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A Decentralized Blockchain Framework forSecure Medicine Traceability in Pharmaceutical Supply Chains

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ABSTRACT

Counterfeit medicines pose a serious threat to global public health and economic stability. The lack of transparency and traceability in traditional pharmaceutical supply chains enables the circulation of falsified and substandard drugs, leading to therapeutic failures, drug resistance, and financial losses. This paper proposes a blockchain-based framework to enhance security, transparency, and trust in pharmaceutical supply chain management. The system leverages the decentralized and immutable nature of blockchain technology integrated with QR code–based product identification to ensure secure tracking of medicines from manufacturers to end-users. A decentralized application (DApp) deployed on the Ethereum network facilitates peer-to-peer interactions and automates verification using smart contracts executed through the Ethereum Virtual Machine. The proposed solution improves traceability, regulatory compliance, and consumer confidence while reducing the risk of counterfeit drug infiltration. Overall, the system provides a scalable and secure approach to safeguarding pharmaceutical distribution networks.

Keywords—Blockchain, Counterfeit Drugs, QR Code, Pharmaceutical Supply Chain, Traceability, Smart Contracts, DApp

INTRODUCTION

The pharmaceutical industry faces a major global challenge due to the increasing prevalence of counterfeit and substandard medicines. According to the World Health Organization (WHO), approximately 10% of medical products in low- and middle-income countries are either falsified or substandard, placing millions of lives at risk. Counterfeit drugs not only endanger patient safety but also contribute to economic losses, therapeutic failures, antimicrobial resistance, and damage to brand reputation.

Traditional supply chain systems rely on centralized databases and manual verification processes, which are vulnerable to data manipulation, limited interoperability, and lack of transparency. Although technologies such as RFID, IoT, and QR codes have been introduced to enhance tracking, they often depend on centralized infrastructures and may not fully eliminate counterfeit risks.

Blockchain technology offers a decentralized, transparent, and tamper-proof solution. By maintaining an immutable distributed ledger, blockchain enables secure recording of pharmaceutical transactions from production to consumer delivery. Smart contracts automate validation processes, ensuring that any unauthorized modification is immediately detected. The integration of QR codes linked to blockchain records allows consumers to instantly verify product authenticity, thereby strengthening trust and regulatory compliance.

This paper presents a blockchain-based pharmaceutical tracking system designed to enhance traceability, transparency, and accountability while minimizing counterfeit drug circulation.

LITERATURE REVIEW

Blockchain has gained significant attention in the pharmaceutical sector due to its decentralized, immutable, and transparent nature, making it a promising tool for combating counterfeit drugs. Numerous studies have explored blockchain’s potential to secure supply chains, improve traceability, and enhance consumer trust. Despite the promising applications, challenges

such as scalability, inclusion of all stakeholders, and integration with complementary technologies remain. This section summarizes the current literature on blockchain-based anti-counterfeiting solutions, emerging technologies, and hybrid models in the pharmaceutical industry.

A. Blockchain Fundamentals & Security Challenges

Blockchain relies on cryptographic security and decentralized consensus to maintain tamper-evident records of transactions. In the pharmaceutical context, blockchain ensures that drug movement from manufacturer to consumer is recorded immutably, preventing unauthorized changes. Several studies, including those by Chen et al. and Bhardwaj, highlight blockchain's capability to enhance transparency and integrity of supply chain data. However, limitations include scalability issues when storing large amounts of product data, reliance on manufacturer nodes, and incomplete inclusion of stakeholders such as hospitals and doctors. Approaches like integrating IPFS for distributed storage and employing hybrid or branched blockchain architectures have been suggested to address these challenges.

B. Blockchain in Pharmaceutical Supply Chain & Anti-Counterfeiting

Blockchain has been widely studied as a solution for drug traceability and counterfeit prevention.

- **Zhu et al.** proposed a PBFT-based blockchain system with drug-specific IDs to enhance supply chain transparency.
- **Musamih et al.** combined blockchain, IPFS, and smart contracts for real-time tracking of pharmaceuticals, improving traceability.
- **Cao et al.** (BE-AC system) implemented decentralized identity authentication and advanced digital signatures to secure drug information.
- **Islam and Islam** focused on production and distribution phases to maintain immutable records and prevent counterfeit drugs.
- **Nawaz et al.** utilized Hyperledger Sawtooth for real-time tracking, emphasizing security and operational efficiency.

These studies demonstrate that blockchain can reduce counterfeit penetration, but effective implementation requires comprehensive stakeholder integration, including regulators, distributors, and healthcare providers.

C. Integration with Emerging Technologies

To further enhance anti-counterfeiting measures, blockchain has been integrated with complementary technologies:

- **QR Codes:** Enable consumers to instantly verify product authenticity linked to the blockchain (Veronica et al.).
- **AI & Machine Learning:** Detect counterfeit products using image and text recognition techniques (Daoud et al., Roy et al.).
- **RFID & NFC:** Facilitate real-time detection of counterfeit goods at the point of purchase (Saeed et al., Khalil et al.).

These integrations improve accuracy, efficiency, and consumer-level accessibility, making blockchain-based systems more practical and robust.

PROPOSED METHODOLOGY

The proposed Blockchain-based Pharmaceutical Product Verification System is designed to ensure authenticity, traceability, and safety of medical products. The system is implemented as a decentralized application (Dapp) on the Ethereum blockchain and integrates QR codes to allow consumers and stakeholders to track product history from the manufacturer to the end user. The system involves three primary modules: Manufacturer, Supplier, and Consumer, each playing a critical role in ensuring product integrity and transparency.

Module 1 – Manufacturer:

The manufacturer is responsible for registering products on the system. Once registered, product details such as batch number, manufacturing date, and unique serial ID are entered into the blockchain ledger, ensuring an immutable record. A unique QR code is generated for each product, which will be used to track its journey. The manufacturer places the QR code on the product packaging before distribution, providing a secure and verifiable origin.

Module 2 – Supplier:

The supplier scans the QR code when receiving products from the manufacturer and updates the system with details such as date of receipt, date of sale, and inventory status. This step ensures that every product movement is recorded on the blockchain, preventing tampering or fraud during distribution. Suppliers act as the intermediate validators in the supply chain, maintaining transparency and accurate tracking.

Module 3 – Consumer:

The consumer can scan the QR code on the product to verify its authenticity and trace the product's history from the manufacturer to the point of sale. If the product information matches the blockchain records, it is considered genuine; otherwise, it is flagged as counterfeit. This empowers consumers to verify products independently, increasing trust and reducing the risk of consuming fake pharmaceuticals.

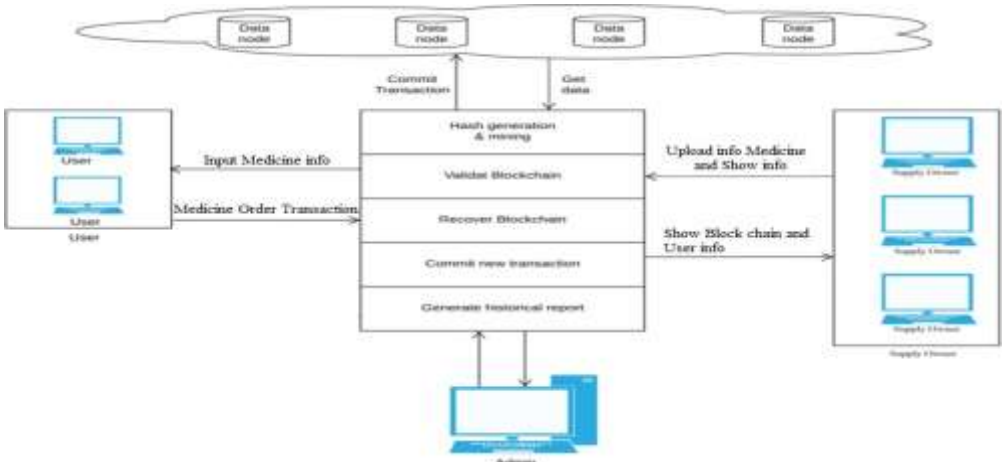

Figure: Proposed System Architecture

RESULTS AND DISCUSSION

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

CONCLUSION AND FUTURE SCOPE

Conclusion:
Blockchain technology, using a decentralized application (DApp) on the Ethereum network, helps prevent counterfeit drugs by securely tracking medicines across the pharmaceutical supply chain. Smart contracts ensure data integrity, transparency, and tamper-resistant records, while QR code verification allows instant authentication of products. This improves supply chain transparency, regulatory compliance, brand protection, and public health safety.

Future Scope:
Future enhancements can incorporate Artificial Intelligence (AI) and advanced analytics to further strengthen counterfeit detection and predictive monitoring. Machine learning models can analyze blockchain transaction data to identify suspicious patterns and forecast potential counterfeit activities.

Additionally, integrating Internet of Things (IoT) sensors for environmental monitoring (such as temperature and humidity tracking) can improve supply chain visibility and product quality assurance. Real-time anomaly detection systems combined with blockchain infrastructure can establish a proactive defense mechanism, ensuring secure, efficient, and globally resilient pharmaceutical distribution networks..

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