous network operations. In 2022, Corici *et al.* [13] have employed autonomous network management for beyond 5G communication, which highlights the advancement of the distribution through AI-enabled ANM. In 2023, Hong *et al.* [14] have designed a combinational framework that integrated big data technology with the IoT for the green transportation system through 6G communication. The integration aimed to improve sustainability and reduce energy consumption. In 2022, Yang *et al.* [15] have introduced the generative adversarial learning model for the 6G wireless network to enhance trust management. Here, the intelligent and heterogeneous 6G framework helps in achieving reliable communication. In 2023, Aykurt and Kellerer *et al.* [16] have employed the ANM using

the Digital Twin (DT) to grant the autonomous management of the network. In 2023, Dwivedi *et al.* [17] have introduced advanced network management to present an innovative solution for UAVs in 6G networks.

In 2023, Caballero *et al.* [18] have employed the novel self-protection, multi-layer defence mechanism for different administrative domains to mitigate the threat using the distributed dual-layer loops. This mechanism enhanced resilience against multi-domain cyber threats. In 2023, Hu *et al.* [19] have presented the passive localization algorithm to minimize the convergence time and to ensure reliable processing in 6G UAV. The system provides efficient track planning within the minimal number of iterations. This is particularly useful in real-time UAV navigation scenarios. In 2024, Wang *et al.* [20] have examined the distributed computation framework for massive data offloading and computationally intensive tasks for supporting the UAV and other low-altitude platforms. In 2024, Tshakwanda *et al.* [21] have suggested the transformative system using the LSTM network for performing the dynamic routing and optimal network performance. In 2024, Elsharief *et al.* [22] have designed an advanced resource management system for improving resource allocation by efficiently sharing each resource status to reduce the value of collision probability. In 2025, Antonopoulos *et al.* [23] have developed the orchestration paradigm for the next-generation network to ensure context-aware decision making using agent collaboration. In 2025, Zhang *et al.* [24] have implemented the decentralized architecture using the machine learning model for performing effective intrusion detection. This eliminated the dependency on centralized monitoring systems. The model could be synchronized and flexible without a central server.

In 2025, Rallabandi *et al.* [25] has presented a private 6G technology, which could enhance the flexibility and reliability with ultra-low latency to empower the telecom sector. This work focused on enterprise-level customization of network services. In 2025, Bordel *et al.* [26] have initiated the predictive management algorithm to determine the network congestion probability for the corresponding resource based on the Gaussian model. In 2026, Taran and Sotnik *et al.* [27] have evaluated the technical characteristics of the 5G and 6G networks to generate an infrastructural foundation for a real-time autonomous system. Their comparative study provided insights into future network evolution. In 2026, Rao *et al.* [28] have aimed to attain reliable end-to-end communication by focusing on core enabling technologies and architectural advancement in an AI-native network. In 2024, Tian *et al.* [29] have designed the proxy framework for the autonomous unit in 6G communication by considering the distributed cloud native stack and computing technologies. This framework improved interoperability and service orchestration. In 2025, Liu *et al.* [30] have developed the technology model for the RAN-based 6G autonomous network. This service-based framework promotes flexible orchestrations in cloud-native services.

3.2 Limitations and Motivation of Traditional Methods

The automation in the 6G networks for virtualization, monitoring and programmability is enabled through mechanisms such as Software-Defined Networking (SDN), Self-Organizing Networks (SON), Simple Network Management Protocol (SNMP), and Network Function Virtualization (NFV), as well as the emerging deep learning models. These technologies have significantly improved network flexibility and automation in previous generations. However, the extreme performance requirements of 6G pose significant challenges to existing models.

3.2.1 Limitations

From the environmental interaction, the optimal action is learned by the Deep Reinforcement Learning Self-Organizing Networks DRL-SON. This approach enables adaptive decision-making in dynamic environments. However, the model needs maximum computational resources, substantial training data and is generally centralized, which tends to ultra-low latency goals. For the device control and telemetry, SNMO is used, which is highly reactive and has predictive intelligence. In addition, it faces a scalability issue in an ultra-dense 6G environment. This becomes critical as the number of connected devices increases exponentially. The dynamic spectrum management is offered using the DNN-based resource allocation with energy efficient routing, but it is limited due to the real-time generalization, especially in the heterogeneous 6G network. The centralized programmability provided by the SDN is based on the decoupled data planes and control planes. This causes a bottleneck to the centralization control, which increases the latency. In order to optimize the scheduling and routing, a Graph Neural Network (GNN) based network topology is designed. This method captures complex relationships between

network nodes. However, the system incurs maximum communication overhead and is computationally intensive in a large-scale network.

3.2.2 Motivation

Consequently, the above challenges motivate the development of an intelligent ANM framework for 6G to attain self-healing, self-optimization, and real-time decision making for heterogeneous infrastructure. Such a framework aims to overcome the limitations of traditional and AI-based methods. By involving the security-aware learning and multi-objective optimization, the framework simultaneously tackles the trust resilience, energy efficiency, latency and throughput to address the limitations of performance and scalability inherent in the standard and deep learning models. It also integrates distributed intelligence to reduce dependency on centralized control. Overall, the motivation is to provide robust, efficient and autonomous management in ANM to support the next generation applications without any human intervention.

4. Network Management Process in 6G Communication System and Comparative Analysis with Literature Works

4.1 Different Functionality of Network Management

The network management incorporates the set of processes and functions to ensure the efficiency, performance and reliability of the communication network. It serves as the backbone for maintaining seamless and intelligent network operations in complex environments. Because of the high dynamic traffic pattern, ultra-low latency, massive connectivity and extreme heterogeneity, the role of the network management becomes more critical. The main functional areas of the network management are detailed below.

- The network failures are corrected using the **fault management**, which is also responsible for isolating and detecting faults to reduce the service disruption. This function plays a vital role in maintaining service continuity. In the 6G system, this functionality performs predictive fault detection to forecast the real-time anomalies.
- The network setup of the elements, maintenance and deployment are ensured using the **configuration management**. It automates the lifecycle management of network components. With the advancement of 6G, it supports zero-touch configuration, network slicing and automated provisioning based on the NFV and SDN technologies.
- The significant metrics are monitored by the **performance management**, such as latency, resource utilization, energy efficiency and throughput. Continuous monitoring helps in maintaining optimal service quality. In order to meet the varying service requirements, adaptive optimization and AI-driven analytics are employed in 6G.
- The network is safeguarded by the **security management** by ensuring the availability, integrity and confidentiality of resources. Security management is crucial due to the increasing number of cyber threats. In the 6G network, it performs trust management, proactive threat detection, blockchain-based authentication and AI-enabled anomaly detection to secure the multi-access and highly distributed infrastructures.
- The resource usage is tracked using the **service management**, which enforces Service Level Agreements (SLA) and supports efficient resource allocation, especially in the multi-tenant network slices. It ensures that service requirements are consistently met. The massive data flow in 6G is handled effectively for real-time usage.
- For efficient scheduling, allocation and network utilization, the **resource management** is highly responsible. It ensures that service requirements are consistently met. Even for multiple users, the resource must be dynamically distributed in the next-generation communication system to manage the QoS requirement.
- Seamless connectivity ensured using the **mobility management** for the mobile users across different network coverage regions. It is essential for supporting high mobility scenarios such as autonomous vehicles. It manages the session continuity, location tracking and handover management to ensure uninterrupted communication.
- For the next-generation network, the **Network slice management** is known to be a key feature, which allows multiple virtual networks to perform on the shared physical infrastructure. It enables customized services for different applications. Corresponding to the service requirement, the network slice is designed accordingly.
- In the network operation, in order to enhance energy efficiency and to reduce power consumption, **energy management** is utilized. Energy-efficient operation is crucial for

sustainable network deployment. In the 6G energy management system, the power usage optimized by the intelligent algorithm to generate a sustainable communication network.

The combination of these functionalities forms the foundation of intelligent ANM in 6G communication. These integrated functions enable autonomous and adaptive network behavior.This comprehensive functionality autonomously adapts to ensure optimal QoS, changing condition and managing the high reliability across heterogeneous 6G infrastructure. The overview of the different functionalities of network management in 6G is illustrated in Fig. 2

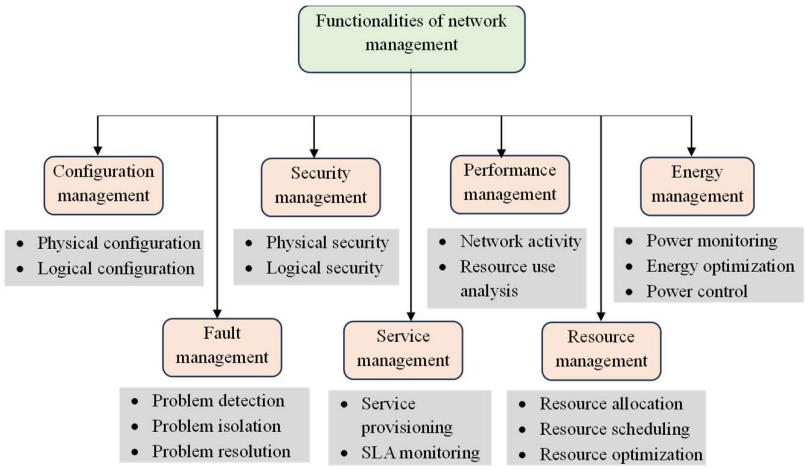

Fig. 2. Overview of network management functionalities in 6G

4.2 Comparative Details

In the previous couple of years, several researchers focused on the topic of ANM in 6G communication. This growing interest reflects the importance of automation in next-generation networks. The previous article around 2021 gave attention to involving AI and ML models to ensure the automated network control mechanism and intelligent decision-making. These early studies laid the foundation for intelligent network management. Their papers highly examined the intelligent resource management, adaptive traffic prediction and self-optimization to improve the energy efficiency and network performance. In 2022 and 2023, the investigation was expanded to tackle the reliability and security issues in the autonomous network environment. Security and trust became key research priorities during this period. Various research studies integrated the secure management mechanism and highlighted the importance of the trust-aware infrastructure to manage the heterogeneous system, which involved the satellite, aerial, and terrestrial communication systems.

Moreover, the present work highly evaluated the advanced technologies like distributed intelligence and blockchain-enabled secure systems to improve the transparency and resilience of the network management operation. These technologies contribute to decentralized and trustworthy network management. The collaborative AI models, edge intelligence and decentralized controlled mechanisms are emphasized from the year 2024 to support the real-time autonomous decision, especially in the ultra-dense network environment. Moreover, some of the research work addressed the energy-efficient network management frameworks to improve the performance of communication and minimize the operational cost. Energy optimization has become a critical factor in modern network design. Other than the advancements, there are several issues remains, including security vulnerability, scalability issue interoperability in a dynamic environment. Hence, analyzing the open limitations and future direction remains essential for ensuring intelligent and fully autonomous network management in 6G systems. The expanded summary of the current and most popular article on ANM in the 6G communication domain is provided in Table 1.

Table 1. The comparison with the related articles focused on ANM over a 6G communication network.

Year	Citation	Technology (5G, B5G, 6G)	Security	Blockchain	AI/ML	Energy efficiency	Comparison	Challenges	Open research topic on 6G
2021	[11]	✓	-	-	✓	✓	✓	✓	✓
	[12]	✓	-	-	✓	-	✓	✓	✓
2022	[13]	✓	-	-	✓	-	✓	✓	✓
	[15]	✓	✓	-	✓	-	✓	✓	✓
2023	[14]	✓	-	-	✓	✓	-	✓	✓
	[16]	✓	-	-	✓	-	-	✓	✓
	[17]	✓	-	-	✓	✓	✓	✓	✓
	[18]	✓	✓	-	-	-	-	✓	✓
	[19]	✓	-	-	-	-	-	✓	✓
2024	[20]	✓	✓	✓	-	-	-	✓	✓
	[21]	✓	-	-	✓	-	-	✓	✓
	[22]	✓	-	-	✓	-	-	✓	✓
	[29]	✓	-	-	-	-	-	✓	✓
2025	[23]	✓	-	-	✓	-	✓	✓	✓
	[24]	✓	✓	-	✓	-	✓	✓	✓
	[25]	✓	✓	-	✓	-	-	✓	✓
	[26]	✓	-	-	✓	✓	✓	✓	✓
	[30]	✓	✓	-	✓	✓	✓	✓	✓
2026	[27]	✓	✓	-	✓	✓	✓	✓	✓
	[28]	✓	✓	✓	✓	-	-	✓	✓

The symbol (✓) denotes that the topic has been covered, (-) represents that the topic has not been addressed.

4.3 Integration of Blockchain, Edge Computing and Security Empowerment in 6G Networks

The emergence of 6G communication network initiated the exceptional requirements like intelligent service delivery, ultra-low latency, extremely high data rate and massive device connectivity. These requirements significantly increase the complexity of network operations. These requirements highly maximize the complexity of network structure. Hence, there is a need for advanced technology to manage the heterogeneous and distributed environment, which can ensure autonomous, secure and reliable network operation. Emerging technologies play a vital role in addressing these challenges. To achieve this, the blockchain, edge computing and advanced security mechanisms are significant to improve the efficiency and trust in 6G network management.

4.3.1 Role of blockchain in 6G network management:

Blockchain provides a transparent, decentralized and tamper-resistant framework for managing data exchanges and network transactions. It eliminates the dependency on centralized authorities. Other than the standard centralized system, the blockchain helps in avoiding the need for a single controlling authority and ensures secure peer-to-peer communication among varying network entities. Several devices, applications and service providers simultaneously interact in the 6G, where the involvement of blockchain ensures the secure coordination and trustworthy communication among these entities. It also enhances accountability in distributed environments.

Secure authentication and identity management are the major advancements in the blockchain system, which involves the cryptography mechanism to verify the participants to prevent unauthorized access. This reduces the risk of identity spoofing and unauthorized entry. The implementation of a smart contract in blockchain automatically executes the predefined action to meet the corresponding condition. By automating these processes, the blockchain enhances efficiency and minimizes manual intervention in the autonomous network management system.

4.3.2 Role of edge computing in 6G network:

Edge computing is known to be the key technological component that ensures the distributed intelligence and low-latency processing in 6G communication networks. It enables real-time data processing closer to the source. There is a massive generation of data because of the connection of billions of devices, which highly depends on the centralized cloud computing, which leads to inefficient bandwidth utilization, maximized latency and network congestion.

These limitations are addressed using edge computing by evaluating the data corresponding to the source, such as the edge server, local nodes and base station.

For the latency sensitive applications, the localized processing capability is significant for smart healthcare systems, smart city infrastructure and autonomous vehicles. By performing the decision-making and the real-time analysis in the edge network, the communication delay can be minimized. This enhances system efficiency and user experience. The intelligent monitoring of the network is enabled by the involvement of AI and ML models. This distributed intelligence enhances the scalability, performance and adaptability of 6G networks.

4.3.3 Security empowerment in 6G network:

Security becomes the significant concern in 6G communication systems because of the large scale of device connectivity and involvement of cyber-physical systems. The increasing attack surface makes the network highly vulnerable. An increase in the number of connected devices enlarge the attack surface, which makes the network more vulnerable to threats like unauthorized access, malicious network manipulation, DDoS attacks, and data breaches. In order to enhance security, edge computing and blockchain are integrated to develop a strong foundation in the 6G environment.

The threat detection and real-time monitoring are enabled through the edge-based security framework. It allows rapid identification of anomalies. The abnormal behaviour detection and network traffic patterns are analyzed through the edge nodes. This ensures the quick detection of the potential attack. The large volume of network data is continuously determined by the AI-driven security mechanism, which acts as a proactive defence strategy.

4.3.4 Combined impact on autonomous 6G network management:

The combination of the blockchain, edge computing and advanced security mechanism generate the resilient and efficient framework for intelligent autonomous network management. Each technology contributes unique advantages to the system. The unique capability contributed by each technology helps in enhancing the reliability and performance of the 6G network.

Together, these technologies convert the 6G network into a fully autonomous system that is capable of intelligent, secure and adaptive management, which meets the demand requirement of digital twin, Industry 4.0, smart cities, and autonomous vehicles. This transformation is essential for future digital ecosystems. The integration of the blockchain, edge computing and security empowerment ensures that 6G networks are resilient, trustworthy, high-performing and future-ready.

The combination of blockchain, edge computing and security empowerment provides a significant technological foundation for the successful deployment of future 6G communication systems. This foundation is critical for supporting next-generation applications. Their integration ensures an intelligent, secure and self-adaptive network infrastructure capable of supporting next-generation digital services like autonomous systems, smart cities, immersive communication applications and digital twins.

5. Conclusion and Future Scope

This research provided a comprehensive technical review of the intelligent ANM in a 6G communication network. It consolidates various research efforts to present a unified understanding of autonomous network management in next-generation systems. This article initially presented an overview of the 6G communication system and elaborated their system model and its potential applications. It also highlighted the technological advancements in 6G in managing the heterogeneous and complex network infrastructure. These advancements are critical for supporting emerging digital ecosystems and real-time applications. This work further reviewed the previous researchers on network management and highly analyze the standard management techniques, evaluating their limitations in maintaining the large-scale and dynamic environments of future networks. The comparative analysis revealed gaps in scalability, latency, and security in existing approaches. In addition, the general procedure involved in the network management was discussed, which included several functional components that are responsible for the automation, monitoring and optimization. Additionally, the work analyzed the incorporation structure, which included the security mechanism, blockchain and edge computing to enhance the decentralized intelligence, trust and resilience within the 6G network. Based on the analysis, the survey defined the necessity of an autonomous and intelligent management framework for building a fully autonomous 6G communication infrastructure.

5.1 Future Direction

The future research on intelligent ANM for 6G communication systems focused on designing a more advanced AI-driven framework, which will be capable of performing the dynamic, heterogeneous, and large-scale traffic patterns in next generation network. These frameworks are expected to incorporate real-time learning and adaptive decision-making capabilities. In order to improve resource management and predictive optimization, there will be the integration of machine learning and reinforcement learning in a dynamic environment. The development of a standardized and interoperable management framework will also be significant for ensuring an autonomous and reliable 6G communication system. Standardization efforts will help in achieving seamless integration across multi-vendor and multi-domain networks.

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