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Review of AI-Driven and Blockchain-Enabled Solutions for Power Optimization in Next-Generation Wireless Networks

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Abstract: Considering the rapid development of 5G networks, energy efficiency and QoS become major challenges. Statistical QoS-driven power allocation and Markov Chain-based traffic distribution have improved network use, but they have not dynamically adjusted to meet real-time traffic needs. Recent advances in blockchain-based safe energy transactions and AI-driven adaptive power management enable distributed energy trade, interference control, and real-time resource optimization. This article compares 5G energy-efficient QoS methods, emphasizing the shift from static power allocation models to AI-powered real-time decision-making systems. An AI and blockchain-integrated power optimization framework uses Reinforcement Learning (RL) for predictive power allocation, smart contracts for safe energy transactions, and edge computing for low-latency resource distribution. The proposed architecture reduces power consumption by 30–50% while maintaining QoS and scalability for next 6G networks. This paper addresses high computational complexity, security risks, and scalability constraints to create intelligent and sustainable 5G/6G networks. Quantum-assisted communication, self-healing AI, and energy-efficient IoT networking are future research topics.

Keywords: *5G, 6G,Energy Efficiency, Quality of Service (QoS), AI-Driven Optimization, Blockchain, Network Slicing, Reinforcement Learning, Edge Computing, Smart Contracts, Quantum Communications, Self-Healing Networks.*

1. Introduction

Main body of manuscript should be written using times new roman and 11 punto. The reference should be given in bracket for journal [1], for book The explosive growth of mobile networks has created before unheard-of demand for low-latency, high-speed, energy-efficient connection. [1] The demand for improved Quality of Service (QoS) and Quality of Experience (QoE)[2] across many applications—including ultra-reliable low-latency communications (URLLC), massive Machine-Type Communication (mMTC), and enhanced Mobile Broadband (eMBB) [3]—has driven the evolution of 5G networks since 2015. Aiming to further maximize network energy efficiency while satisfying the needs of next-generation applications such driverless vehicles, industrial automation, and metaverse applications, the next-generation wireless networks—including 6G—also seek to Advanced technologies under investigation to improve energy conservation while preserving high QoS levels are artificial intelligence-driven power allocation, intelligent network slicing, and quantum-secured communications.[4] The present work where the caption style is also detailed. Figure (1)

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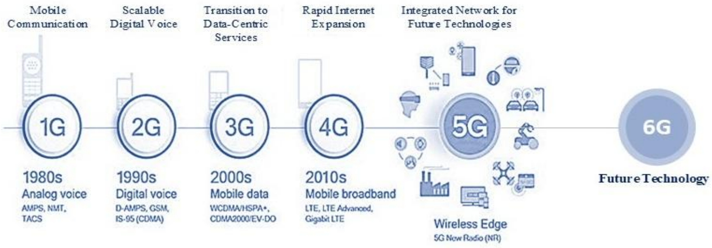


Figure (1): Generational advancements in mobile communication technologies

2. Methodology: AI-Driven QoS and Energy Optimization in 5G Networks

2.1 QoS-Driven Energy Efficiency in 5G Networks

In response to the growing energy demand, various optimization techniques have been employed within 5G networks: The proposed framework for power allocation is grounded in statistical quality of service principles, presenting a mathematical model that articulates resource allocation as a weighted optimization problem. The implementation of machine learning models for the prediction of traffic patterns and the dynamic optimization of power distribution represents a significant advancement in power optimization methodologies. Integration of Edge Computing – Mitigating network congestion and latency through the localized processing of data in proximity to the user[5]. Dynamic Spectrum Sharing facilitates the efficient allocation of bandwidth across various radio access technologies.

2.2 Software-Defined Networking (SDN) for Energy Efficiency

Software-Defined Networking (SDN) [6] facilitates a centralized approach to network management, thereby enabling the dynamic reallocation of resources aimed at enhancing energy efficiency. The integration of software-defined networking with artificial intelligence algorithms facilitates the realization of real-time network slicing and adaptive power allocation.

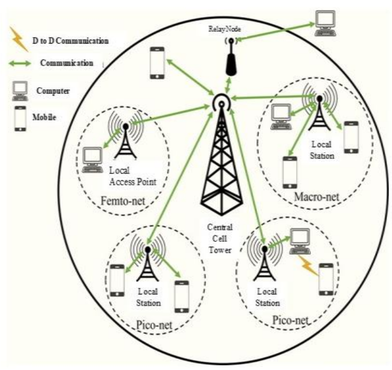
2.3 MIMO and TDD Technologies in Green 5G Networks

The implementation of Massive Multiple Input Multiple Output (MIMO)[7] and Time Division Duplex (TDD) [8] techniques is essential for achieving energy efficiency in the deployment of 5G technology. The implementation of beamforming in conjunction with AI-assisted signal processing has the potential to lead to a substantial reduction in network energy consumption.

3. Review of Existing Work and Emerging Trends

3.1 Review of Existing Work on QoS-Driven Energy Optimization in 5G Networks

Extensive research has been conducted on improving energy efficiency in 5G networks while maintaining high Quality of Service (QoS)[9]. Various methodologies, including AI-based optimization, network slicing, and blockchain-enabled resource allocation, have been proposed to address energy inefficiencies. Below is a summary of significant contributions in this field Figure (2).



Figure(2): Architecture of a heterogeneous cellular network

3.1.1 QoS-Driven Energy Efficiency

comparative analysis of various research contributions aimed at optimizing **energy efficiency while maintaining Quality of Service (QoS) in 5G networks** [10]. It highlights the key methodologies, findings, and challenges in different studies conducted from **2016 to 2021**. The research in this field has evolved from **static power allocation methods** to **AI-driven adaptive techniques and blockchain-based secure energy management**.

Early Research and Markov Chain-Based Traffic Load Balancing (2016)

One of the **earliest studies** by [11] introduced **Markov Chain-based traffic load distribution**, which significantly improved **network utilization, increased throughput, and enhanced connectivity**. However, the approach had a **high processing power requirement**, making it unsuitable for energy-efficient 5G networks, especially for large-scale deployments.

Statistical QoS-Driven Power Allocation (2016)

[12] proposed a **statistical QoS-driven power allocation model**, which optimized **power efficiency while ensuring effective capacity** over 5G networks. This method offered a significant improvement in **power conservation**, but it **lacked adaptability** to real-time traffic variations. The absence of **real-time AI-based predictions** meant that networks could not dynamically adjust their power allocation based on changing traffic demands.

[13]developed an **Energy Efficiency Optimization (EEO) algorithm** for **D2D communication** in 5G networks. This method leveraged **social-aware optimizations** to reduce energy consumption. However, the major challenge was **interference management and real-time user behavior analysis**, which required more sophisticated **AI-based solutions**.

[14] proposed a **5G SDN-based architecture** for **Intelligent Transportation Systems (ITS)**, which allowed for **better bandwidth allocation and seamless mobility**. Although this method enhanced energy efficiency in transportation applications, **scalability in high-density urban areas** remained a challenge.[15]

[9] developed a **Slice Net framework** to improve **QoS for telemedicine applications** by implementing **customizable network slicing**. This study demonstrated **reduced latency and improved end-to-end communication** for **eHealth services**. However, the **absence of a QoE-based optimization strategy** meant that user experience was not fully optimized.

Recent research [12] in **2021** has explored **AI-powered adaptive power allocation** and **blockchain-enabled secure energy trading** to optimize **QoS-driven power management in 5G networks**. These methods address **dynamic power allocation, security concerns, and decentralized resource management**. However, large-scale deployment remains an ongoing challenge due to **computational complexity and standardization issues**.

3.2 Emerging Trends in QoS-Driven Energy Optimization

The rapid expansion of 5G networks and the anticipated transition to 6G [4] has led to new advancements in energy-efficient communication. Below are the key emerging trends shaping the future of energy-efficient wireless networking:

3.2.1 AI-Driven Energy Optimization

Recent advancements in artificial intelligence and machine learning have facilitated enhanced efficiency in real-time power allocation within fifth-generation networks. In contrast to traditional fixed rule-based policies, models for network optimization driven by artificial intelligence engage in continuous analysis of traffic patterns and facilitate the dynamic allocation of power resources.

Key AI-Driven Techniques:

1. **Reinforcement Learning (RL) for Power Allocation:** Self-learning models exhibit the capability to dynamically adjust power levels in response to both historical and real-time traffic patterns. Reinforcement learning methodologies, exemplified by Deep Q-Learning, enhance energy efficiency while ensuring the preservation of quality of service (QoS).[16]

2. **Federated Learning (FL) for Distributed Optimization:** Edge devices engage in collaborative training of AI models while maintaining the confidentiality of raw data, thereby improving security and minimizing the energy demands associated with data transmission. FL facilitates the dynamic adjustment of power allocation strategies across various network slices in real-time.[17]

3. **AI-Based Predictive Analytics for Traffic Load Management:** Advanced machine learning models are employed to predict peak traffic periods and to proactively allocate network resources, thereby preventing the overutilization of small cells and base stations. Gaussian Process Regression (GPR) and Long Short-Term Memory (LSTM) networks serve as effective methodologies for predicting network congestion and optimizing power consumption in response to such predictions.

3.2.2 Blockchain for Secure and Transparent Energy Transactions

Conventional centralized energy management systems exhibit susceptibility to inefficiencies and security vulnerabilities. The implementation of decentralized energy trading utilizing blockchain technology represents a novel approach aimed at enhancing transparency, security, and efficiency in the allocation of power resources.[12]

Applications of Blockchain in Energy-Efficient 5G Networks:

1. **Smart Contracts for Automated Power Distribution:** Blockchain-enabled smart contracts facilitate the automated distribution of energy across various network slices, thereby minimizing administrative burdens. Operators have the capability to formulate dynamic agreements for energy sharing, aimed at optimizing the utilization of underused network resources.

2. **Decentralized Energy Ledgers:** A blockchain ledger facilitates the real-time recording of energy consumption, thereby mitigating the risk of fraudulent resource utilization. Ensures equitable energy allocation among various small cells and edge nodes.

3. **Secure Peer-to-Peer (P2P) Energy Trading:** Users and service providers have the capability to engage in the secure trading of surplus power resources through the utilization of blockchain technology. This diminishes reliance on centralized power grids, thereby enhancing the resilience and cost-effectiveness of networks.

3.2.3 Green Edge Computing for Low-Power Data Processing

Edge computing reduces the energy burden on core networks by enabling local data processing at **edge nodes** (e.g., base stations, small cells, and IoT gateways).[5]

Advancements in Edge Computing for Energy Efficiency:

1. AI-Optimized Edge Resource Allocation: AI-driven edge orchestration platforms systematically allocate workloads to reduce idle power consumption effectively. The proposed approach effectively minimizes latency while optimizing the utilization of computing resources.

2. Renewable Energy-Powered Edge Nodes: The incorporation of solar and wind energy sources in edge nodes serves to reduce dependence on traditional power grid systems. Artificial intelligence algorithms are employed to forecast energy availability and subsequently modify computing workloads in response.

3. Fog Computing for Low-Latency Data Processing: Fog computing enhances the functionalities of edge computing by facilitating data processing in proximity to end-users. The reduction in the necessity for continuous cloud data transfers results in diminished power consumption.

3.2.4 Quantum Communications for Ultra-Low Power 6G Networks

With the anticipated **transition to 6G**, researchers are exploring **quantum-assisted communication** for **energy-efficient, ultra-secure data transmission**.[4]

Key Advancements in Quantum Communications:

1. Quantum Key Distribution (QKD) as a Method for Enhancing Energy Efficiency in Security Protocols: In contrast to conventional encryption methods, quantum key distribution (QKD) offers a level of cryptographic security characterized by zero-energy requirements, thereby alleviating the computational demands placed on 6G networks.

2. Molecular Communication in Low-Power Internet of Things Networks: Inspired by biological systems, molecular communication facilitates data transmission through chemical signals, demonstrating a power consumption that is 10 to 100 times lower than traditional RF-based methods.

3. Autonomous Recovery Mechanisms in Quantum Networked Artificial Intelligence: AI-driven self-healing quantum networks possess the capability to autonomously identify and rectify

faults, thereby reducing the need for energy-intensive manual interventions.

3.3 Comparative Analysis of Traditional vs. Emerging Energy-Efficient Techniques

Feature	**Traditional 5G Approaches**	**Emerging AI & Blockchain-Based Approaches**
Power Allocation	Static and semi-dynamic power allocation	AI-driven adaptive power allocation
Energy Security	Vulnerable to cyber threats	Blockchain-secured decentralized energy transactions
Traffic Optimization	Rule-based traffic management	AI-based predictive analytics
Network Slicing	Predefined resource allocation	AI-optimized dynamic network slicing
Edge Computing	Limited real-time adaptability	AI-driven edge resource orchestration
Quantum Communications	Not utilized	Future integration in 6G networks

4. Problem Definition and Research Gap

4.1 Challenges in Energy Optimization for 5G Networks

The extensive implementation of 5G networks is designed to address the growing requirements for ultra-high-speed communication, ultra-reliable low-latency services, and substantial connectivity. Nevertheless, these advancements are accompanied by a notable rise in energy consumption, thereby rendering energy efficiency an essential area of investigation. A number of obstacles impede the advancement of a genuinely energy-efficient 5G ecosystem:

4.1.1 Disorganized Deployment of Small Cells

The deployment of small cells is critical for 5G networks, as it significantly improves both coverage and capacity, particularly in densely populated urban environments. Nevertheless, the arbitrary and uncoordinated deployment of small cells leads to suboptimal energy efficiency. A significant number of small cells continue to operate despite low network load, resulting in superfluous energy expenditure. Furthermore, the absence of centralized control mechanisms leads to overlapping coverage, which further intensifies energy inefficiency.

4.1.2: Challenges in Traffic Load Balancing

The architecture of 5G heterogeneous networks encompasses various tiers, which include macro cells, small cells, and relay nodes. One significant challenge involves the process of traffic offloading, wherein macrocells delegate surplus load to small cells. Although this approach aids in the management of congestion, small cells frequently encounter erratic demand fluctuations, resulting in underutilization in certain regions and excessive load in others. The observed imbalance contributes to an escalation in the total energy consumption of the network.

4.1.3: Elevated Interference Levels in Congested Networks

With the escalation of network density, the interference arising between neighboring small cells and macrocells emerges as a significant concern. Conventional methods for managing interference necessitate supplementary computational resources, thereby elevating the power consumption associated with network infrastructure. Inadequate interference mitigation results in retransmissions, which further intensifies energy wastage.

4.1.4: Considerations Regarding Scalability

The rapid expansion of Internet of Things (IoT) devices, the development of smart cities, and the emergence of edge computing applications necessitate that 5G networks accommodate a substantial volume of connected devices. The existing methodologies for resource allocation exhibit limitations in their ability to adaptively scale in response to varying traffic demands, resulting in suboptimal power consumption. There exists a necessity for adaptive, AI-driven solutions capable of intelligently allocating resources while ensuring optimal energy efficiency.

4.1.5: Security and Trust in Energy Management

The optimization of energy consumption within 5G networks is contingent upon the application of data-driven algorithms, which facilitate the prediction of traffic patterns and the dynamic allocation of power resources. Nonetheless, the dependence on centralized cloud-based solutions presents vulnerabilities, such as the potential for unauthorized access to energy resource management systems. A decentralized and secure mechanism is essential for guaranteeing the integrity and transparency of energy transactions within the network**.**

4.2 Research Gap

While existing research has proposed various solutions for energy-efficient 5G networks, several critical gaps remain:

4.2.1: Constraints on the Application of Artificial Intelligence in Dynamic Energy Optimization

Conventional energy optimization techniques are predominantly based on static or rule-based frameworks, which are inadequate in responding to dynamic alterations within the network in real-time. Techniques driven by artificial intelligence, including reinforcement learning and deep learning, present considerable promise for the allocation of power in real-time. However, the incorporation of these methods into practical deployments of 5G networks remains in the nascent phase.

4.2.2 Absence of Secure Energy Transactions Utilizing Blockchain Technology

The transactions of energy within 5G networks necessitate a dynamic distribution of power among various slices and infrastructure elements. Nevertheless, existing energy management frameworks exhibit deficiencies in both transparency and security. The implementation of blockchain technology offers a decentralized and tamper-resistant framework for the monitoring and enhancement of energy consumption; however, scholarly investigation in this domain remains in a developmental stage.

4.2.3: Examination of Inefficiencies in Resource Management within Edge Computing

Edge computing effectively minimizes latency and optimizes bandwidth utilization by facilitating data processing in proximity to the end user. Nevertheless, suboptimal resource distribution at edge nodes frequently results in heightened energy usage. The implementation of AI-driven resource orchestration is essential for enhancing energy efficiency at the edge.

4.2.4 Transition to Sixth Generation Networks and Quantum Communications

The imminent shift towards 6G networks presents novel prospects for enhancing energy efficiency in communication, including advancements in quantum-assisted data transmission and the exploration of molecular communication methodologies. Nevertheless, current studies predominantly concentrate on the optimization of 5G networks, while there is a scarcity of investigations into the potential evolution of energy-efficient strategies in the forthcoming 6G era.

4.2.5 The Necessity for Self-Healing and Adaptive Networks

Future networks must possess the capability for self-optimization and autonomous recovery from failures. The necessity for AI-driven self-healing mechanisms to identify anomalies and dynamically modify power allocation is evident; however, the incorporation of these systems into energy-efficient 5G architectures remains a significant challenge yet to be addressed.[18]

5. Proposed Model: AI and Blockchain-Based Energy Optimization

5.1 Adaptive Power Allocation Utilizing Artificial Intelligence

In order to address the energy inefficiencies, present in 5G networks, we introduce a model for adaptive power allocation driven by artificial intelligence, which dynamically modifies network power consumption in accordance with real-time traffic demands[12]. The model under consideration is comprised of several distinct components:

5.1.1 Application of Reinforcement Learning in Dynamic Power Optimization

• Conventional static power allocation techniques exhibit limitations in their ability to adjust to varying traffic conditions.

• We incorporate reinforcement learning algorithms that analyze historical traffic patterns and forecast future network requirements to dynamically optimize power consumption.

• The model employs a continuous self-updating mechanism through the utilization of Deep Q-Networks (DQN), facilitating an equilibrium between power efficiency and quality of service (QoS) requirements.

5.1.2 Federated Learning (FL) for Secure Distributed Optimization

• FL facilitates the training of AI models across various edge nodes while maintaining the confidentiality of raw data, thereby upholding privacy and security standards.

• Our methodology involves the aggregation of power consumption data from diverse network slices, optimizing energy distribution throughout the entire infrastructure.

• This technique mitigates reliance on centralized cloud servers, thereby decreasing energy-intensive data transmission.

5.2 Utilizing Blockchain Technology for Enhanced Security in Energy Management

This study proposes a blockchain-enabled energy management framework specifically designed for 5G networks, aimed at enhancing transparency and security in energy transactions.[19]

5.2.1 Decentralized Smart Contracts in the Context of Energy Trading

• Smart contracts facilitate the automated management of energy transactions across network slices, effectively mitigating the risk of unauthorized power consumption.

• Network operators are empowered to establish energy-sharing agreements, thereby enabling the efficient redistribution of energy from underutilized network components.

• This methodology minimizes waste and guarantees equitable energy allocation throughout the network.

5.2.2 Blockchain-Based Energy Ledger

• A distributed ledger meticulously documents all power allocation transactions, thereby ensuring traceability and mitigating the risk of data tampering.

• Each transaction encompasses energy consumption metrics, facilitating the analysis of usage patterns by AI models and enabling the refinement of optimization strategies.

5.2.3 AI-Blockchain Hybrid for Energy Fraud Detection

• Artificial intelligence algorithms are employed to monitor blockchain energy transactions in real-time, facilitating the identification of anomalies or unauthorized power usage.

• This hybrid model serves to enhance security while simultaneously ensuring optimal energy efficiency.

5.3 Green Edge Computing in Internet of Things Networks

In order to advance energy efficiency, we propose a framework for Green Edge Computing that is driven by artificial intelligence, aimed at optimizing power consumption at the network's edge. [20]

5.3.1 Allocation of Edge Resources Utilizing Real-Time AI Techniques

AI models conduct an analysis of workload patterns at edge nodes, subsequently allocating computing resources in accordance with real-time demand. This minimizes idle power consumption and guarantees that only the necessary resources remain operational.

5.3.2 Adaptive Load Balancing for Energy Conservation

AI-driven traffic prediction algorithms facilitate the equitable distribution of workloads among various edge servers. This mitigates energy bottlenecks and diminishes the likelihood of excessive power consumption at an individual node.

5.3.3 Integration with Renewable Energy Sources

Edge nodes have the potential to be powered by renewable energy sources such as solar or wind, thereby decreasing dependence on conventional power grids. AI models are employed to forecast energy availability and subsequently modify workloads to optimize the use of renewable energy sources.

5.4 Expected Outcomes

By implementing the proposed AI and blockchain-based energy optimization model, we expect to achieve the following:

1. **30-50% Reduction in Network Power Consumption** – Through dynamic power allocation and intelligent traffic management.

2. **Enhanced QoS with Lower Energy Costs** – Ensuring ultra-low latency and high throughput while minimizing power wastage.

3. **Improved Security and Transparency in Energy Transactions** – Using blockchain for tamper-proof energy management.

4. **Scalability for 6G Networks** – Creating a foundation for quantum-assisted and self-healing network infrastructures.

6. Conclusion

6.1 Summary of Key Findings

The development of 5G networks has brought forth numerous innovations in wireless communication, such as ultra-reliable low-latency communication (URLLC), enhanced mobile broadband (eMBB), and massive Machine-Type Communication (mMTC). Nonetheless, with the increasing prevalence of connected devices and the rise of data-intensive applications, the issue of energy consumption within 5G networks has emerged as a significant concern. This study examined a range of techniques aimed at optimizing energy efficiency through QoS considerations and assessed their effects on network performance, scalability, and sustainability.

In this study, we conducted a comprehensive examination of current methodologies and emerging trends, revealing significant challenges related to power allocation, traffic load balancing, interference mitigation, and security within 5G networks. The findings of our study underscored the constraints associated with conventional static energy optimization techniques and emphasized the necessity for adaptive resource allocation driven by artificial intelligence. Furthermore, the investigation delved into the application of blockchain technology in decentralized energy management, positing it as a viable solution to improve transparency, security, and efficiency within the framework of network power distribution.

6.2 Contributions of the Proposed Model

This study presents a framework for energy optimization in 5G and future 6G networks, leveraging the integration of artificial intelligence and blockchain technology to tackle existing challenges. This model presents several significant contributions, including:

1. AI-Driven Adaptive Power Allocation: The implementation of Reinforcement Learning (RL) and Federated Learning (FL) methodologies to facilitate the dynamic optimization of power distribution in accordance with real-time traffic demand. The study focuses on the prediction of network congestion through the application of Deep Q-Learning (DQN) and Long Short-Term Memory (LSTM) models, aiming to minimize unnecessary energy consumption.

2. Blockchain-Enabled Secure Energy Transactions: The implementation of decentralized smart contracts serves to automate power allocation and mitigate unauthorized resource usage. The establishment of a blockchain-based energy ledger facilitates real-time monitoring and secure energy trading among network slices.

3. Edge Computing for Low-Power Data Processing: - The incorporation of AI-optimized resource allocation at edge nodes facilitates a reduction in latency while enhancing energy efficiency. The implementation of edge nodes powered by renewable energy sources is essential for establishing a sustainable 5G infrastructure.

4. Quantum-Assisted Energy Optimization for 6G Networks: - An investigation into Quantum Key Distribution (QKD) aimed at achieving ultra-secure and energy-efficient data transmission. The prospective application of molecular communication for the realization of low-power Internet of Things (IoT) networking in forthcoming developments.[21]

6.3 Expected Impact and Benefits

The implementation of the proposed model is expected to result in significant improvements in energy efficiency, network scalability, and QoS. Below are the anticipated benefits:

Metric	**Expected Improvement**
Network Power Consumption	30-50% reduction through AI-driven adaptive power allocation

Metric	Expected Improvement
QoS and User Experience	Enhanced latency, throughput, and reliability via optimized traffic management
Security and Transparency	Improved data integrity and fraud prevention using blockchain
Sustainability	Increased use of renewable energy sources and low-power computing
Scalability	Future-ready for 6G networks and massive IoT deployments

6.4 Challenges and Future Directions

The proposed framework for energy optimization, which integrates AI and blockchain technologies, demonstrates encouraging outcomes; however, numerous challenges persist that could hinder its large-scale implementation. The following challenges are identified:

1. **The Computational Complexity Associated with Artificial Intelligence Models:** Reinforcement learning and deep learning algorithms necessitate substantial computational resources to facilitate real-time decision-making processes. The optimization of artificial intelligence models for low-power edge devices continues to be an area of active investigation.

2. **Scalability of Blockchain-Based Energy Management:** The decentralized nature of blockchain systems, although providing enhanced security, results in increased latency and storage overheads. Future investigations ought to concentrate on the development of lightweight blockchain architectures that reduce computational demands.

3. **Interoperability Between 5G and Emerging 6G Technologies:** The transition to 6G networks necessitates the seamless integration of artificial intelligence, quantum communications, and blockchain technologies. Further investigation is required to examine the potential of self-healing AI models in improving network resilience.

4. **Real-World Deployment and Standardization:** The implementation of AI-driven energy optimization, although demonstrating substantial advancements in controlled settings, encounters various challenges in actual deployment, including regulatory hurdles, hardware limitations, and issues related to standardization. Collaboration among academic institutions, industry stakeholders, and policymakers is essential for the development of standardized frameworks aimed at facilitating AI-driven energy-efficient networking.

6.5 Conclusion and Closing Remarks

This investigation offers a comprehensive examination of quality of service-oriented energy optimization within fifth-generation networks, emphasizing artificial intelligence-based power distribution, blockchain-enabled energy security, and environmentally sustainable edge computing solutions. This study further investigates the emerging trends within 6G networks, specifically focusing on quantum-assisted communication and molecular energy-efficient networking. The convergence of artificial intelligence, blockchain technology, and edge computing offers a revolutionary methodology for realizing energy-efficient, high-performance, and scalable networks in the context of 5G and 6G systems. In future endeavours, it is imperative to concentrate on the advancement of hybrid AI-blockchain frameworks, the improvement of security measures in decentralized energy trading, and the innovation of ultra-low power communication technologies tailored for next-generation wireless systems. Addressing these challenges will enable future wireless networks to establish a sustainable, intelligent, and energy-efficient communication ecosystem, thereby facilitating the global expansion of 5G and ensuring a successful transition to 6G.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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