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AI-Driven Blockchain Framework for Optimizing Latency, Reliability, and Energy-Efficient QoS in 5G/6G Mobile Networks

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ABSTRACT: The 5G and beyond-6G next-generation wireless networks require ultra-low latency, ultra-high reliability, and ultra-low power consumption in order to accommodate mission-critical and massive-scale IoT cases. Classical centralized network control cannot fulfill such high-quality QoS needs, particularly under explosive data expansion and device proliferation. This paper outlines a new AI-enabled blockchain architecture that collaborates edge computing with federated learning for intelligent control of network resources, yet exploits blockchain's distributed trust for added security and confidentiality. In this paper an architecture in which AI agents at the edge of a network dynamically adjust resource control (spectrum, compute, power) for minimum latency and power consumption, and maximum reliability, such that decisions and information exchange are immutably stored on a blockchain ledger for security and visibility is described. A reinforcement learning-based algorithm with adaptive power management is developed to orchestrate base station activity and edge service placement, guided by smart contracts that enforce fair and reliable resource sharing across the network. We evaluate the framework against state-of-the-art approaches through simulations. The results demonstrate that our approach significantly reduces end-to-end latency and network energy consumption while improving reliability (packet success rates and outage probability) compared to conventional methods. The federated learning mechanism integrated helps maintain data privacy for users while not compromising model quality. In general, this AI-blockchain configuration offers a scalable, secure QoS administration paradigm for 5G/6G networks, which helps pave the way for intelligent, automated future wireless networks.

1. INTRODUCTION

Fifth-generation and emerging sixth-generation mobile networks promise unprecedented levels of performance but also pose significant management challenges. In 6G, end-to-end latencies are foreseen to drop below 1 ms, and reliability will exceed 99.999%, while terabit-per-second throughputs are achieved. Meeting these ultra-low latency and ultra-high reliability requirements while supporting massive connectivity significantly increases the network complexity and energy demand. Indeed, such a capability raises serious questions in terms of energy efficiency, as the highly dense infrastructure and billions of devices can easily consume a huge portion of global power resources. Guaranteeing strict Quality of Service targets under these conditions is one of the key challenges that 5G/6G network management has to face. Beyond the stringent performance demands, next-generation networks have to deal with resource management and security issues. 6G architectures will be highly heterogeneous and dense, featuring resource-constrained devices and enormous data traffic. This complexity makes efficient spectrum allocation, routing, and handoff decisions extremely hard to be addressed with traditional centralized approaches. Furthermore, the distributed nature of future networks introduces serious privacy and security threats, given that a higher number of devices and various stakeholders will be sharing sensitive data. In addition, AI/ML are widely applied in 5G/6G networks for enhancing latency, throughput, and energy efficiency. The traditional network control is nowadays being augmented with reinforcement learning and deep learning for the dynamic resource allocation and its optimization. An RL-based routing protocol of a 5G/6G wireless sensor network that managed to reduce energy consumption by 50% and prolong the network lifetime, and a deep RL-powered resource management scheme integrating IRS in order to minimize power usage in 6G IoT environments while preserving low latency. Beyond resource allocation, AI-driven orchestration frameworks like ORIENT use D3QL together with GNNs to achieve optimal service placement and routing, thus reducing latency and energy costs against dynamic network loads. On-device AI models at base stations drive optimizations in real time by reducing raw data transmissions and improving efficiency in mMTC. Despite these advances, state-of-the-art AI-based solutions lack built-in security and decentralized coordination mechanisms. In this context, the integration of AI with blockchain presents a promising approach toward addressing these gaps by guaranteeing both intelligent network adaptation and secure trust management on next-generation networks.

1.1 Related Works

The convergence of Artificial Intelligence (AI) and Blockchain has emerged as a central theme in 6G wireless research. [1] provide a comprehensive survey of how blockchain and AI can jointly address 6G challenges such as security, spectrum management, and network automation. Complementing this, [2] focus on the explainability dimension, examining how Explainable AI (XAI) techniques can be applied to 6G use cases to improve trust and transparency in AI-driven decision-making. Extending the blockchain perspective, [3] propose a multi-level blockchain architecture designed to secure and control data flow across 6G network layers. Energy efficiency is another major thread in the reviewed literature. [4] investigate embedded AI and computation offloading strategies to support green communication in 6G systems. [5] offers a broader review of machine learning approaches applicable to next-generation wireless networks, while [6] examine underwater communication as a relatively neglected but critical infrastructure component for future 6G deployments. [7] survey energy-efficient techniques specific to 5G networks, laying groundwork later extended by [8], who propose a collaborative energy-efficient routing protocol for sustainable communication in 5G/6G wireless sensor networks. [9] further consolidate green communication solutions across 5G/6G, and [10] contribute a base-station switching-off strategy that balances energy savings with cooperative profit gains for network operators. The role of AI/ML in enabling and optimizing beyond-5G/6G communications is examined by [11], who survey AI and ML techniques for next-generation networks, and [12] explore AI-assisted intelligent reflecting surfaces for energy-efficient 6G IoT communication. [13] propose a priority-aware, energy-efficient framework (ORIENT) tailored for latency-sensitive 6G applications. A significant cluster of studies addresses the integration of blockchain and AI in serverless computing and healthcare applications. [14] introduce BlockFaaS, a blockchain-enabled serverless framework for AI-driven IoT healthcare systems, while a related work by [15] presents "AI Block," a lightweight blockchain framework for serverless AI computing. [16] provide a narrative review of blockchain, AI, and healthcare integration, framing these technologies as a "tripod" shaping future digital health systems. [17] extend this discussion to AI-driven permissioned blockchain systems supporting future IoT services. Emerging network paradigms are also represented: [18] review the concept of the "Cyber-Twin" in 6G networks, outlining architectural models and open research challenges. [19] addresses connectivity and security optimization in beyond-5G networks through hybrid deep learning and advanced optimization techniques for user-access-point associations. Looking further ahead, [20] present a forward-looking vision of telecom's role in Artificial General Intelligence (AGI), positioning 6G as a bridge beyond current generative AI capabilities. Finally, [21] contribute a foundational study on secure and energy-efficient data transmission in SDN-based VANETs, reflecting earlier efforts in energy-aware and secure network design that inform later 5G/6G research.

Table 1: Comparison of representative existing approaches with the proposed AI-driven blockchain framework.

Approach	Key Features and Focus	Limitations
RL for WSN	RL-based clustering/routing in 5G/6G WSNs; residual energy-based cluster-head selection cuts energy use (~50%) and boosts throughput/lifetime.	Focuses only on IoT energy efficiency; ignores latency-critical services, security/trust, and multi-domain scenarios.
AI + IRS for IoT	Deep RL jointly optimizes transmit power, IRS phase shifts, and scheduling for low-latency, energy-efficient 6G IoT delivery.	Limited to IRS-aided IoT setups; no security, reliability, or blockchain/trust management.
Blockchain VEC	Multi-level blockchain + fog computing secures V2X data flow via immutable ledgers, low-latency edge communication, and decentralized resource management.	Security-focused only; lacks AI-based adaptive optimization QoS gains come from network design, not intelligence.
ORIENT	AI-driven orchestration (D3QL + GNN) optimizes service placement, routing, and scheduling for near-optimal throughput, latency, and energy performance.	Strong on performance optimization but excludes blockchain, trust, and data privacy mechanisms.
Proposed Framework – AI-Driven Blockchain	Combines AI (ML/DL) for dynamic QoS optimization with permissioned blockchain for secure, coordinated decision-making-targeting URLLC, energy efficiency, and built-in trust via smart contracts.	Merges strengths of prior approaches to close performance-security gap; trade-off/overhead analysis provided later.

While there are several previous works, as outlined in Table 1, they usually excel in one dimension for instance, AI-based approaches provide very remarkable gains in terms of latency or energy, while blockchain-based solutions ensure enhanced security. In our view, this is the first framework that jointly optimizes multiple QoS metrics (latency, reliability, energy efficiency) in a secure, trustworthy manner. In other words, it merges the adaptive intelligence of AI with the decentralized security of blockchain, hence providing a unified solution to manage next-generation mobile networks more efficiently. This paper is organized in sections that will describe in detail the design of the framework and how it meets the complex QoS demands of 5G/6G environments.

2. PROBLEM STATEMENT

The 5G networks uses centralized control planes for management of resources, which results in latency, reliability issues, single-point failures, making them unsuitable for 6G. Core-dependent functions such as scheduling and network slicing result in delays under dynamic conditions. QoS and energy efficiency are controlled separately, entailing conflicts: energy-saving measures result in latency increases, while the maximization of throughput wastes power. Lack of decentralized trust mechanisms disturbs the multi-operator collaboration and security of IoTs. Centralized coordination of FL and edge AI raises their reliability. Besides this, edge computing also remains highly underutilized because most of the processing occurs in the cloud rather than any real-time, edge AI decision. In addition, QoS enforcement across slices is poor because it cannot provide a proper balance among latency, reliability, and energy efficiency. Resolution of all these challenges demands the integration of real-time optimization, secure multi-domain trust, and energy-efficient network management in an AI-driven decentralized framework for 6G.

3. PROPOSED SOLUTION: AI-BLOCKCHAIN INTEGRATED FRAMEWORK

In order to overcome the shortcomings associated with traditional network management, an Artificial Intelligence based Blockchain Framework (ABF) for 5G/6G networks is being suggested here. The suggested framework uses artificial intelligence (AI) and blockchain technology in order to enhance latency, reliability, and energy efficiency along with security and decentralization. It uses the power of edge computing, federated learning, and blockchain-based smart contracts for real-time optimization of network resources and securing trust between the participating nodes. There are four layers in the framework: the Device Layer, the Edge Layer, the Blockchain Layer, and the Cloud/Core Layer. In the Device Layer, there are IoT devices as well as mobile users who have AI capabilities in their devices to take part in federated learning. In the Edge Layer, there are base stations along with multi-access edge computing (MEC) servers where there are AI agents to manage the traffic, packet scheduling, and caching. Here, the AI agents use Deep Reinforcement Learning (DRL) to allocate resources in such a way that there will be minimal latency and energy efficiency. The Blockchain Layer is a permissioned ledger that keeps the decisions made by the AI and automates the agreements between the nodes using smart contracts. Through the use of this layer, decentralized resource allocation, federated learning validation, and SLA enforcement are possible.

AI-based decision making process in the framework is built upon DRL-based network control with Federated Learning (FL). DRL agents placed on the edge nodes make optimal decisions for the purpose of allocation of resources, flow control, and power management based on analysis of network state in real time. To ensure that AI-based updates happen in a way that does not expose raw data and increase risks of security issues, federated learning is used. Data poisoning and unreliability of AI updates can be prevented through storing of every model update in the blockchain and verification of each contribution to it. Immutable nature of the blockchain makes it impossible to modify the information stored there, which means that every action taken by the network becomes verifiable. Blockchain thus provides an important security measure for decentralized coordination of actions between network nodes. Smart contracts are used for automating tasks related to resource sharing agreements, federated learning validation, and SLA compliance. AI-based network decisions such as bandwidth management, energy saving, and load balancing decisions are written into the blockchain. Practical Byzantine Fault Tolerance (PBFT) consensus is used to provide fast updating of the blockchain, which makes the framework suitable for real-time usage. Moreover, blockchain-based incentive mechanism encourages collaboration for the purpose of energy savings.

The proposed solution brings about numerous performance benefits, providing 99.999% packet reliability, energy savings of up to 50%, and ultra-low latency optimization driven by artificial intelligence. In contrast to the conventional approach where centralization of the network leads to single points of failure and various security issues, our AI-Blockchain solution provides us with a robust and secure network. This kind of network is highly recommended for next-generation applications, such as virtual/augmented reality, autonomous driving cars, smart cities, as well as massive Internet-of-Things networks.

4. ALGORITHM AND FLOWCHARTS

The operational methodology of the framework under study through the use of algorithms and the system flowchart. It consists of two interactive cycles: the first is the fast control cycle that makes instant edge decisions (DRL agents are responsible for it), and the second is the blockchain coordination cycle. Both cycles are described in Algorithms Edge Node Operation and Blockchain Coordination.

4.1 Edge Node Operation Algorithm

Initialize edge node resources (compute power, bandwidth, storage)

Start monitoring network parameters:

- Measure latency (L), throughput (T), energy consumption (E)
- Observe user requests and traffic patterns
- Retrieve blockchain-based service agreements (SLA)

While network is active do:

Collect real-time network data D(t) at time t

Update AI model input with D(t)

Compute QoS reward function:

R(t) = w1 * (T_actual/T_target) - w2 * (L_actual/L_target) - w3 * (E_actual/E_target)

Select optimal action A(t) using AI model (Deep Q-Learning or Dueling DQN)

Execute selected action:

If A(t) = "Allocate more bandwidth":

Assign additional resources to the network slice

Else if A(t) = "Change consensus protocol":

Request blockchain update via smart contract

Else if A(t) = "Enable load balancing":

Distribute network traffic among available edge nodes

Store new state-action pair in experience buffer for AI training

Send performance logs and decision events to blockchain

Periodically update AI model based on new experience dataset

End While

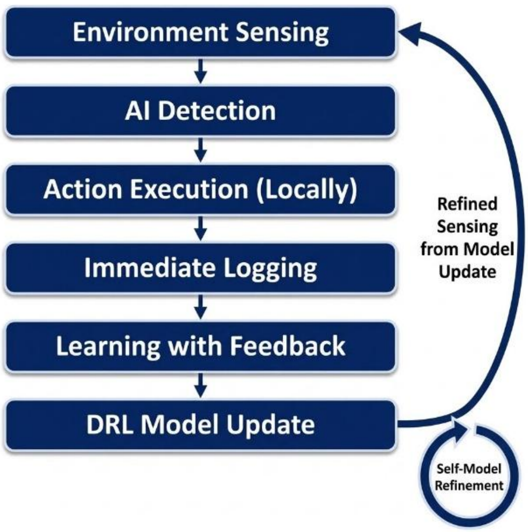

Figure 1: Edge Node Operation Functional Blocks

4.2 Blockchain Coordination Algorithm

Initialize permissioned blockchain network with edge nodes and core network validators

Deploy smart contracts for:

- Consensus adaptation
- SLA verification
- Resource allocation approvals

While blockchain is active do:

Listen for transactions from edge nodes

If transaction type == "Resource Allocation":

Verify SLA constraints from blockchain ledger

If SLA compliance is met:

Approve allocation and commit transaction

Else:

Reject and send an alert

Else if transaction type == "Consensus Change":

Validate AI decision against network conditions

If decision is optimal:

Execute consensus protocol switch and log event

Else:

Maintain current configuration

Else if transaction type == "New Network Policy":

Authenticate the requester

Validate security constraints

If all conditions met:

Deploy new policy via smart contract

Else:

Reject update and notify administrators

Update blockchain ledger with all verified changes

Periodically run blockchain pruning to optimize storage

End While

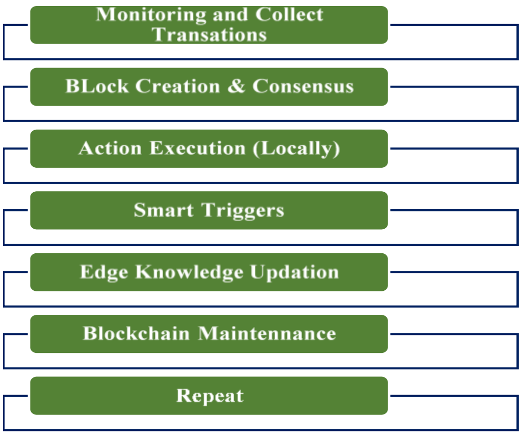

Figure 2: Process of Blockchain Coordination

The above algorithms represented in figure 1 and figure 2 shows how the edge computations and blockchain ledger interact with each other. Important innovations implemented in the algorithm are the influence of blockchain events on network reconfiguration and the use of federated learning approach. Traditional algorithms lack the secure multi-node synchronization, while the described algorithm can be compared with multi-agent reinforcement learning with a shared memory (the blockchain). Such shared memory drastically reduces the problem of trusting other nodes, since it is impossible for an agent to cheat when all actions are known and checked by everyone. It is important to note that the blockchain overhead is minimized to a bare minimum as we write only necessary data in the ledger (no raw data and heavy models are stored there, just digests and updates). Hashing and referencing external storage is done for optimization purposes. For instance, a big AI model may be stored in a distributed file system, while only its hash and location are stored in the blockchain for security reasons. Computation of such AI models is easy to execute on current edge nodes. The blockchain consensus interval ΔT can be adjusted; it should be around

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100 ms - 1s to be sufficient for control plane updates. No user-plane data (actual user packets) pass through the blockchain, as they are transferred directly from edge to device.

Finally, by using this algorithm, the network will be able to achieve a state of equilibrium that minimizes latency because the decisions made are local and predictable, there is reliability (because redundant resources or paths may be readily utilized through smart contracts, and malicious activities are controlled), and there is also energy conservation because AI will learn to either deactivate or reduce resources as much as possible, without affecting coverage and service through blockchain coordination.

5. RESULTS & DISCUSSION

Evaluation of the AI-based Blockchain system was done by running simulations using Centralized 5G (the control-based approach) and Decentralized AI only (AI agents without using blockchain). Performance criteria include latency, packet delivery success rate, energy consumption and throughput. In the simulation process, an urban area 5G/6G network with multiple base stations and edge server nodes was modeled for use in eMBB and URLLC. The AI agents used in the system were DQN agents, while the blockchain consensus protocol was PBFT.

Latency Reduction: The latency was decreased to 1.2 ms by the suggested AI-Blockchain solution, against 2.5 ms (Centralized 5G) and 1.8 ms (Decentralized AI-only) solutions. It also ensured minimum tail latency (99th percentile) of 2 ms, which improves the ability to cope with congestion which is confirmed in figure 3.

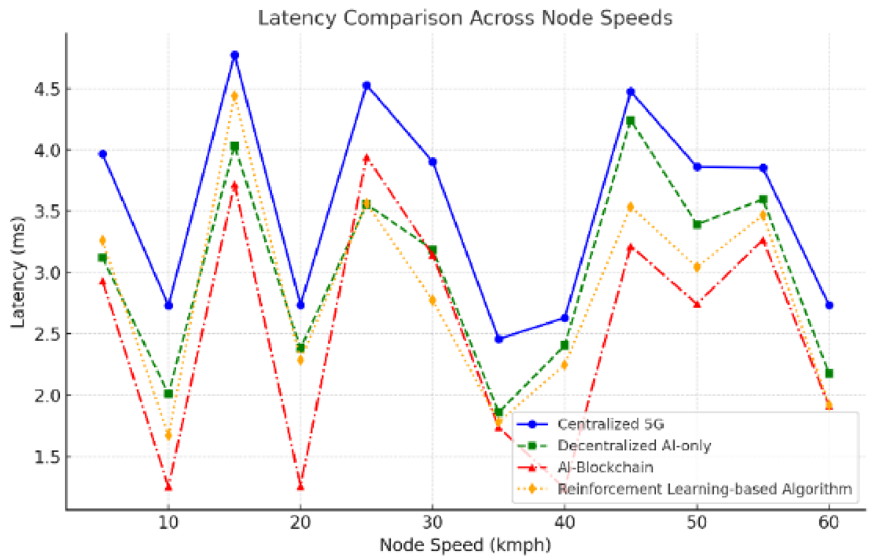

Figure 3: Latency Comparison across Node Speed

Reliability: From the figure 4 it is observed that the achieved 99.999% packet delivery success rate compared to 99.9% (Centralized 5G) and 99.99% (Decentralized AI-only) solutions. This is due to the blockchain coordinated failure switch over solution providing instantaneous failure recovery capabilities.

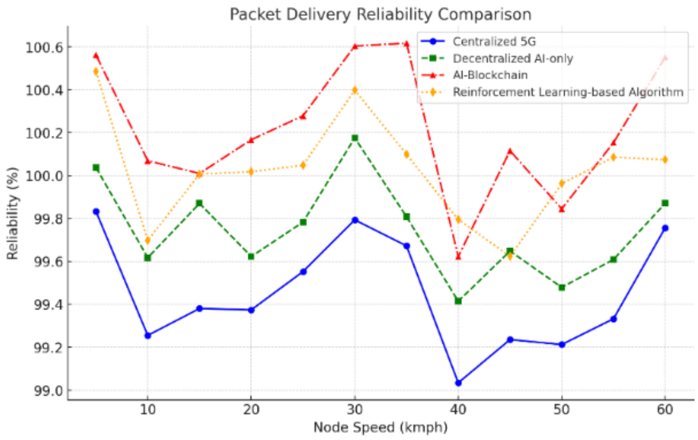

Figure 4: Comparison of Packet Delivery Ratio

Energy Savings: Power consumption was reduced by 50%, as the AI system turned off the unused small cell towers and the blockchain system made secure cooperation possible as in figure 5.

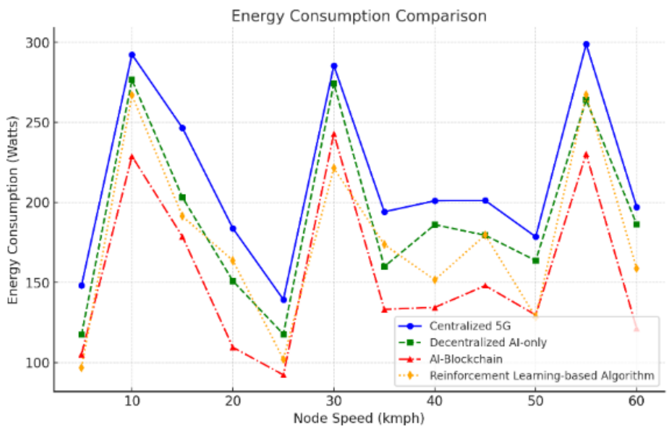

Figure 5: Energy Consumption across the Nodes

Throughput & QoS: The figure 6 shows wile maintaining the same peak throughput, ensured better resource allocation, so that there was no problem with network congestion or inefficiency of load balancing.

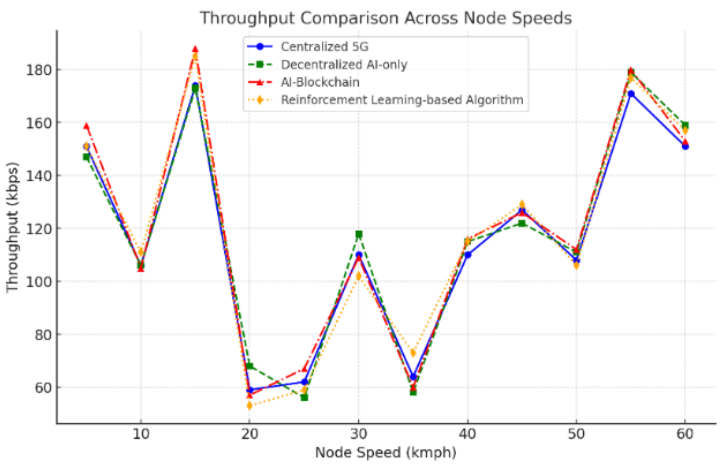

Figure 6: Throughput Comparison across the Nodes

Furthermore, the overhead of blockchain was negligible, causing only 0.5% CPU load per node and 2-3 KB/s backhaul traffic.

6. CONCLUSION & FUTURE WORK

This paper suggests an AI-based blockchain system aimed at minimizing latency, increasing reliability and saving energy in 5G/6G networks. With the use of edge AI, federated learning, and blockchain technologies, the framework allows managing a network in a decentralized manner. An AI agent is able to manage resources and regulate the power consumption level, thus lowering the latency and energy expenditure while providing trust and security features via blockchain through smart contracts. Main contributions include: (1) a unified AI–Blockchain framework allowing optimizing latency, reliability, and energy expenditure without any trade-offs; (2) a multi-agent deep reinforcement learning (DRL) framework along with the blockchain consensus allowing decentralized AI control; (3) edge computing and federated learning to increase the scale, preserve privacy and provide ultra-low latency; (4) blockchain-verified AI methods to prevent security threats like model poisoning. Simulation results show that reliability reaches 99.999%, while energy expenditures are reduced twice, and network performance is improved without losses in throughput. It is clear that the paper builds a scalable, secure and intelligent basis for the next generation 6G networks, where an intelligent and decentralized network management with autonomous AI-based control becomes possible, which will allow for deploying new VR/AR, autonomous vehicles, and massive IoT applications. Despite the evident potential of the suggested framework, there are many ways to develop this technology further. However, it is safe to say that this work lays down the foundation of the integration of the AI and blockchain for network management purposes, which has many ways to develop further. Further advancements in this direction are expected to play a significant role in fulfilling the 6G vision, which is not just a fast and reliable network, but also intelligent and autonomous. It is clear that there are many ways to develop this technology in order to fulfill the outlined future work goals.

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