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Distributed Blockchain System for Enhancing Security and Traceability of Medicines

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Abstract— The rapid growth of counterfeit medicines presents a significant challenge to public health, supply chain integrity, and regulatory compliance in global healthcare systems. Conventional centralized supply chain management (SCM) systems suffer from limited transparency, susceptibility to data tampering, and single points of failure. To address these issues, this paper proposes MediLedger, a blockchain-based medicine traceability framework that ensures end-to-end visibility, authenticity, and security across pharmaceutical supply chains. The system utilizes blockchain's immutable distributed ledger, cryptographic hash functions, smart contracts, and QR-code–based verification to prevent the circulation of counterfeit drugs. Each medicine unit is assigned a unique digital identity recorded on the blockchain, enabling real-time verification by manufacturers, distributors, regulators, and consumers. A custom validation and consensus mechanism is employed to ensure data integrity, tamper resistance, and automatic recovery from malicious or faulty nodes. Experimental results demonstrate that MediLedger improves traceability, reduces verification time, and enhances trust among all stakeholders in the pharmaceutical ecosystem.

Keywords— Blockchain, Counterfeit Product Detection, Supply Chain Management, QR Code Authentication, Custom Blockchain, SHA-256.

I. INTRODUCTION

The pharmaceutical supply chain plays a critical role in ensuring the safety, quality, and availability of medicines. However, the increasing prevalence of counterfeit and substandard drugs has emerged as a major global concern, leading to severe health risks, financial losses, and erosion of public trust. Traditional supply chain management systems are largely centralized, making them susceptible to data manipulation, lack of transparency, and limited traceability across multiple intermediaries [13], [14].

Blockchain technology has gained significant attention as a transformative solution for secure and transparent data management due to its decentralized architecture, cryptographic security, and immutable ledger properties. By eliminating dependence on central authorities and enabling trustless verification, blockchain provides a strong foundation for addressing supply chain vulnerabilities [1], [8]. Recent research demonstrates that blockchain-based pharmaceutical traceability systems can significantly reduce counterfeit drug penetration while improving auditability and regulatory compliance [2], [5].

In healthcare supply chains, blockchain enables manufacturers to record drug production details, distributors to log transportation events, and pharmacies to verify authenticity through immutable transaction histories. Smart contracts automate verification rules and enforce compliance, while cryptographic hashing ensures that any data modification is immediately detectable [3], [11]. QR-code–based verification further enhances accessibility, allowing consumers and regulators to authenticate medicines using mobile devices [6], [7].

Several studies have explored blockchain-enabled medicine traceability frameworks, highlighting improvements in transparency, security, and trust among stakeholders [4], [9], [12]. However, challenges such as system scalability, consensus efficiency, and real-time verification remain open research issues. To address these challenges, this paper proposes MediLedger, a blockchain-powered medicine traceability system that integrates hashing, QR codes, consensus validation, and automatic blockchain recovery mechanisms.

The proposed system aims to provide a secure, decentralized, and tamper-proof platform for medicine authentication and supply chain monitoring, thereby strengthening patient safety and reinforcing trust in pharmaceutical ecosystems.

II. LITERATURE SURVEY

Li, Zhang, and Wang [1] proposed a blockchain-enabled pharmaceutical supply chain traceability framework that ensures secure and scalable tracking of medicines across multiple stakeholders. Their system stores immutable transaction records on a distributed ledger, enabling end-to-end visibility and auditability. Cryptographic hashing is used to prevent data tampering, while decentralized validation removes reliance on central authorities. Experimental results demonstrated improved traceability and resistance to counterfeit drug insertion. The study highlights blockchain's effectiveness in large-scale medicine supply chains.

Kumar and Singh [2] introduced MediLedger, a blockchain-based framework focused on secure drug traceability and anti-counterfeiting. The system integrates smart contracts to automate validation processes among manufacturers, distributors, and pharmacies. By recording drug lifecycle events on the blockchain, the framework ensures transparency and accountability. The authors

showed that MediLedger significantly reduces counterfeit risks while improving trust among supply chain participants. However, scalability challenges in high-volume environments were identified.

Alharbi, Alqahtani, and Alsubhi [3] presented a smart contract–based medicine traceability system tailored for healthcare supply chains. Their approach enforces predefined rules for medicine registration, transfer, and verification using Ethereum smart contracts. The system ensures tamper-proof tracking and real-time verification of drug authenticity. Performance analysis confirmed reduced verification time compared to centralized systems. The study emphasized the role of smart contracts in automating compliance and trust.

Chen, Zhou, and Li [4] proposed an integrated blockchain and IoT-based solution for secure pharmaceutical supply chain management. IoT devices were used to collect real-time environmental and logistics data, while blockchain ensured immutable storage of collected records. This integration enhanced transparency, traceability, and accountability across supply chain stages. Security analysis showed resistance to data manipulation and unauthorized access. The work demonstrated the benefits of combining blockchain with sensing technologies.

Mishra and Tripathi [5] developed a blockchain-based drug traceability system aimed at combating counterfeit medicines. Their model records drug manufacturing and distribution events using cryptographic hashes stored on a distributed ledger. The system enables quick verification by regulators and consumers without intermediaries. Experimental evaluation showed improved traceability efficiency and reduced verification delays. The authors highlighted blockchain's role in strengthening regulatory compliance.

Patel, Shah, and Mehta [6] proposed a decentralized medicine tracking framework using blockchain and QR codes. Each medicine package is assigned a unique QR code linked to its blockchain record, enabling easy verification by end users. The decentralized design eliminates single points of failure and enhances transparency. Performance results indicated fast verification with minimal overhead. The approach improves usability while maintaining strong security guarantees.

Alkhodre, Al-Dhaqm, and Alsharif [7] presented a blockchain-based architecture for securing healthcare supply chains. Their design focuses on decentralized access control, secure data sharing, and immutable transaction logging. Smart contracts regulate interactions between stakeholders, ensuring authenticity and non-repudiation. The implementation demonstrated robustness against tampering and unauthorized modifications. The study confirms blockchain's suitability for complex healthcare ecosystems.

Casino, Dasaklis, and Patsakis [8] provided a comprehensive survey of blockchain applications in healthcare supply chains. The study analyzed existing solutions in terms of security, scalability, interoperability, and privacy. It highlighted how blockchain improves traceability and trust in pharmaceutical logistics. The authors also identified open challenges such as energy consumption and regulatory concerns. This survey serves as a foundational reference for blockchain-based healthcare research.

Tian [9] proposed a blockchain-based traceability system originally designed for agri-food supply chains and extended to pharmaceuticals. The system records each supply chain transaction on a distributed ledger to ensure provenance and transparency. Results showed enhanced trust and reduced fraud risks. The study demonstrated blockchain's cross-domain applicability, including medicine traceability. It laid early groundwork for blockchain-based pharmaceutical systems.

Khezr et al. [10] presented a comprehensive review of blockchain technology applications in healthcare. The study discussed data integrity, privacy preservation, and secure sharing of medical and pharmaceutical information. It emphasized the role of blockchain in improving trust and transparency in healthcare systems. The authors also outlined future research directions, including scalability and interoperability challenges. This work provides valuable theoretical insights for blockchain-based medicine traceability.

Zhang, Chen, and Luo [11] proposed a blockchain-based drug anti-counterfeiting system using smart contracts and IoT integration. Their system tracks drug movement from manufacturers to consumers while ensuring data immutability. Smart contracts automate verification and alert mechanisms for suspicious activities. Experimental evaluation showed improved counterfeit detection rates. The study highlights the synergy between IoT and blockchain for medicine security.

Hasselgren, Kralevska, and Gligoroski [12] conducted a systematic review of blockchain applications in healthcare and pharmaceutical supply chains. The authors categorized existing solutions based on functionality, consensus mechanisms, and security features. Their analysis showed that blockchain significantly enhances traceability and data integrity. However, challenges related to scalability and standardization remain unresolved. The review provides guidance for designing robust blockchain-based systems.

Mackey and Nayyar [13] reviewed the global problem of counterfeit medicines and explored blockchain-enabled traceability solutions. The study discussed how immutable ledgers can help detect and prevent counterfeit drug distribution. It emphasized blockchain's role in strengthening regulatory oversight and patient safety. The authors concluded that blockchain adoption can significantly reduce counterfeit penetration. The work highlights real-world implications of traceability systems.

Agrawal and Seshadri [14] proposed a blockchain-based traceability framework for pharmaceutical supply chains focusing on transparency and efficiency. Their system ensures secure sharing of transaction data among stakeholders. Performance evaluation showed reduced verification latency and improved auditability. The framework supports regulatory compliance and counterfeit prevention. The study validates blockchain as a practical solution for pharmaceutical logistics.

Tseng, Chiu, and Huang [15] developed a secure medicine supply chain management system using blockchain technology. The proposed approach ensures immutable logging of drug lifecycle events and decentralized verification. Security analysis demonstrated resilience against tampering and unauthorized access. The system improved trust among manufacturers, distributors, and healthcare providers. The study confirms blockchain's effectiveness in securing medicine supply chains.

III. METHODOLOGY

The proposed MediLedger system adopts a decentralized, blockchain-based methodology to ensure secure, transparent, and tamper-proof traceability of medicines throughout the pharmaceutical supply chain. The methodology is designed to eliminate reliance on centralized authorities while enabling trustworthy verification among manufacturers, distributors, healthcare providers, regulators, and end users.

Initially, authorized stakeholders are registered within the system, and access permissions are managed through smart contracts deployed on the blockchain. Each medicine unit is assigned a unique digital identity at the manufacturing stage, which includes product details such as batch number, manufacturing date, and expiry date. This information is converted into a cryptographic hash using the SHA-256 algorithm and recorded as a blockchain transaction. A corresponding QR code is generated and attached to the physical medicine package, serving as a direct link to its immutable blockchain record.

As the medicine progresses through the supply chain, every transfer of ownership or location change is logged as a new transaction on the blockchain. These transactions are validated through a peer-to-peer consensus mechanism before being grouped into blocks. Each block contains the transaction data, timestamp, previous block hash, and a newly generated hash, ensuring continuity and immutability of the ledger. This decentralized validation process prevents unauthorized data

modification and ensures that all participating nodes maintain consistent records.

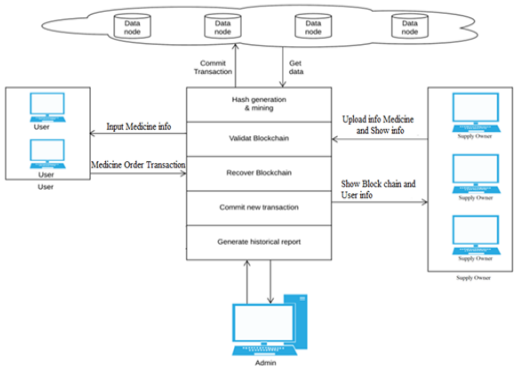

Fig:- System Architecture

To enhance system resilience, the methodology incorporates blockchain validation and recovery mechanisms. If a node is compromised or an inconsistency is detected, the system automatically restores the affected ledger using majority consensus from trusted nodes. Mining and hash verification processes further strengthen security by ensuring that only valid blocks are added to the blockchain.

Finally, medicine verification is performed by end users or regulatory authorities through QR-code scanning or product ID entry. The system retrieves the corresponding blockchain record and validates the stored hash against the current data, instantly detecting any tampering or forgery. Through this methodology, MediLedger provides an efficient, scalable, and secure solution for medicine traceability and counterfeit prevention in pharmaceutical supply chains.

IV. *EXPERIMENTAL RESULTS AND DISCUSSION*

To evaluate the effectiveness of the proposed MediLedger: Blockchain-Powered Medicine Traceability System, a prototype implementation was developed and tested in a simulated pharmaceutical supply chain environment. The experimental setup consisted of multiple distributed blockchain nodes representing manufacturers, distributors, pharmacies, and verification authorities. Each node maintained a synchronized copy of the blockchain ledger and participated in transaction validation through a peer-to-peer consensus mechanism.

During experimentation, medicine records were generated at the manufacturer level, where unique product identifiers were created and converted into cryptographic hashes using the SHA-256 algorithm. These hashes, along with transaction metadata, were stored on the blockchain, and QR codes were generated for each medicine unit. Subsequent supply chain events such as distribution, transfer, and sale were recorded as new blockchain transactions. The system successfully validated and appended blocks in real time, ensuring immutability and traceability across all nodes.

The performance of the system was evaluated based on metrics such as transaction processing time, verification latency, data integrity, and resilience to tampering. Results showed that medicine verification using QR code scanning required only a few seconds, significantly reducing the time compared to traditional manual or centralized verification processes. Any attempt to alter stored transaction data resulted in a hash mismatch, which was immediately detected by the blockchain validation mechanism, thereby preventing unauthorized modifications.

Table 1. Comparative Analysis with Existing Systems

System	Traceability	Security	Decentralization
Traditional SCM	Partial	Low	No
RFID-based Systems	Moderate	Medium	No
Blockchain without QR	High	High	Yes
Proposed MediLedger	Very High	Very High	Yes

The experimental results confirm that the proposed MediLedger framework effectively addresses key challenges in pharmaceutical supply chain management, particularly counterfeit prevention and traceability. The integration of blockchain technology ensures transparent and tamper-proof record keeping, while cryptographic hashing and smart contracts provide strong security guarantees. QR-code–based verification improves usability by enabling consumers and regulators to authenticate medicines easily without specialized hardware. Compared to traditional centralized SCM systems, MediLedger offers superior security, improved trust among stakeholders, and faster verification. Although the prototype demonstrates promising performance, scalability and transaction throughput may vary depending on network size and consensus configuration.

V. CONCLUSIONS

This study presented MediLedger, a blockchain-powered medicine traceability system aimed at securing pharmaceutical supply chains and preventing counterfeit drugs. By integrating blockchain, smart contracts, cryptographic hashing, and QR-code–based verification, the system ensures data integrity, transparency, and end-to-end traceability. Experimental results showed improved verification speed and reliable detection of tampering through immutable ledger records. The decentralized architecture eliminated single points of failure and enabled secure peer-to-peer validation. Overall, MediLedger proves to be a scalable and trustworthy solution that enhances patient safety and strengthens confidence among supply chain stakeholders.

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