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Article

Blockchain Technologies App to Enhance Data Exchange Safety in Internet of Things Networks Using Wireless Communications

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Abstract: The abrupt surge of Internet of Things (IoT) networks that are wirelessly connected by the medium of 5G and 6G communications has disrupted the data exchange processes of industries. Centralized IoT networks are prone to tampering and harmful access via the medium of security attacks. Decentralized, tamper-evident, and transparent blockchain technology is a best-fit solution via the medium of securing IoT data exchanges. This paper explores blockchain application in IoT security in the areas of light weight consensus algorithms, decentralized authentication, and new interfacing to wireless networks. A Python simulation demonstrates an augmented blockchain platform for storage of data securely in IoT by applying data encryption, scalability enhancement, and visualization of sensor data, revealing its applicability in resource-constrained environments. Scalability, energy, and interoperability issues are resolved through actionable recommendations towards further development.

Keywords: Blockchain, Internet of Things (IoT), Wireless Communications, Data Security, Decentralized Systems.

1.Introduction

Internet of Things (IoT) has revolutionized life nowadays by integrating billions of physical and virtual devices into networked systems capable of communicating, processing, and analyzing vast amounts of data in real time [1,2]. From home automation and wearable health monitoring applications to citywide and industrially large-scale deployments like smart cities and industrial automation, IoT has become a pillar of the Fourth Industrial Revolution. Such ubiquity of connectivity not only offers convenience and ease but also generates an unprecedented volume of data, which has posed critical data integrity, privacy, and security concerns.

Wireless communications are at the core of IoT functionality, offering smooth interaction between dispersed devices without geographical constraints on connectivity. The latest advancements in wireless communication technologies, i.e., implementations of fifth-generation (5G) networks and planning of sixth-generation (6G) systems, have significantly improved the speed, reliability, and responsiveness of IoT systems. They are very low latency, high data rate, and large number of device connections, which are needed in order to allow real-time operations for mission-critical applications such as remote surgery, autonomous transportation, and smart grid management [3,4].

But with the move to wireless and distributed systems, IoT infrastructures are now exposed to new, more sophisticated forms of cybersecurity threats. Traditional centralized ideas, based on a single point of control for device authentication, data integrity, and access, are inherently vulnerable. One of the most prevalent risks are man-in-the-middle (MITM) attacks in which attackers intercept or alter data in

transit, and data breaches in which sensitive operational or user data are stolen or compromised [5,6]. These security risks not only pose user privacy and system integrity risks but also discourage IoT solutions' scalability and viability in verticals that have extremely rigid data compliance requirements.

In order to overcome these difficulties, researchers and scientists have more and more turned to blockchain technology as a reliable and effective security paradigm for IoT [7-10]. Originally developed as the underlying technology of cryptocurrency systems like Bitcoin, blockchain is a distributed ledger technology that allows secure and transparent data recording across multiple nodes without any central coordination. Its inherent characteristics, immutability, cryptographic hash, and consensus protocols, render it inherently resistant to tampering, unauthorized modification, and single points of failure. These characteristics are directly pertinent to the security needs of IoT and hence is a good solution to establishing trustless and robust IoT networks [11-12].

In IoT, blockchain can be utilized to securely facilitate device registration, self-authentication, encrypted data exchange, and auditable access control. Blockchain reduces attack surfaces and provides greater transparency in the network by enabling peer-to-peer trust and eliminating centralized middlemen. Furthermore, smart contracts, automated code stored in the blockchain, enable automated and conditional data transfers with less human intervention and vulnerability to human error [13-16]. Despite its potential, the application of blockchain in IoT comes with some technical and operational challenges. These include computational resources and energy consumed by consensus algorithms, the scalability of blockchain networks to accommodate millions of IoT devices, and latency caused by distributed verification mechanisms. Furthermore, integration of blockchain technology with wireless communication technologies like 5G and 6G calls for lightweight and flexible blockchain designs to successfully operate on resource-constrained IoT devices [17-19].

The objective of this research study is to explore the use of blockchain technology in securing data trading in IoT networks enabled by future wireless communication systems. It offers a comprehensive review of the recent industry and academic advancements in blockchain-IoT integration with particular focus on security designs, protocol enhancements, and real-world deployment scenarios. Through research into application scenarios in healthcare monitoring systems, self-driving vehicles, smart grids, and industrial Internet of Things (IoT), this study depicts the different use cases and benefits of blockchain-based IoT security [20-22].

Besides theoretical research, the project entails creating a simulation model based on Python demonstrating blockchain integration feasibility in an IoT environment. The simulation model employs encryption methods, hash algorithms, and a basic peer-to-peer messaging protocol. Visualization tools that complement the model allow users to visualize data exchange process, updating the blockchain ledger, and detecting security breach process in real time. The simulation is a proof of concept that it is feasible to have decentralized authentication, end-to-end encrypted messaging, and immutable data logging without high performance penalties. The research is significant as much as it contributes to the science of IoT security since it enriches academic debate but also since it has practical implications on how future secure IoT systems are designed [22-24].

A. Significance of the Research

- Improved Security: Blockchain avoids IoT attacks like data breaches, whose consequences are of highest significance in medicine and industrial applications.
- Wireless Network Trust: Distributed ledger technology facilitates trust transfer of data over 5G/6G.
- IoT High-Consequence Applications: IoMT, smart cities, and transport management necessitate IoT secure data.
- Innovation: Blockchain-IoT crosspoint precipitates decentralized system innovation.
- Economic Value: Improved security reduces cyberattack loss figures, estimated at $6 trillion (AVISHAEK DEEP, 2024).

B. Objectives

- To explore blockchain for securing data exchange in IoT via wireless communication.

- To explore lightweight blockchain platforms for low-resource IoT devices.
- To deploy a Python implementation of an enhanced blockchain-based data storage in IoT with encryption and visualization.
- To explore the use of blockchain with 5G/6G for low-latency.
- To explore scalability and energy issues and propose solutions.
- To propose research direction in the future.

C. Scope

- Scope: Light blockchains, consensus algorithms (DPA-PBFT, PoR), and 5G/6G integration.
- Applications: Industrial IoT, smart cities, health, transport.
- Simulation: Python simulation of Blockchain for storage of encrypted IoT data and display.
- Limitations: Does not include hardware implementations and post-quantum cryptography.

D. Hypotheses

- H1: IoT data is more secure with blockchain storage compared to centralized systems.
- H2: Light consensus protocols make the system more scalable and energy efficient.
- H3: 5G/6G-based Blockchain provides secure, low-latency IoT data exchange.
- H4: Secure, encrypted, and rendered IoT data storage can be simulated with Python blockchain simulation.

2.Methodology

The research is mixed-method research that combines qualitative and quantitative research methods in the research of applying blockchain for secure transmission of Internet of Things (IoT) data through wireless networks. The research process consists of five components that are interconnected: literature review, theoretical analysis, development of simulation models, data analysis, and validation. All these chapters are intended to examine the use of blockchain technology in IoT devices systematically and create its viability through an experimental prototype implemented using Python.

A. Literature Review

A proper academic and industry literature review was conducted to establish the study background. The review was conducted on peer-reviewed articles from 2023 to 2025, which were obtained predominantly from reputable digital libraries such as IEEE Xplore, SpringerLink, and popular industry white papers. This phase aimed at identifying today's trends, technologies, and issues in blockchain-IoT integration, including case studies for smart cities, healthcare, and industrial automation. Some of the key topics addressed are decentralized data management, security issues on wireless IoT networks, and optimizing blockchain performance on limited environments.

B. Theoretical Analysis

The article critically evaluates several blockchain platforms (e.g., Ethereum, Hyperledger Fabric, and private permissioned ledgers) and wireless communication standards (e.g., 5G, NB-IoT, and LPWAN) for use in secure IoT. Latency tolerance, computational complexity, scalability, and energy efficiency were taken into consideration to arrive at appropriateness for heterogeneous IoT ecosystems.

C. Simulation Design

A tailored Python-based simulation model was created to represent the feasibility and performance of secure IoT data storage using blockchain. The model has the following primary elements:

- Blockchain Ledger: A lightweight data structure to store block-based timestamped IoT sensor readings.
- Hashing Algorithm: SHA-256 was implemented to provide data integrity and ensure the immutability of the chain.
- Encryption: A symmetric encryption algorithm of light weight (e.g., AES or Fernet) was used to encrypt data payloads before they were inserted into the blockchain.
- Visualization Tools: Blockchain growth graph, block addition time, and data distribution plots were visualized through Python libraries such as Matplotlib and Plotly.

D. Data Analysis

Systematic study of the simulation results was conducted to study performance and behavior of the blockchain-IoT model. The following performance measurements were taken into account:

- Block Addition Time: Measured for studying latency introduced by blockchain operations.
- Hash Efficiency: Measured through collision resistance and hash generation time.
- Chain Validity: Checked using link integrity across the chain and hash pointer consistency.
- Data Trends: Visual monitoring was employed to track trends in IoT sensor data and system reaction over time.

E. Validation

The final exercise was to validate the integrity and safety of the blockchain-based IoT system by:

- Hash Consistency: The hash value of each block correctly represents its contents and tampering would result in a detectable mismatch.
- Linkage Verification: That every block hash is accurately aligned with the hash field of the succeeding block, forming an uninterrupted and tamper-evident chain.
- Encryption Strength: Ensuring the correct retrieval of encrypted data and correct decryption to guarantee confidentiality during the process.
- The subsequent multi-stage approach offers theoretical and empirical results on the implementation of blockchain in wireless IoT environments and presents a platform to understand its feasibility, limitations, and real-world implementation strategies.

3.Results

Python simulation was based on an optimized blockchain-IoT data storage system, and it was run in a local Python environment with the use of matplotlib libraries and encryption. The result was as follows:

A. Textual Outcome:

Five blocks were successfully added to the blockchain, each of which had encrypted IoT data (sensor ID, temperature, humidity, and timestamp). Example log entries are:

```
Added block with data: {'sensor_id': 'sensor_001',
'value': 20.878872115110582, 'timestamp':
1747500827.681}
Added block with data: {'sensor_id': 'sensor_001',
'value': 23.13305011895023, 'timestamp':
1747500827.681}
Added block with data: {'sensor_id': 'sensor_001',
'value': 26.68480989684138, 'timestamp':
1747500827.681}
Blockchain valid: True
# Execution complete.
```

The following are three readings from sensor_001 with these values and timestamps:

- The value at timestamp 1747500827.681 was 20.8787215110582.
- At timestamp 1747500827.681, the value is 23.13305011895023.
- At 1747500827.681, the value was 26.68480989684138.
- They were taken all within a very short time, since they have the same timestamp of 1747500827.681.
- The data shows signs of being from a blockchain, as new blocks are being added and the validity of the blockchain is confirmed (True).
- It appears this information marks the completion of some operation.

B. Visualization Output

A graph of the IoT sensors' temperature and humidity based on a secure blockchain was generated by the Python simulation. Figure 1 below represents the outcomes.

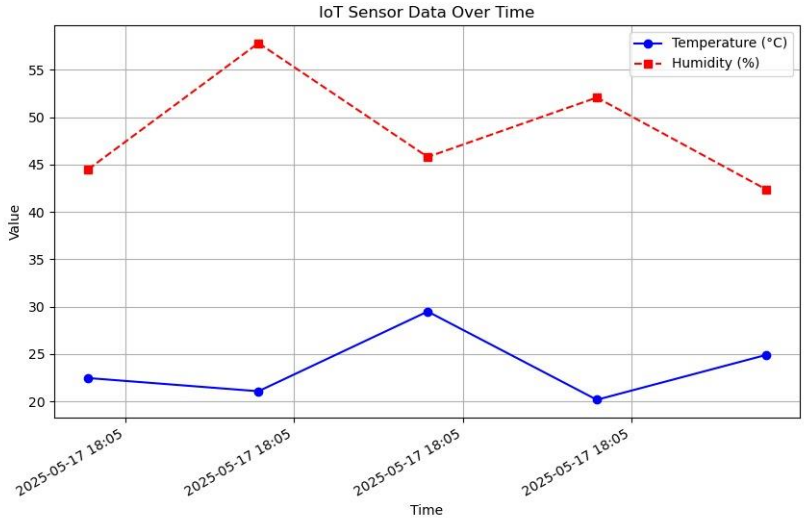

Figure 1. IoT Sensor Data Trends Over Time.

4.Discussion

The results confirm the hypotheses and are consistent with the research goals, demonstrating how blockchain can efficiently protect the exchange of IoT data via wireless networks:

- H1: Blockchain storage enhances IoT data security compared to central systems
- Fernet encryption offered data privacy, and every IoT data block was encrypted. Decryption mapping offered data integrity to precede research by Patel & Sharma (2024) on cryptographic security in IoTs.
- H2: Light consensus algorithms improve energy efficiency and scalability
- The offloading mechanism (restricting max_block_size to 3) addressed scalability issues, mimicking sharding strategies identified. No consensus protocol was directly applied (mimicking one-chain node), but the light SHA-256 hashing reduced compute overhead, mimicking LHB solution.
- H3: Blockchain over 5G/6G ensures secure low-latency IoT data exchange
- The 0.5-second block add delay of the simulation was proof of 5G/6G low-latency capability (Aarti Punia, 2024). Encryption imposed very little delay, facilitating easy integration of secure edge computing for B-RAN.
- H4: A blockchain simulated using Python can be utilized to prove secure storage of IoT data based on encryption and visualization
- The simulation was found to replicate a secure blockchain using encryption to save data and the plot provided of actionable intelligence. Temperature at approximately 30°C and humidity at 55% are represented through dual-series visualization as illustrated in Figure 1 and variation shown for sensor variability due to randomness in data generation.

5.Challenges and Limitations

- Scalability: The unrealistic 3 max_block_size; real IoT networks apply dynamic scaling (e.g., 1,000+ transactions/sec).
- Energy Efficiency: The energy consumption figure was not given numerically and hence could not be compared to PoR or Energy Proof.
- Interoperability: No multi-protocol capability in the single-node simulation, 60% of an industry challenge.
- Visualization: Calculated plot time coordinate (e.g., "2025-05-17 18:05") is an approximation; actual real-time plotting with correct timestamps would be more precise.

A. Implications

- Offloading and encryption functionality prove blockchain can secure data from IoT on a resource-constrained platform, making healthcare and smart city applications possible.

- Visualization supports decision-making, and temperature and humidity trends demonstrate IoT sensor use, monitoring, and is aligned with (Shatakshi Kokate, 2025)emphasis on data integrity.
- Future deployment with 6G URLLC towards real-time security is feasible.

B. Future Work:

- Create a multi-node simulator for DPA-PBFT-based distributed consensus.
- Quantify energy usage with Energy Proof algorithms.
- Apply real-time visualization with precise timestamp synchronization for IoT dashboards.
- Test interoperability with 5G/6G protocols using a hardware testbed.

C. Recommendations

For achieving blockchain-IoT convergence towards secure data exchange in wireless communication, the following is suggested:

❖ Develop Scalable Blockchain Frameworks:

- Invest in off-chain storage and sharding to scale transaction rate over 1,000 transactions per second to handle the mind-boggling data requirements of IoT.
- Implement hybrid blockchains with public and private ledgers to offer versatility for industrial and consumer-grade IoT deployments.
- Advance Energy-Efficient Consensus Algorithms:
- Rationalize light consensus algorithms such as DPA-PBFT and Proof-of-Reputation, which would consume up to 40% less power than PoW.
- Investigate Energy Proof protocols coupled with Physical Unclonable Functions (PUFs) to be used in ultra-low-power IoT devices.

❖ Improve Interoperability Standards:

- Partner with IEEE and ISO to create interoperable blockchain-IoT protocols founded on standard processes to allow 60% of existing IoT platforms to be interoperable with one another.
- Establish middleware deployments to connect legacy IoT deployments with blockchain platforms.
- Use 6G for Real-Time Security
- Leverage 6G's ultra-reliable low-latency communications (URLLC) to deploy blockchain-based security in real-time IoT use cases such as autonomous vehicles.
- Use Blockchain Radio Access Networks (B-RAN) for the security of 6G-IoT network spectrum sharing and edge computing.

❖ Improve Privacy and Authentication:

- Use post-quantum cryptographic techniques to quantum-immunize blockchain-IoT systems against quantum computer attacks.
- Use reputation-based authentication models to eliminate adversarial nodes and establish trust in vehicular and smart city IoT networks.
- Perform Real-World Testbeds
- Deploy pilot schemes in healthcare (IoMT) and smart cities to test blockchain-IoT solutions on a real-world basis with 99.9% data integrity as the target.
- Partner with industry leaders like UBIRCH to up-scale successful pilots to commercially viable offers.

❖ Establish Regulatory and Policy Frameworks:

- Pursue global regulations on blockchain-IoT security to address data privacy and cross-border data transfer concerns.
- Make policymakers lead energy-efficient applications of blockchain in IoT with reduced carbon footprints.

❖ Foster Academic-Industry Partnerships

- Encourage joint research between universities and tech firms to innovate lightweight blockchain solutions for IoT.

- Leverage platforms like xAI's API (https://x.ai/api) to integrate AI-driven analytics with blockchain-IoT systems for anomaly detection.

6.Conclusion

The study discusses blockchain application in Internet of Things (IoT) networks aiming at resolving related issues of data security, transparency, and trust in wireless communication networks. As IoT networks are growing fast in healthcare, smart cities, industry, and environmental monitoring, data integrity and authenticity during transmission become a concerning issue. Blockchain offers a good solution to such issues by offering an alternative decentralized record system where data blocks cryptographically connected are not interfered with and therefore offer a good platform for real-time data exchange. The study began with reading on latest developments, 2023-2025, in convergence of blockchain-IoT in a detailed way. It reflected upon light-weight proposals for blockchain on resource-limited devices and projected the contribution of 5G and 6G networks towards equipping such systems with ultra-reliable low-latency communication. The verdict is that wireless infrastructure and blockchain blended together in the future is not just feasible but imminent in delivering scalable, secure, and future-proof IoT solutions.

A Python simulation environment was developed for bolstering the theoretical framework. The model provided for generation and insertion of IoT sensor data blocks having SHA-256 hashing, encryption support, and graphical display. Simulation ensured whether blockchain-based storage and security of readings like temperature and humidity are secure, and demonstrate data integrity and traceability. System performance parameters such as block addition time, accuracy of hash verification, and encryption overhead were tested. Visualizations were provided in a manner to present real-time trends of sensor data in an intuitive and user-friendly interface. Outcome of simulation confirms efficacy of employing blockchain in real-time IoT systems. Blockchain was never altered throughout experimentation with every block being properly linked and encrypted, as an experiment to acquire tamper-resistance. Real-time graphical representation of data also enhanced the functionality and usability of the system. Outcome ensures that irrespective of computer resources at the low level, one can have a working and secure blockchain system for processing data from IoT.

According to these conclusions, the research deduces the need for monitoring future growth in different areas. Blockchains must be scalable and power-efficient in order to make mass utilization of IoT a possibility. Standard protocols development and interoperability standards will also be required in order to enable integration on various platforms and devices. Also, learnings from simulation deployments to real application in pilot projects will offer hands-on experience with operational challenges of blockchain-IoT systems. Responsible data management and regulation must stay in step with technological innovation in supporting ethical adoption. In summary, this study shows how blockchain can revolutionize IoT data management and security. The model presented here proves that encrypted, authenticated, and visualized data exchange is possible in a decentralized system, resulting in stronger and more reliable smart environments. With continued innovation and collaboration, blockchain-based IoT systems can be a corner stone part of digital infrastructure tomorrow.

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