Medicine Supply Chain Management Using Blockchain

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Abstract: The prevalence of counterfeit medicines poses a significant threat to public health and safety, largely due to the opaque nature of traditional medicine supply chains. This research introduces a blockchain-based solution designed to bring transparency, traceability, and enhanced security to the medicine distribution process. The proposed system records every transaction in the supply chain, thereby preventing tampering and ensuring the authenticity of pharmaceutical products. Smart contracts are utilized to automate the verification and transfer of products between stakeholders such as manufacturers, distributors, and retailers. A decentralized application (DApp) was developed using React to facilitate user interaction, while the backend was implemented using the Truffle framework and connected to a local Ethereum blockchain via Ganache and Web3.js. The system supports real-time tracking of medicines and reduces dependency on intermediaries, which not only improves operational efficiency but also enhances the overall integrity of the supply chain. This blockchain-based approach represents a significant advancement over conventional methods by offering a transparent, tamper-resistant, and verifiable solution for medicine supply chain management.

Keywords: Blockchain, Smart Contracts, Drug Counterfeiting, Supply Chain, Product Traceability, Security.

I. INTRODUCTION

The pharmaceutical supply chain is complex, involving multiple entities such as suppliers, manufacturers, distributors, and retailers, making it difficult to track and verify the authenticity of drugs. Counterfeit drugs pose a significant threat, with nearly 10-30% of medications in developing countries being fake, leading to severe health risks. The lack of transparency in the current system makes it challenging for customers to determine the authenticity of products and for authorities to investigate supply chain tampering. Blockchain offers a revolutionary solution by providing a decentralized, immutable ledger that ensures transparency and trust among all entities. Using smart contracts, each transaction is securely recorded, enabling efficient product traceability. A decentralized application (DApp) is developed using React, with smart contracts deployed on a local blockchain via Ganache and connected using Web3.js and Truffle. This system ensures security, transparency, and efficiency in drug supply chain management, reducing fraud and improving customer trust.

These contracts automate key processes such as authentication checks, batch recording, and ownership transfers, reducing the dependency on intermediaries and minimizing human error or manipulation. Furthermore, this blockchain-based solution can be extended to integrate with IoT devices for real-time monitoring of drug storage conditions (like temperature and humidity), and with regulatory compliance modules to ensure adherence to legal standards. Such innovations pave the way for a robust, transparent, and secure pharmaceutical supply chain, ultimately contributing to public health and safety.

II. LITERATURE SURVEY

According to [1], a blockchain-based solution is proposed to enhance the security and transparency of the pharmaceutical supply chain. This approach integrates blockchain technology with smart contracts to track and verify the authenticity of medicines. The system ensures tamper-proof records, mitigates counterfeit drug risks, and enables real-time monitoring of medicine movement across the supply chain.

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According to [2], a decentralized blockchain framework is designed to improve efficiency and trust in the pharmaceutical supply chain. The proposed system employs Hyperledger Fabric to maintain a secure and distributed ledger that records drug transactions. Smart contracts automate compliance verification, reducing the risk of fraud and ensuring adherence to regulatory standards.

According to [3], an advanced blockchain-based drug traceability system is introduced to address the challenges of counterfeit drugs. The system employs an Ethereum-based blockchain network to store drug-related data immutably. Furthermore, it integrates Internet of Things (IoT) devices for real-time tracking, improving visibility and control in the supply chain.

According to [4], a novel blockchain-based pharmaceutical supply chain model leverages a combination of cryptographic techniques, including hashing and asymmetric encryption, to safeguard sensitive drug-related information. The system utilizes a permissioned blockchain, ensuring that only authorized entities can access critical data while maintaining transparency and accountability.

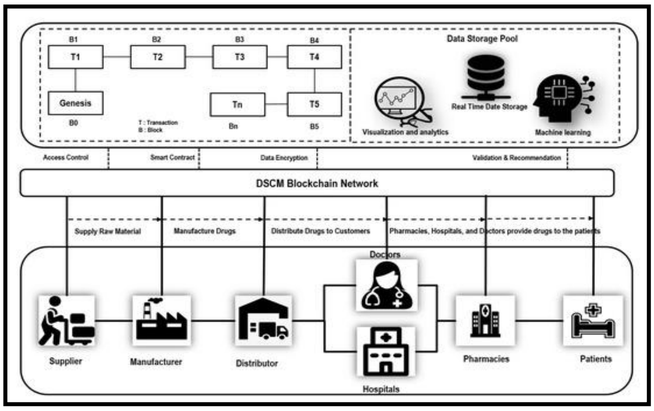
An [5] architecture is proposed to ensure the secure storage and distribution of medicines within a blockchain-powered supply chain. The architecture employs encryption techniques such as RSA and AES to protect sensitive data. Evaluation results indicate improvements in security, data integrity, and operational efficiency.

In [6], the study focuses on privacy and security concerns in blockchain-based medicine supply chains. It provides a detailed examination of potential threats, including data breaches, unauthorized access, and counterfeit drug insertion. To address these issues, the study discusses security solutions such as zero-knowledge proofs, attribute-based encryption, and decentralized identity management.

According to [7], blockchain technology is explored for its potential to enhance drug authenticity verification in supply chain management. The study highlights blockchain's role in eliminating fake medicines by enabling end-to-end traceability. Additionally, it emphasizes regulatory challenges and the need for industry-wide adoption to maximize effectiveness.

In [8], a systematic review of blockchain applications in the pharmaceutical industry is conducted, analyzing various blockchain platforms such as Ethereum, Hyperledger. The study categorizes blockchain-based solutions by key functionalities, including traceability, transparency, and compliance monitoring, while discussing scalability and interoperability challenges.

In [9], the impact of blockchain on pharmaceutical logistics is examined, particularly in improving efficiency and reducing delays in medicine distribution. Blockchain is shown to facilitate seamless coordination between manufacturers,



distributors, and healthcare providers, ultimately enhancing supply chain resilience.

According to [10], a blockchain-based medicine supply chain management system is developed to ensure secure, tamper-resistant, and efficient drug distribution. The system leverages decentralized ledgers to eliminate discrepancies, enhance data integrity, and minimize operational risks associated with traditional supply chain models.

III. PROPOSED SYSTEM DESIGN

The proposed system for medicine supply chain management using blockchain aims to enhance transparency, security, and efficiency in pharmaceutical logistics. This system eliminates reliance on a Trusted Third Party (TTP) by leveraging a decentralized blockchain network within a fog computing environment. The primary objectives are to ensure data integrity, confidentiality, real-time traceability, and prevention of counterfeit medicines across all stakeholders, including manufacturers, distributors, pharmacies, healthcare providers, and regulatory authorities.

The system employs blockchain technology to store all transactional data, ensuring tamper-proof record-keeping. When a medicine batch moves from one entity to another, the recipient can access its complete history through fog networks, providing an immutable audit trail. Blockchain technology validates each transaction across multiple servers, enhancing quality of service, reducing delays, and ensuring regulatory compliance. The system utilizes thread-based middleware for load balancing and parallel transaction processing across blockchain nodes. A cryptographic hash generation algorithm ensures data security, and peer-to-peer verification validates all transactions before execution. If any chain is deemed invalid, the system updates or recovers it from the latest valid state.

Fig.1: System Design Methodology

The system consists of the following modules:

1. Manufacturer
   - Records essential details of drug production, including batch number, expiry date, ingredients, and quality control measures.
   - Stores the hashed data in the blockchain for traceability and verification.
2. Distributor
   - Manages the transportation of medicines and verifies received drug batches.
   - Logs transaction data on the blockchain to maintain authenticity and prevent unauthorized tampering.
3. Pharmacy
   - Ensures medicine authenticity by verifying blockchain records before sales.
   - Maintains real-time stock levels and ensures compliance with regulatory guidelines.
4. Regulatory Authority
   - Monitors transactions for adherence to pharmaceutical regulations and compliance standards.
   - Uses blockchain records for auditing, fraud prevention, and ensuring drug authenticity.

Verification Transaction is detected -

Majority Voting: A consensus mechanism ensures transaction validation when more than 50% of nodes approve it. Weighted majority voting is used for enhanced security, giving greater influence to trusted participants.

Recovery Data: Each blockchain node retains a copy of all records, allowing data recovery through consensus-based synchronization in case of node failure or corruption.

Custom Blockchain Workflow Overview:

A block in the blockchain contains a series of verified transactions. The process for creating a new block follows these steps:

Transaction Collection

- Record transactions related to drug manufacturing, distribution, and sales.
- Validate transactions by checking digital signatures, compliance rules, and authenticity.

Merkle Tree Creation:

Organize transactions into a Merkle tree structure and compute the Merkle root.

Block Assembly:

- Construct the block header with required fields such as previous block hash, Merkle root, timestamp, etc.
- Append validated transactions to the block body and compute the block hash.

Proof of Work or Proof of Authority

- If using Proof of Work, miners must solve a cryptographic puzzle before adding a new block.
- In case of Proof of Authority, verified nodes validate and approve transactions before they are appended to the blockchain.

Entity description for the application.

- **Block**: Stores multiple transactions and links to the previous block.
- **Transaction**: Records details of drug movement, verification, and sales.
- **Wallet**: Digital representation of participants' identities and transactions.

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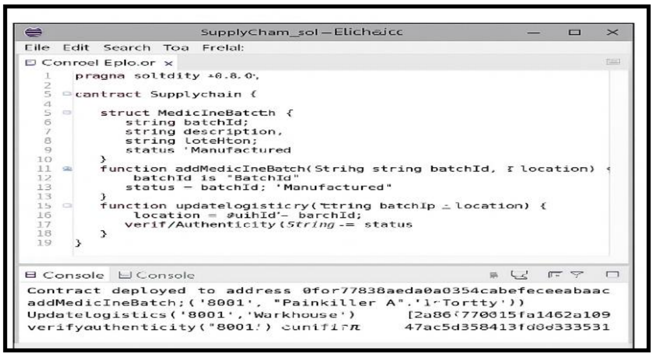
- **Node**: Maintains the blockchain ledger and validates transactions.
- **Smart Contract**: Automates business rules for medicine tracking and compliance.
- **Consensus Mechanism**: Ensures network-wide agreement on the validity of transactions.
- **Ledger**: Immutable record of transactions maintained across nodes.



- **User**: Any stakeholder interacting with the system.

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Smart Contract Implementation

A smart contract is a digital agreement stored on the blockchain that executes automatically when predefined conditions are met.

Functions of Smart Contracts in the System:

- Verify the authenticity and compliance of medicines at every stage of the supply chain.
- Automate compliance checks and updates.
- Trigger alerts for suspicious transactions or inconsistencies..

Fig2. shows the execution of a blockchain-based program within the Eclipse IDE

Fig 3: - Demonstrating the integrity and replication of blockchain data across all data nodes.

Steps in Blockchain-Based Medicine Supply Chain Management

Step 1: Drug Manufacturing and Data Recording

- When a manufacturer produces a medicine batch, all production details are recorded and stored in the blockchain.
- The data remains immutable, ensuring authenticity and traceability from the point of origin.

Step 2: Smart Contract-Driven Logistics Tracking

- As medicines are shipped, smart contracts validate and record each transaction.
- If a transaction does not meet predefined conditions, it is flagged for review.

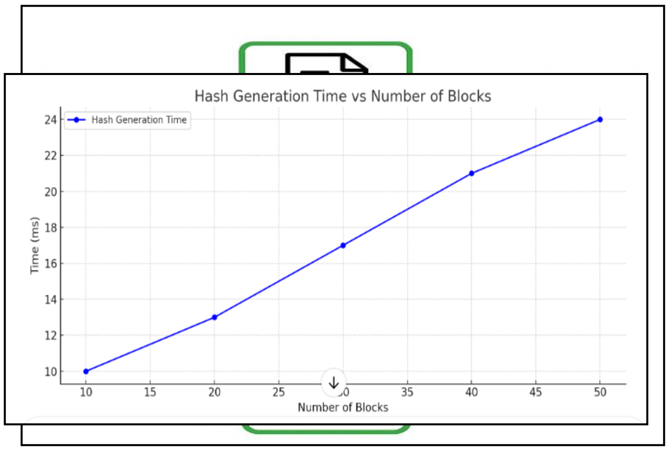
Step 3: Distributor and Pharmacy Verification

- Distributors and pharmacies verify drug authenticity before further distribution or sale.
- Counterfeit drugs are eliminated from the supply chain through blockchain validation.

Step 4: Regulatory Compliance and Auditing

- Regulatory authorities access real-time blockchain records to ensure compliance with industry standards.
- Ensures adherence to safety measures and prevents fraudulent practices.

Step 5: Secure Transactions and Consumer Verification



- Transactions between stakeholders are encrypted and recorded on the blockchain.
- Consumers can verify medicine authenticity using a blockchain-validated QR code.

IV. RESULT

The time required for the consensus algorithm to validate the blockchain in four nodes is shown in Figure 2. The X-axis depicts the size of the blockchain, while the Y-axis depicts the time needed in milliseconds for each of the four nodes

Fig. 4. Comparative Analysis of Blockchain hash generation time and number of blocks

In the second experiment, we evaluate the proposed system with smart contract validation by consensus algorithm in a different number of peer to peer nodes.

Fig.5: Time required for smart contract validation with different no. of P2P network in the blockchain.

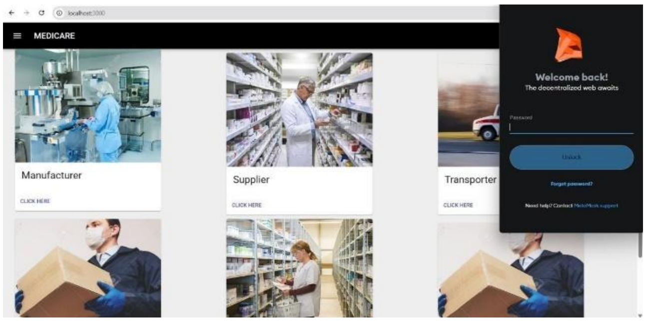


Fig.6: The UI of Application

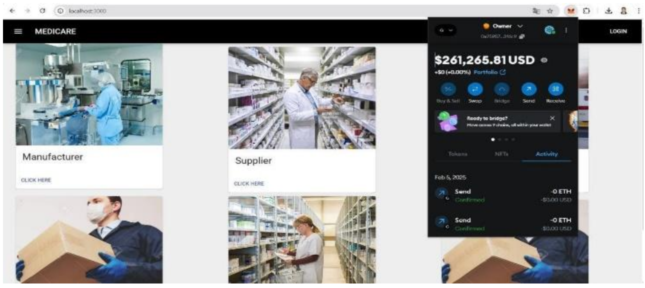


Fig.7: Metamask Login

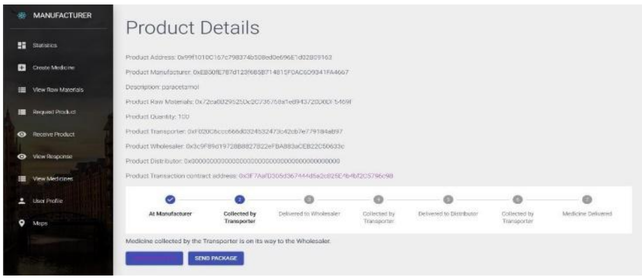
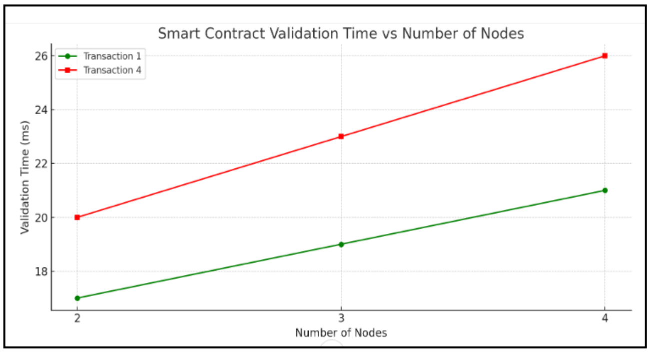


Fig.8: Tracking of Medicines



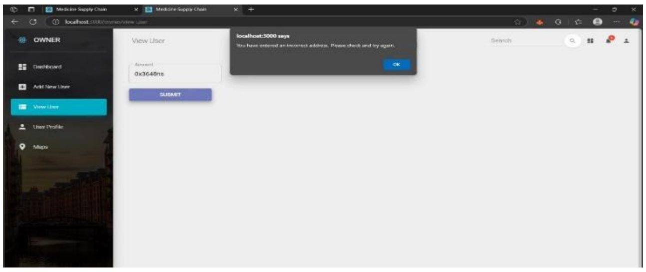


Fig.9: Security Alerts

V. CONCLUSION

The proposed blockchain-based medicine supply chain management system enhances security, transparency, and efficiency in pharmaceutical logistics. By integrating decentralized storage, smart contracts, and secure validation mechanisms, it ensures a reliable, tamper-proof, and compliant pharmaceutical supply chain. This innovative approach can revolutionize the industry by reducing fraud, improving drug authenticity, and fostering trust among stakeholders. As blockchain technology evolves, its adoption in the pharmaceutical sector will further strengthen the integrity and efficiency of medicine supply chains worldwide.

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