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A Blockchain Based Approach for Drug Traceability in Healthcare and Supply Chain

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ABSTRACT
This paper presents the complete implementation of a custom blockchain-based system for drug traceability in the healthcare supply chain. The system features an OTP-based verification mechanism to ensure secure delivery to the correct patient. Built on a proprietary blockchain framework, it ensures transparency, security, and protection against fraudulent activities. Performance evaluation highlights the system's efficiency, scalability, and reliability. This research demonstrates how blockchain technology and secure verification methods can enhance trust and safety in healthcare logistics.

Keywords: Blockchain, Drug Traceability, Healthcare Supply Chain, OTP Verification, Patient Safety, Transparency, Security, Fraud Prevention, Custom Blockchain, Healthcare Logistics.

1. INTRODUCTION

In modern healthcare systems, ensuring the authenticity and secure delivery of medicines is a significant challenge. The rise of counterfeit drugs and fraudulent deliveries poses severe threats to patient safety, demanding advanced technological solutions for traceability and verification. This research presents the complete implementation of a custom blockchain-based drug traceability system, which offers a secure, transparent, and efficient approach to managing the healthcare supply chain.

The backend of the project is developed using the Java programming language with a NoSQL database, ensuring high performance, scalability, and flexibility in managing large volumes of healthcare records. The frontend is designed using HTML and CSS only, providing a simple yet functional interface for all users. The system includes multiple pages, such as Dashboard, User Sign-In, User Sign-Up, Patient Panel, Admin Panel, Dealer Panel, About Us, and Contact Us, each serving a specific role in the traceability process.

During the Sign-Up process, users are required to register by providing necessary details, including the name of the hospital where they wish to be diagnosed. This hospital-centric registration system ensures that patient records are correctly associated with their respective healthcare providers. Once registered, users can log in through the User Sign-In page, where they can edit their personal information, apply for insurance, view their insurance history, and track their prescribed medicines.

The Hospital Page is a dedicated interface for healthcare providers. Upon logging in, hospitals can fill in

patient details, including medical conditions and diagnostic information. Additionally, hospitals can search for specific patients and prescribe medicines directly through the system. At this point, the hospital's role is complete, and the responsibility shifts to the Admin.

The Admin Panel plays a crucial role in the medicine delivery process. After reviewing the hospital's prescription, the admin assigns a Dealer for medicine delivery. The delivery process is designed to be secure and direct, involving only the dealer and the patient, with no third-party logistics partners. To ensure that medicines reach the intended patient, an OTP-based verification system is implemented. The system sends a unique OTP to the patient's registered email, and the dealer delivers the medicine only after receiving the correct OTP from the patient. This mechanism prevents unauthorized deliveries and eliminates the risk of black-market sales, such as those witnessed during the COVID-19 pandemic with critical drugs like Remdesivir.

The Sign-Up and Sign-In pages are shared among three user types: Hospital, Patient, and Dealer, while the Admin has a separate login page to manage assignments and oversee the delivery process.

Overall, this custom blockchain-based system integrates secure authentication methods with transparent record-keeping, ensuring that only authorized patients receive their prescribed medicines. The project highlights the potential of blockchain technology combined with OTP-based verification to transform drug traceability, enhance patient safety, and prevent fraudulent activities within the healthcare supply chain.

1.1 OVERVIEW OF THE BLOCKCHAIN-BASED DRUG TRACEABILITY SYSTEM

The blockchain-based drug traceability system is designed to enhance security, transparency, and efficiency in the healthcare supply chain. This project uses a custom blockchain to ensure that medicines reach the correct patients, preventing fraudulent deliveries and black-market sales. The system plays a crucial role in maintaining trust within the healthcare sector, especially in scenarios where life-saving drugs are in high demand. By leveraging blockchain technology, the project offers a secure, immutable ledger that records every transaction, from prescription to delivery.

A key feature of this system is the implementation of an OTP-based verification mechanism, which ensures that medicines are delivered only to the intended recipients. When a patient places an order for medicine, a unique OTP is sent to their registered email. The delivery dealer will hand over the medicine only after verifying this OTP, which prevents unauthorized deliveries and reduces the risk of fraud, such as those seen during the COVID-19 pandemic with medicines like Remdesivir.

The system is developed with a Java-based backend and a NoSQL database, providing scalability and efficient data management. The frontend is created using HTML and CSS, ensuring a user-friendly interface for all participants. The project includes various interactive pages such as the Dashboard, User Sign-In and Sign-Up pages, Hospital Panel, Patient Panel, Dealer Panel, Admin Panel, About Us, and Contact Us pages.

The sign-up process is designed for multiple users—hospitals, patients, and dealers—who share the same sign-in page, while the admin has a separate login interface. During registration, patients are required to specify the hospital where they wish to receive treatment, ensuring proper association of medical records. Once logged in, patients can manage their profiles, apply for insurance, review their insurance history, and track their medications.

The hospital page allows healthcare providers to input patient details, including their diagnosis and prescribed medicines. After the hospital submits the prescription, the admin assigns a dealer for the delivery of the prescribed drugs. Notably, the delivery process does not involve third-party logistics providers; instead, it is handled directly between the dealer and the patient, with the OTP verification

serving as a security checkpoint.

1.2 TECHNOLOGY STACK AND SYSTEM ARCHITECTURE

The technology stack for this blockchain-based drug traceability system comprises a combination of backend, frontend, and database technologies. The backend is developed using Java, ensuring strong performance and compatibility with the NoSQL database used for storing transactional data. The frontend employs HTML and CSS for a simple and user-friendly interface. Eclipse Oxygen serves as the primary development environment, and Tomcat 8.5 is used as the web server to host the application.

The system architecture outlines the interaction between patients, hospitals, dealers, and the blockchain. Patients initiate the process by signing up and submitting their information, including hospital details. Hospitals then access the system to update patient records and prescribe medicines. The blockchain layer manages critical operations such as hash generation, mining, transaction validation, and historical record storage. The admin assigns a dealer for delivery, and the dealer requires the patient's OTP to complete the handover, ensuring secure and authenticated delivery.

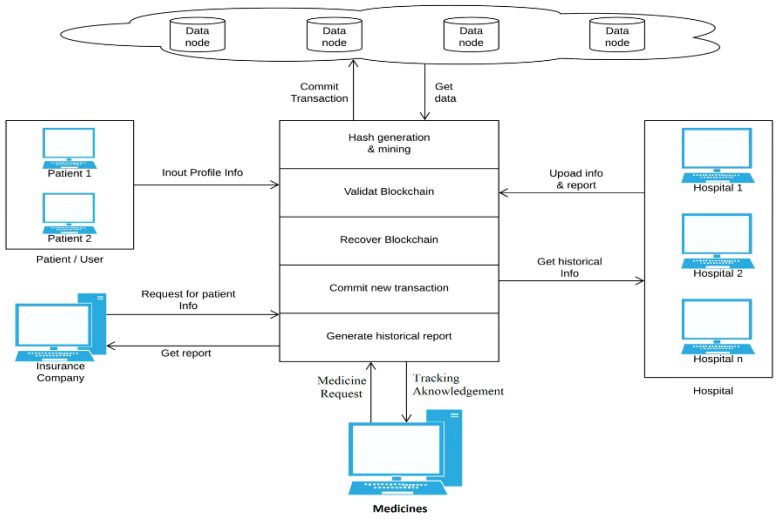

Figure 1 : System Architecture

The architecture also highlights data flow to insurance companies, which can access patient records for verification purposes. Data nodes are responsible for storing all blockchain transactions, ensuring security, transparency, and traceability throughout the system.

2. SYSTEM IMPLEMENTATION AND MODULES

The blockchain-based drug traceability system comprises several key modules designed to ensure secure, transparent, and efficient healthcare operations. Each module plays a vital role in managing users, hospital records, blockchain operations, and delivery verification processes.

The User Management Module enables hospitals, patients, and dealers to register and log in through dedicated interfaces, maintaining secure access and user authentication. The Hospital Operations Module allows hospitals to input patient information, diagnose illnesses, and prescribe medications. This module ensures that all patient data is securely stored and accessible only through authorized channels.

The Blockchain Integration Module powers the system’s security and transparency by handling crucial processes such as hash generation, peer verification, and mining. This module guarantees data integrity by securely recording transactions and preventing unauthorized alterations.

The Delivery Verification Module adds another layer of security using an OTP-based authentication system. Patients receive a unique OTP via email, which they must provide to the dealer during delivery. This feature prevents fraudulent deliveries and ensures that only the intended recipient receives the prescribed medication.

Collectively, these modules integrate seamlessly to create a secure, transparent, and efficient drug traceability system, protecting patient data and ensuring the authenticity of every transaction recorded on the blockchain.

Table 1: Modules with their Functionality

Module	Function
User Management	Manages hospital, patient, and dealer registrations with secure logins and authentication.
Hospital Operations	Records patient data, diagnoses, and prescriptions with authorized access controls.
Blockchain Integration	Oversees hash generation, peer verification, and mining to maintain data integrity.
Delivery Verification	Uses OTP-based authentication to ensure only the intended recipient receives the medicine.

2.1 DATA SECURITY AND INTEGRITY IN BLOCKCHAIN-BASED DRUG TRACEABILITY

In the pharmaceutical industry, ensuring the security and integrity of drug-related data is crucial to prevent counterfeit medicines, unauthorized modifications, and data breaches. Blockchain technology provides a robust solution by offering a decentralized, tamper-proof system where all transactions are securely recorded and verified.

One of the key advantages of blockchain in drug traceability is its ability to create an immutable ledger. Once a transaction, such as drug manufacturing, distribution, or delivery verification, is recorded on the blockchain, it cannot be altered or deleted. This ensures that all records remain accurate and trustworthy, preventing fraudulent activities like altering drug expiration dates or faking batch numbers. Each transaction is linked to a cryptographic hash, making it impossible to modify previous records without detection.

Another important aspect of data security in blockchain-based drug traceability is encryption. Patient information, prescription details, and drug delivery records are stored in an encrypted format, allowing only authorized users, such as hospitals, pharmacies, and regulators, to access them. This prevents unauthorized access and protects sensitive medical data from cyber threats. Furthermore, access control mechanisms ensure that different stakeholders have different levels of permissions, preventing misuse or accidental modification of critical data.

Peer verification is another security feature that strengthens data integrity. In a blockchain network, every transaction undergoes validation by multiple nodes before being added to the ledger. This consensus mechanism ensures that only legitimate transactions are recorded, eliminating the possibility of fraudulent data entry. Since there is no central authority controlling the records, manipulation or corruption of data becomes extremely difficult.

To enhance trust and compliance, blockchain-based drug traceability systems also incorporate smart

contracts. These self-executing contracts enforce predefined rules, such as verifying a drug's source, confirming batch authenticity, or triggering alerts if suspicious activity is detected. For example, if a counterfeit medicine enters the supply chain, the blockchain can immediately flag the discrepancy and notify the relevant authorities, preventing its distribution.

Additionally, blockchain provides end-to-end visibility across the drug supply chain. Every stakeholder, from manufacturers to patients, can trace a drug's journey in real time. This transparency not only ensures regulatory compliance but also helps in quick recall of defective or expired drugs. If a patient receives a faulty medicine, the blockchain can instantly identify its source and distribution path, facilitating a swift response.

By implementing blockchain technology for drug traceability, the healthcare industry can significantly reduce fraud, enhance data security, and ensure that only genuine medicines reach patients. The combination of cryptographic security, decentralized verification, and immutable records makes blockchain an ideal solution for maintaining data integrity in pharmaceutical supply chains.

2.2 BLOCKCHAIN SECURITY AND SMART CONTRACTS FOR DRUG VERIFICATION

The security of blockchain technology plays a crucial role in ensuring the authenticity and traceability of drugs in the healthcare supply chain. Blockchain uses cryptographic hashing, where each transaction is securely recorded, making it tamper-proof. Once a record is added, it cannot be modified without altering all subsequent blocks, ensuring data integrity. This feature prevents counterfeit drugs from entering the system by providing a transparent and verifiable history of every medicine.

Smart contracts enhance this security by automating drug verification processes. These self-executing contracts operate on predefined conditions, ensuring that only verified and authorized entities can record transactions. For instance, when a manufacturer logs a newly produced batch of medicine, the smart contract validates the entry and cross-checks it with predefined rules before allowing the transaction to be recorded. Similarly, when a hospital prescribes medicine, the smart contract verifies the prescription details before allowing further distribution. This automated approach eliminates human errors, speeds up the verification process, and ensures that only genuine drugs are distributed to patients.

2.3 COMPARATIVE ANALYSIS: TRADITIONAL VS. BLOCKCHAIN-BASED DRUG TRACEABILITY

Traditional drug traceability systems rely on centralized databases and paper-based records, which are prone to human errors, data manipulation, and security vulnerabilities. In these systems, a single entity often manages the records, increasing the risk of unauthorized alterations and data breaches. Moreover, tracing a drug's history in traditional systems can be time-consuming, as data must be collected from multiple sources, leading to delays in identifying counterfeit medicines.

Blockchain-based drug traceability overcomes these limitations by providing a decentralized, transparent, and immutable ledger. Every stakeholder, including manufacturers, hospitals, dealers, and patients, can access real-time records, ensuring complete visibility across the supply chain. Unlike traditional systems that depend on intermediaries for verification, blockchain eliminates the need for third-party involvement, reducing operational costs and minimizing the chances of fraud. Additionally, blockchain ensures that once a drug's details are recorded, they cannot be altered or deleted, maintaining authenticity throughout its lifecycle. This shift from centralized to decentralized verification significantly enhances security and efficiency, making blockchain the preferred choice for modern drug traceability.

3. CHALLENGES, REGULATORY COMPLIANCE, AND FUTURE SCOPE

Despite its advantages, implementing blockchain in drug traceability comes with challenges. One of the primary concerns is scalability, as blockchain networks require significant computational power and storage to maintain an ever-growing ledger. Additionally, integrating blockchain with existing healthcare IT infrastructure demands careful planning and collaboration among stakeholders. The adoption of blockchain also requires regulatory approval, as different regions have specific compliance requirements for drug traceability. Ensuring that blockchain-based systems align with global standards, such as those set by the FDA, WHO, and other regulatory bodies, is essential for widespread implementation.

Looking ahead, blockchain technology is expected to revolutionize drug traceability by integrating advanced features such as artificial intelligence (AI) and the Internet of Things (IoT). AI-powered analytics can enhance fraud detection by identifying unusual transaction patterns, while IoT-enabled smart packaging can provide real-time monitoring of drug conditions, such as temperature and humidity, during transportation. As blockchain adoption grows, collaborations between governments, pharmaceutical companies, and tech providers will play a crucial role in establishing a standardized, blockchain-powered drug traceability system that ensures transparency, security, and efficiency in the healthcare industry.

4. CONCLUSION

The integration of blockchain technology into drug traceability systems represents a groundbreaking advancement in ensuring the security, transparency, and efficiency of pharmaceutical supply chains. By leveraging blockchain's decentralized and immutable nature, the system effectively prevents counterfeit drugs, ensures real-time tracking, and enhances data security. The implementation of cryptographic techniques, peer verification, and smart contracts further strengthens the reliability of drug records, reducing the risk of fraud and unauthorized alterations.

With features like OTP-based delivery verification, encrypted medical records, and automated compliance monitoring, this system provides an end-to-end solution that benefits all stakeholders, including hospitals, patients, regulatory bodies, and pharmaceutical manufacturers. By eliminating third-party interference and ensuring only verified transactions are recorded, blockchain-based drug traceability significantly improves patient safety and regulatory adherence.

Overall, this approach establishes a more robust and trustworthy healthcare supply chain. As technology advances, further enhancements, such as AI-driven analytics and integration with IoT devices, can further optimize drug tracking, storage conditions, and predictive fraud detection. Blockchain technology is not just a tool for improving efficiency—it is a crucial step toward building a safer, more transparent, and corruption-free pharmaceutical industry.

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