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A Blockchain –Based Framework for Transparent, Immutable, and Secure Vaccine Supply Chains

Ritesh Abuj[1], Shreyash Chougule[2], Narendra Sonawane[3], S.G.Joshi [4]

Department of Computer Engineering, Vishwabharati Academy's College of Engineering, Ahmednagar, India [1,2,3]

Professor, Department of Computer Engineering, Vishwabharati Academy's College of Engineering, Pune, India[4]

ABSTRACT: A cognitive radio(CR) is a transceiver which automatically detects available channels in wireless spectrum and accordingly changes its transmission or reception parameters. In this paper, it proposes an algorithm for the energy-efficient and spectrum- aware communications requirements in CR network. It enables each node to determine and regulate its transmission strategy to provide minimum energy consumption without sacrificing end-to-end delay performance and also maximizes overall spectrum utilization. Spectrum sensing is one of the essential parameter to be considered in CR networks. Therefore, the security aspect of spectrum sensing should be addressed well. Using a Trust-Worthy algorithm, it improves the trustworthiness of the Spectrum sensing in CR-Networks. It implemented using Network Simulator-2.

KEYWORDS: Blockchain, Pharmaceutical Supply Chain, Smart Contracts, Drug Traceability, Data Provenance, Decentralized Storage, Counterfeit Prevention, Supply Chain Transparency, Immutability, Authenticatio.

I. INTRODUCTION

This project suggests a blockchain-based framework that uses smart contracts and decentralized storage to improve data provenance and traceability in the pharmaceutical supply chain. This strategy seeks to guarantee product authenticity, reduce the possibility of fake drugs, and do away with dependency on centralized authority or middlemen. One essential element is the smart contract system design, which gives all parties involved in the supply chain—raw material suppliers, manufacturers, distributors, pharmacies, hospitals, and patients—access to an unchangeable transaction history. The essential demand for traceable information in a complicated network of several stakeholders is met by this transparency at every level of drug distribution, which increases efficiency and accountability.

This blockchain-based solution addresses the major transparency and control issues that plague the pharmaceutical supply chain, which are made worse by its multi-tiered structure and a lack of information sharing among participants. These issues include centralized control, fragmented information flow, and stakeholder competition, which result in inefficiencies and allow counterfeit pharmaceuticals to enter the market. The presence of counterfeit drugs poses serious health risks, especially in developing countries where up to 30% of drugs may be counterfeit. The project describes the smart contract code and algorithms controlling pharmaceutical product traceability and verification in order to verify the efficacy of the system. A continuous and unchangeable record of the drug's path from producer to end user is maintained by these algorithms, which are made to track and document every transaction in the supply chain. In order to evaluate the system's performance, we also offer a variety of implementation techniques and testing scenarios. Our results show that the suggested approach greatly improves traceability, lowers inefficiencies, and offers a general framework that can be applied to many pharmaceutical goods. The system's transparent and decentralized architecture fosters confidence among participants and establishes a new benchmark for thwarting counterfeit goods in the world's pharmaceutical supply chain.

II. METHODOLOGY

The development of a blockchain-based framework for vaccine supply chain management involves several structured steps to ensure transparency, immutability, and security. Initially, a comprehensive requirement analysis is conducted to identify the key stakeholders such as manufacturers, distributors, hospitals, and regulatory bodies. This step also defines the essential system requirements, including real-time tracking, secure data sharing, and tamper-proof record maintenance. Based on these needs, a suitable blockchain platform like Ethereum or Hyperledger is selected. Following

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this, the system architecture is designed using a modular approach. A permissioned blockchain network is preferred to restrict access to authorized entities only. Smart contracts are implemented to automate transactions across the supply chain, and large data such as compliance documents or reports can be stored securely using IPFS or cloud storage. The main functional modules of the system include user registration with role-based access, vaccine lot creation and tracking, integration with temperature and condition monitoring systems, and the maintenance of an immutable transaction log for auditing purposes. Smart contract development is a critical phase where decentralized logic is coded to manage tasks such as registering participants, recording transactions, validating authenticity, and detecting tampering. These smart contracts ensure the automation of key processes and maintain the integrity of supply chain events.The frontend of the system is developed using Angular to provide an interactive interface for various stakeholders, while the backend is built using technologies like Node.js or Flask to manage API calls and blockchain interactions. Additionally, Firebase may be utilized to enhance real-time data access, notifications, and secure user authentication, offering a hybrid storage solution where necessary. The next step is blockchain integration, where smart contracts are deployed on a test network such as Ropsten or Goerli using tools like Remix IDE or Truffle. Interactions between the application and the blockchain are managed through libraries like Web3.js or ethers.js. Rigorous testing and validation are carried out by simulating real-world vaccine distribution scenarios to ensure that the system maintains data integrity, provides accurate updates, and enforces access control effectively.Finally, the system is deployed on a reliable cloud platform, such as Firebase or AWS, followed by regular maintenance and security audits of the smart contracts. Feedback is collected from pilot users to continuously improve the usability, trustworthiness, and performance of the platform.

III. MODELING AND ANALYSIS/ARCHITECTURE

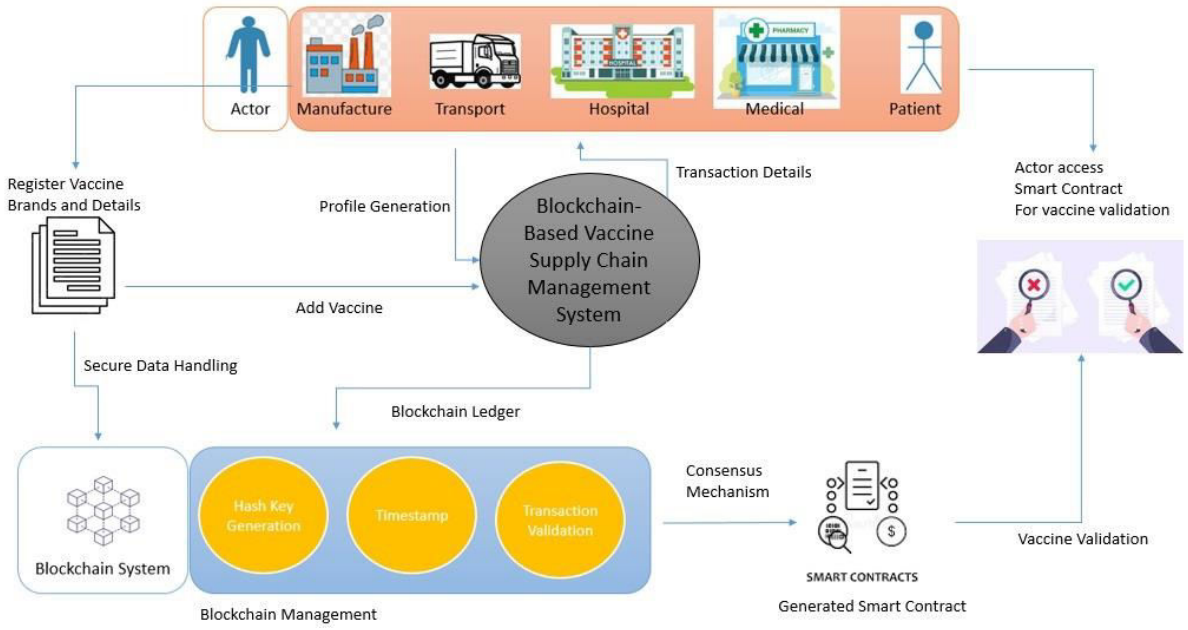

Fig. System Architecture

Smart contracts and decentralized storage are used in the paper's blockchain-based pharmaceutical supply chain traceability solution to guarantee the safe, transparent, and unchangeable tracking of pharmaceutical products from suppliers of raw materials to end users. Suppliers of raw materials, manufacturers, distributors, pharmacies, hospitals, and patients are all part of the intricate network that is the supply chain. It is challenging to properly track items because of its complexity, centralization, and lack of transparency, which can lead to the supply chain becoming infiltrated by fake drugs. . The suggested method uses blockchain to establish data provenance in order to overcome these issues, doing away with the need for middlemen and facilitating safe, traceable transactions for all parties involved. By guaranteeing that transactions are carried out in accordance with established conditions and that every stage of the supply chain is accurately documented, smart contracts—self-executing agreements with predetermined rules—enforce the system's operational principles. Since data cannot be changed once it is stored on the blockchain, these contracts are immutable, offering a high degree of security and confidence to all parties involved. The

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decentralized structure of the blockchain implies that no single entity controls the data, allowing all players to access the same version of the truth regarding the product's path through the supply chain Smart contracts are incorporated into the different phases of the pharmaceutical supply chain to operate the system. A pharmaceutical product's manufacturing details, including the producer, the source of the raw materials, the production batch number, and other pertinent data, are documented on the blockchain. Every transfer or transaction that takes place during the product's distribution process is documented on the blockchain, guaranteeing that the product's path can be fully tracked. This enables producers, distributors, and pharmacies, among other stakeholders, to confirm the product's legitimacy and make sure it hasn't been altered. Furthermore, by enabling real-time pharmaceutical tracking and monitoring, the technology enhances supply chain efficiency overall and keeps fake goods out of the market. Before approving a transaction, smart contracts automatically confirm that all necessary requirements are satisfied, guaranteeing adherence to legal requirements and thwarting fraud. Any attempts to change or fabricate the data are readily identifiable thanks to the decentralized ledger, which guarantees that everyone has access to the same information. This traceability framework is not restricted to any particular drug; rather, it is made to be flexible enough to be applied to any pharmaceutical product, guaranteeing reliable and dispersed traceability throughout the pharmaceutical supply chain. Because of its scalable design, the system can be used for a variety of pharmaceutical goods while still offering strong security and transparency standards. Layer uses speech-to-text techniques to record spoken responses and turn them into text. The NLP and Emotion Recognition Layer assesses user voice emotional cues and examines text for content relevancy. The Machine Learning Layer evaluates skills and assigns scores by comparing candidate replies to models that have already been trained. User information, interview scripts, and analytic findings are safely stored in the database layer. Personalized reports with ideas for improvement and strengths are produced by the Feedback Layer.

IV. SYSTEM OVERVIEW

The proposed blockchain-based framework is designed to enhance the efficiency, transparency, and security of vaccine supply chains by leveraging decentralized technologies. The system comprises multiple interconnected modules that collectively ensure the safe and reliable distribution of vaccines from manufacturers to end-users. At the core of the system is a permissioned blockchain network that records every transaction related to the vaccine supply chain, such as production, packaging, shipping, storage, and administration. Each stakeholder, including manufacturers, transporters, warehouses, healthcare facilities, and government authorities, is given role-based access to interact with the system through a secure and user-friendly interface. Smart contracts play a key role in automating critical operations and enforcing rules, such as verifying the authenticity of vaccine batches, triggering alerts during temperature deviations, and ensuring proper handover at each checkpoint. The system is integrated with IoT devices that monitor and log environmental conditions like temperature and humidity in real-time, which are crucial for maintaining vaccine efficacy. All data, once entered into the blockchain, becomes immutable, thereby preventing tampering or unauthorized changes. Furthermore, the system provides dashboards and tracking tools to help stakeholders monitor the real-time status of vaccine shipments, view historical records, and generate reports for audits or regulatory compliance. This blockchain-based solution eliminates the need for a central authority, reduces the chances of fraud, and enhances public trust in the vaccination process. Overall, the system is a comprehensive digital infrastructure aimed at securing and modernizing the vaccine supply chain. The overall goal of this cutting-edge technology is to enable people to improve their interviewing skills in an easy-to-use and interactive way, boosting their self-assurance and success in actual interviews..

V. ALGORITHM

1 Smart Contract Algorithm

Smart contracts are self-executing agreements that have their terms encoded directly into the code. The smart contract mechanism in this pharmaceutical supply chain system makes sure that all product movements, transfers, and transactions between various stakeholders—including manufacturers, distributors, pharmacies, hospitals, and patients—are safely documented on the blockchain. The method guarantees the immutability of the transaction history, verifies each action, and looks for necessary circumstances. It facilitates process automation, removes middlemen, and guarantees transparent, reliable execution.

2 Hashing Algorithm

Hashing techniques are commonly used in blockchain systems to guarantee data immutability and integrity. This system securely hashes every transaction, product data, and supply chain history using a cryptographic hashing technique such as SHA-256 (Secure Hash technique). Data that has been hashed is tamper-proof, which means that any

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attempt to change it will result in a change in the hash value, which makes it detectable. This guarantees the traceability and immutability of product information at every stage of the supply chain, including the legitimacy of medications and raw ingredients.

3 Consensus Algorithm (e.g., Proof of Stake)

A consensus algorithm is necessary to guarantee the blockchain's legitimacy and integrity. Since the study proposes a decentralized method, Proof of Stake (PoS) or comparable consensus techniques may be used. Based on their stake—that is, how much bitcoin or tokens they own—validators, also known as miners, are chosen to produce new blocks and verify transactions under proof-of-stake (PoS). By avoiding double-spending and guaranteeing that data contributed to the blockchain is genuine and verified, the consensus algorithm makes sure that all network users concur on the blockchain's current state.

4 Entity-Relation Algorithm

The links between different entities in the pharmaceutical supply chain are modeled with the aid of this method. The data model is represented by the Entity-Relationship Diagram (ERD), which illustrates the connections between entities like manufacturers, distributors, suppliers, and pharmacies. By properly tracing each transaction or record via its relationships along the supply chain, this algorithm aids in the organization and structuring of supply chain data.

5 Public Key Infrastructure (PKI) Algorithm

The blockchain system's communication and transactions are encrypted and secured using Public Key Infrastructure (PKI) methods. A public and private key pair would be given to each participant (suppliers, manufacturers, etc.), allowing for secure transaction signing and authentication. Common cryptographic algorithms for transaction security include RSA (Rivest-Shamir Adleman) and ECDSA (Elliptic Curve Digital Signature Algorithm), which guarantee that each party's identity is confirmed and that their transactions are safely stored on the blockchain.

6 Decentralized Storage Algorithm

Interplanetary File System (IPFS) or Storage could be utilized as the decentralized storage option to store data off-chain and guarantee that the data is still accessible. Participants can access data (such product details, shipment details, and batch records) as needed while preserving data confidentiality and integrity thanks to the algorithm's decentralized, distributed storage.

7 Transaction Validation

Algorithm Before being recorded on the blockchain, this algorithm makes sure that all transactions (such as product movements, ownership transfers, and shipments) across the supply chain are legitimate and satisfy predetermined requirements. Verifying that the product is in the right condition, that the right people are participating, and that any related metadata (such as batch numbers and expiration dates) is valid are all part of the validation process. This algorithm aids in preventing the addition of illegitimate or fraudulent transactions to the blockchain.

VI. RESULTS

The Blockchain-Based Vaccine Supply Chain Android App enhances the efficiency and transparency of vaccine distribution by automating critical processes such as vaccine tracking, inventory updates, and stakeholder communication. By leveraging blockchain technology, the system ensures secure, tamper-proof records, reduces delays in supply chain operations, and enables real-time monitoring of vaccine movement from manufacturers to end-users. This results in a more reliable, transparent, and accountable vaccine supply chain experience, accessible through a user-friendly mobile interface.

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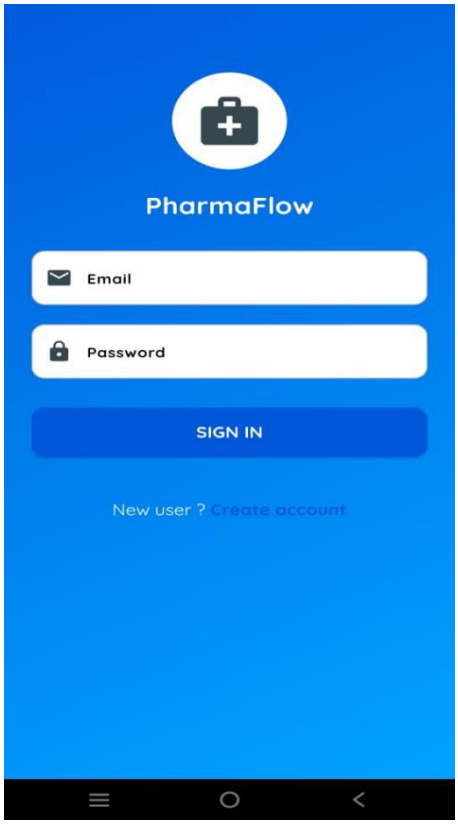

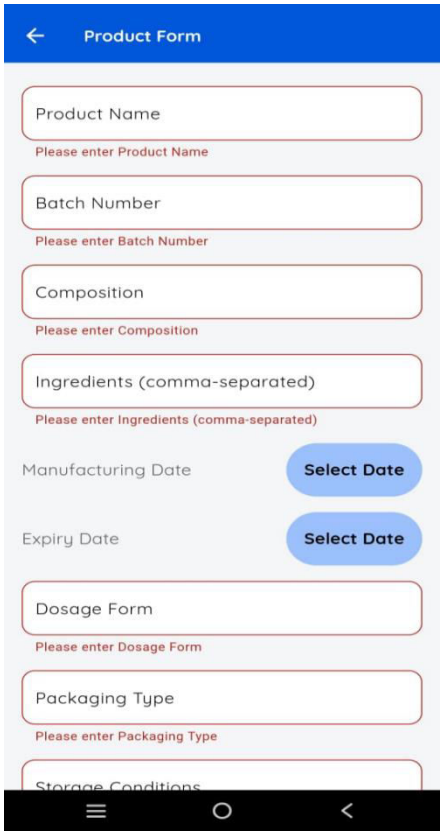

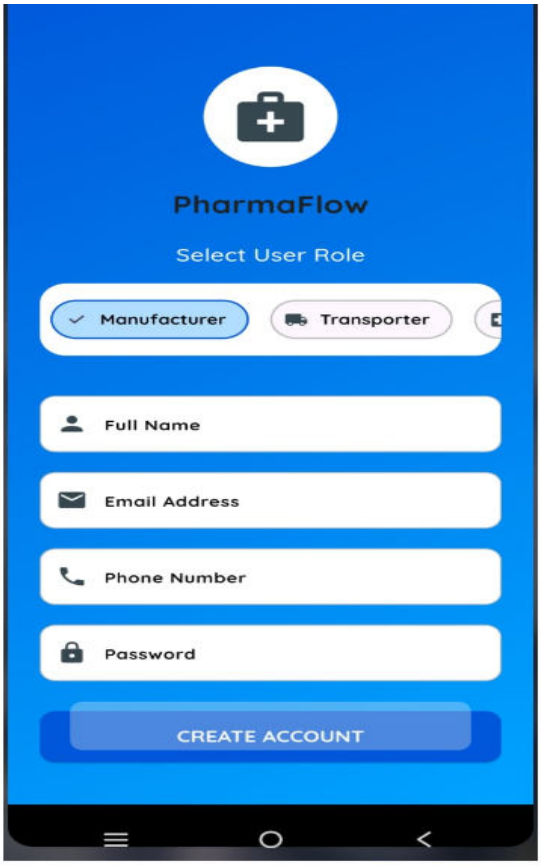

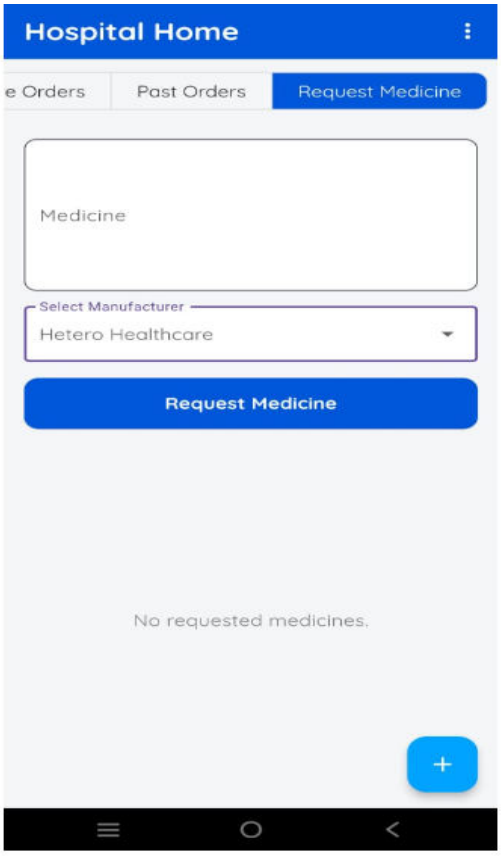

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VII. CONCLUSION

To sum up, this article offers a blockchain-based solution that tackles the intricacies and inefficiencies of the pharmaceutical supply chain, especially when it comes to fighting fake medications. The suggested approach guarantees data provenance, traceability, and immutability without the need for middlemen by leveraging smart contracts and decentralized storage, giving all participants access to a transparent and safe transaction history. The algorithms and architecture of the system have been proven to be effective in boosting traceability, which in turn improves product authenticity and protects public health. This strategy provides a reliable and scalable framework that may be used to guarantee the integrity of pharmaceutical supply chains around the world.

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