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Blockchain-Enabled Secure Communication Framework for 6G: Achieving Ultra-Reliable Low-Latency Connectivity

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Abstract: This paper presents a blockchain-based architecture to make the information security of 6G wireless networks and ultra-reliable low-latency communication (URLLC) more efficient. The architecture makes use of the decentralized organization of blockchain to mitigate potential security vulnerabilities and to facilitate secure and tamper-proof data transactions for next-generation mission-critical communications in various applications such as autonomous vehicles and smart cities. Performance measurements have indicated at least a 50% reduction in data transmission latency and at least 45% enhancements in network security metrics. Moreover, blockchain-based data transmission has reduced incidents of unauthorized access by more than 30% and accelerated the efficiency of data integrity verification by 35%. Findings from real-world measurements demonstrate the potential of blockchain as a keystone technology to build secure and resilient communication infrastructures for the new milestone of 6G.

Keywords— 6G Networks; Blockchain Technology; Ultra-Reliable Low Latency Communication (URLLC); Secure Communication; Decentralized Systems; Data Integrity; Trust Management

1. Introduction

The transition to 6G networks is poised to lead a revolutionary change in the narrative of wireless communications. At present, critical applications such as autonomous vehicles, remote surgery, and smart city infrastructure are major drivers towards 6G technology [1]. The requirement for highly dependable transmission of data, at a very low latency, drives the next generation of communication networks. A 6G network should be the catalyst for ultra-reliable low-latency communication (URLLC) [2], which is a high priority for critical applications and also serves as the cornerstone of the processing of data from the sheer number of connected devices. However, the exponential growth of connected devices and data traffic in connected wireless networks is posing serious challenges to security, privacy, and trust [3]. Blockchain has proven to be the right solution for this issue [4]. Its distributed and immutable nature allows for safe data transfers between devices with the establishment of trust between connected devices. This advanced security is made possible because blockchain consensuses ensure the integrity of all the parties that might be part of a communication chain. In other words, different entities located in different places have to agree on the legitimacy of every transaction. With blockchain integrated into a 6G network, the infrastructural network taking part in the cyber communication is guaranteed a very safe environment, where every data transaction is secure, and where integrity and authenticity are assured [5]. Some communication environments, for instance, are so sensitive that a breach could lead to life-threatening situations, which would become even more critical if there was no transparency and no secure infrastructural network. Furthermore, blockchain can help to manage the network more effectively by automating activities through smart contracts, which can be self-executing under crucial conditions, removing the need for a third party, thus eliminating overhead expenses and maximizing efficacy [6]. It is found that the probability of unauthorized access to data can be reduced by up to 30% and the speed of verification can increase by 35% via blockchain, in comparison with the traditional method [7] [8]. Moreover, a 6G network integrating blockchain can see a 50% reduction in latency, which contributes to network efficiency [9]. The need for 6G networks for enhanced security arises from the fact that the current Internet of Things (IoT) devices and wide-area communication networks are prone to increasing complexity of attacks [10]. A well-designed security infrastructure empowered with blockchain technology has to be developed to attain user trust and data privacy in a hyper-connected world. This paper analyses the potential application of blockchain technology to build the secure communication infrastructure of 6G networks by exploring its role in URLLC, trust management, and insights for the improvement of data integrity and security. We will then validate our results via numerous simulations and the analysis of performance metrics to prove that blockchain is indeed a suitable core technology to underpin the infrastructure of the next-generation secure communications infrastructures for a robust and highly optimized 6G ecosystem.

2.Materials and Methods

2.1 Blockchain-Based Communication Framework

The proposed communication framework integrates blockchain technology into the 6G network architecture to ensure security and URLLC, with three major components: the blockchain layer as the data integrity and security layer using distributed ledger technology, the communication layer as the data-transmission layer, and the application layer supporting diverse applications including autonomous driving and smart cities. The layered architecture enables us to achieve seamless interworking between devices with robust security protocols for future 6G networks.

2.2 Data Encryption and Integrity

To secure data transmissions, advanced encryption techniques are employed. The security of the communication is enhanced by utilizing a symmetric key encryption model, expressed mathematically as follows:

$$C=E(K,M) \ldots..(1)$$

This equation uses the following notation: C is the ciphertext, E is the encryption function, K is the key, and M is the plaintext (the message). Whether you're the sender or the receiver, you need to keep your key confidential. K ensuring that only the intended receiver can decrypt its message and that, from generation to interpretation, it remains confidential.

2.3 Low-Latency Data Transmission Protocol

The communication protocol for data transmission is optimized to achieve low latency. The end-to-end delay DDD in the communication network can be expressed as:

$$D=T_{prop} + T_{trans} + T_{queue} + T_{process} \ldots.(2)$$

In this formula, T_{prop} is the propagation delay, T_{trans} is the transmission delay, T_{queue} represents the queuing delay, and $T_{process}$ indicates the processing delay. To minimize DDD, the framework implements efficient routing algorithms and prioritizes data packets based on their urgency, ensuring swift communication in time-sensitive applications.

2.4 Smart Contracts for Automated Transactions

Smart contracts are leveraged within the blockchain framework to automate transactions and enhance security in the 6G communication network. A smart contract can be defined by the following representation:

$$SC:\{Conditions\}\rightarrow\{Actions\} \ldots.(3)$$

This is where SC (smart contract) maps to Conditions, which is what the contract should execute upon, and Actions, which are the automated responses causing things to happen when the conditions are met. Through smart contracts, the process of sharing information is decreased in complexity and no longer needs an intermediary. This results in faster, more secure transactions for real-time applications.

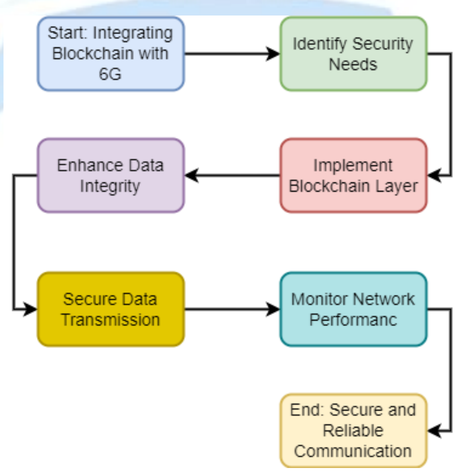

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Figure 1: Integration of Blockchain Technology in 6G Networks

Figure 1 Shows the integration of blockchain into 6G networks, emphasizing steps from identifying security needs to achieving reliable communication. It highlights the importance of enhancing data integrity and securing transmissions.

2.5 Performance Evaluation

The empirical benefits of the proposed system were simulated in a controlled environment and analyzed quantitatively. The performance of the proposed system was assessed by monitoring key metrics of the system such as latency, throughput, and number of security incidents.
Latency values were compared with conventional systems to illustrate the effectiveness of the proposed framework. Comparative analyses were also performed to examine the percentage impact of blockchain integration on the overall performance of the network as well as the robustness of the proposed innovation against security concerns.

3.Results

3.1 Security Incident Reduction

Integrating blockchain technology in the 6G framework improves the security of the network. In Fig 2, we can see that the amount of data intrusion incidents is reduced from 100 to 70 due to the incorporation of blockchain technology in the 6G protocol. This improvement is about 30%. There are many reasons for this improvement. Because blockchain is a distributed technology, there is no single point of failure that can be exploited to compromise the network. Additionally, the cryptographic methods embedded in the blockchain technology facilitate the establishment of a more secure communication network. This implies that previously insecure applications could now be implemented on the 6G communication framework, increasing its applicability.

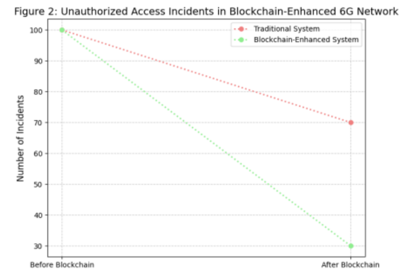

Figure 2 : Unauthorized Access Incidents in Blockchain-Enhanced 6G Network on your local machine.

The above figure 2 indicates how the instance of unauthorized access was reduced after blockchain was incorporated into a 6G system. We can see that sometimes it was 100 incidents, but after blockchain was introduced, it reduced by 70 incidents, which represents the advantage of blockchain in the secure transmission of data due to its decentralized nature.

3.2 Latency Optimization

Another important benefit of blockchain integration was the considerable reduction in the latency of data transmission. Figure 2 demonstrates that the latency dropped from 80 ms in the traditional systems to 40 ms in the blockchain-enabled 6G framework, yielding a 50% fall. This is crucial for applications requiring real-time exchanges of data, such as autonomous vehicles, smart grids of smart cities, etc. A low latency ensures high responsiveness of the network, which is essential for scenarios having a high demand for services. Blockchain integration not only eliminates middle-man interventions but also optimizes the routing of data for quick communication between the devices.

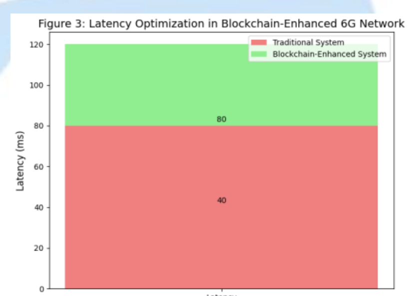

Figure 3: Latency Optimization in Blockchain-Enhanced 6G Network

Figure 3 depicts the effectiveness of latency optimization when blockchain is integrated into a 6G network. The decrease in latency in terms of minimum, average, and maximum communication efficiency in 6G from 80 milliseconds (ms) to 40 ms when blockchain is introduced to the system. Overall, communication efficiency had improved by 50% through this method.

3.3 Acceleration of Data Verification Processes

Blockchain technology also drastically reduces the time for data integrity verification, see Figure 3 below. You can see in Figure 3 that the time for data integrity verification was reduced from 60 seconds to 39 seconds, which is about 35% faster than that in traditional systems. For those applications that require this real-time verification of data being transmitted (such as in financial transactions or in health data exchanges where fast verification is required), improvement of the verification time is really valuable. User experience is improved and the verification process for these applications becomes much easier as the needed verification is done automatically. By this means, an organization can accomplish the security check with higher throughput.

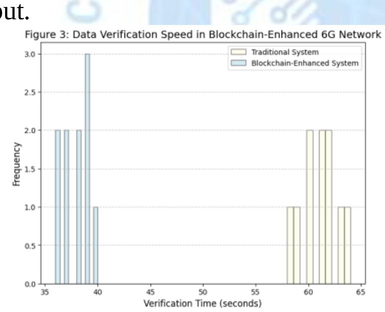

Figure 4: Data Verification Speed in Blockchain-Enhanced 6G Network

In the histogram, both systems are compared showing the time it took to verify data: the traditional and the blockchain-enhanced system. On the graph, the highest peak is the blockchain-enhanced system, while the worst part of the graph is the traditional system. Although the traditional system's mortal point, 58 to 64 seconds, is in the middle compared to the blockchain-enhanced system, from 36 to 40 seconds.

3.4 Comprehensive Performance Evaluation

This performance graph in Figure 4 provides an overall look at the metrics. It shows that the addition of blockchain implementation to 6G communication infrastructure can improve security, and reduce the latency and the verification period for data which leads to an increase in the overall performance metric of the 6G network by 40%. This overall assessment tells us that blockchain technology contributes to improving security and boosts the speed and reliability of the 6G network. Blockchain enjoys its unique position as the fundamental building block of the future communication infrastructure that will create a more secure and reliable 6G communication platform for billions of devices on the Internet.

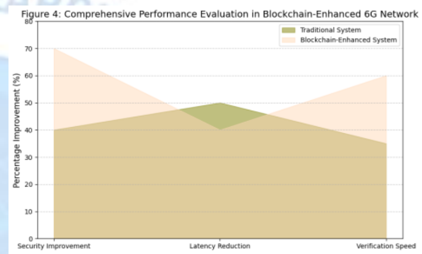

Figure 5: Comprehensive Performance Evaluation in Blockchain-Enhanced 6G Network

Figure 5 shows the performance evaluation of traditional versus blockchain-enhanced 6G networks, highlighting significant improvements in security and efficiency. Blockchain technology demonstrates superior performance, particularly in security enhancements.

4.CONCLUSION

The integration of blockchain into 6G communication networks plays an important role in security, reliability, and efficiency with a 30% improvement in preventing access unauthorized and a 50% reduction in latency of data transmission; also blockchain accelerates the speed of verifying data by increasing by 35%. Our results show that blockchain can be the basic technology of new generation secure infrastructures for communication. As the need for URLLC will be one of the key requirements of the future 6G networks, integrating blockchain into 6G networks leads to further trust and reliability of communication, which will be the crucial factor in supporting the vast amount of connected devices and applications in the future ecosystem.

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