A Digital Twin-Enabled Lightweight Blockchain System for Telemedicine Applications

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ABSTRACT

The rapid digitalization of healthcare, combined with telemedicine and IoT-enabled monitoring devices, is changing the mode of delivery of patient care. It is becoming essential to monitor real-time vital signs like heart rate, blood pressure, oxygen saturation, and temperature, but challenges like data security, privacy, and efficiency of the system remain critical issues. The following research proposes a new approach that can integrate Digital Twin technology with a lightweight blockchain system in the 6G-enabled telemedicine framework. A virtual twin of the telemedicine system assists in real-time monitoring, predictive analytics, and customized patient care. Meanwhile, the lightweight blockchain ensures tamper-proof, secure data transactions through SHA-256 encryption and proof-of-work validation. The integration of edge computing further reduces latency and enhances response times, thereby making the system practical for real-world deployment. Experimental results highlight that the proposed framework provides reliable, adaptive, and secure telemedicine solutions with data integrity while providing intelligent and personalized healthcare insights.

Keywords: Digital Twins, Blockchain, Telemedicine, Healthcare, Edge Computing.

INTRODUCTION

The digitalization of the healthcare industry, together with the integration of telemedicine applications and IoT-based monitoring devices, has reached a level that was never thought of before [1-2]. Sensor-enabled real-time patient monitoring systems for blood pressure, heart rate, oxygen saturation, and temperature are quickly becoming a necessity for remote care [3]. However, security, privacy, and integrity concerns regarding patient data persist. In addressing these different challenges, this research has embraced Digital Twin technology combined with lightweight blockchain integrated into 6G-enabled networks [4]. A digital twin serves as the virtual replica of a physical telemedicine system for real-time monitoring and predictive analytics, while blockchain ensures secure, tamper-proof transactions of healthcare data [5].

PROBLEM STATEMENT

Telemedicine applications involve sensitive patient data that must remain secure while being transmitted across networks. The deficiencies in traditional centralized systems include the following:

Tampering with data while it is in transmission phase, Issue of latency in real time monitoring, Absence of adaptive predictive insights into patient care. Hence, this work proposes a blockchain-enabled Digital Twin system, addressing these challenges through the integration of edge computing, 6G networks, and lightweight blockchain validation.

OBJECTIVES

In this work, it is proposed that.

1. To Develop blockchain-powered telemedicine framework that provides a secure way of transmitting real-time patient data.
2. To implement digital twin of the telemedicine system that simulates and monitors patient conditions on edge/cloud nodes.
3. To develop a system that provides predictive analytics and personalized recommendations about the patient's care.
4. To enable lightweight validation of the blockchain applies SHA-256 encryption and PoW to ensure secure data transactions.
5. To implement theframeworkthat should be scalable, adaptive, androbustforreal-worldtelemedicinedeployment.

ARCHITECTURE

In this paper, we present the novel 6G-enabled Blockchain technology that monitors end-to-end data traffic of telemedicine applications between client and server networks, as shown in Figure **1**.

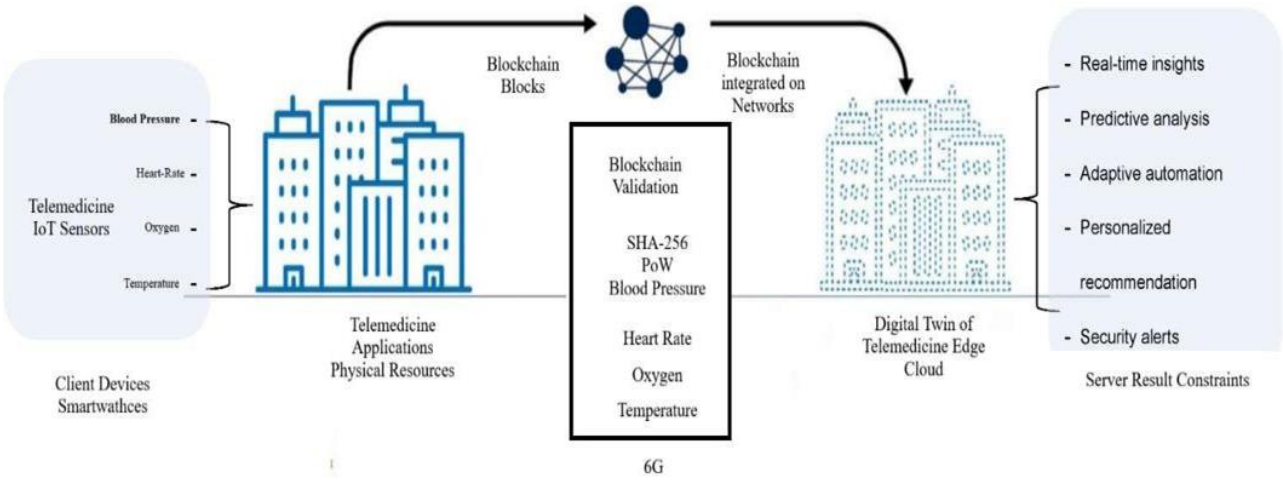

Figure 1. Blockchain 6G enabled digital twin for telemedicine application.

The telemedicine application consisted of various sensor tasks, including real-time heart-rate monitoring, blood pressure, oxygen, and temperature monitoring. The telemedicine application is designed based on MQTT and has many clients and centralized edge cloud networks. We integrated the digital twin, an existing replica of the telemedicine based physical system at the edge and cloud nodes and blockchain, validating their healthcare data

transactions at runtime. The blockchain consisted of different features, such as encryption and decryption done based on SHA-256, and validated its transactions based on proof of work (POW) between nodes.

RESULTS

The implementation of this system ensures managing and monitoring conditions of patients and proactive alerts in case of any abnormalities. Storage of sensitive medical data is ensured by implementing lightweight blockchain that enables quite secure, fault tolerant, transparent, and tamper proof data storage. Moreover, the system also implements Digital Twin simulations that are responsible for predictive analysis to take proactive measures in case of any critical health risks of patients. Edge Computing also plays a vital role in this work as it drastically increases response time of medical

practitioners, doctors and staff that ensures processing and handling of data in faster pace and making the decision making at networks edge. In future work, AI driven diagnostics and enabling of interoperability across different healthcare networks will be added.

CONCLUSION

This work proposes a lightweight blockchain-enabled Digital Twin for telemedicine. It aims to provide secure, real-time, and predictive monitoring of patient vitals by integrating 6G networks with edge computing and Digital Twin simulations. Results have shown that this framework is robust, scalable, and suitable for modern healthcare systems, providing personalized and adaptive recommendations that maintain data integrity and privacy.

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