Blockchain for Pharmaceutical Supply Chain Integrity: A Decentralized Approach to Combat Counterfeit Drugs

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Abstract—This study introduces a blockchain-based solution for tracking the pharmaceutical drug supply chain, enhancing transparency, security, and authenticity from production to final sale. By leveraging Ganache for blockchain simulation and MetaMask for account management, we establish a decentralized ledger that immutably records every transaction in a drug's lifecycle.

The system monitors each stage, from raw material sourcing to manufacturing, distribution, and retail, enabling authorized participants to update and track drug movement in real time. Smart contracts automate the verification process, ensuring compliance with predefined conditions at every stage.

This approach not only safeguards supply chain integrity but also provides a reliable audit trail for regulatory authorities, mitigating the risk of counterfeit drugs. End users, including consumers and pharmacies, can verify drug authenticity and safety, fostering a more secure and trustworthy pharmaceutical ecosystem.

Index Terms—Blockchain, Pharmaceutical Supply Chain, Transparency, Security, Smart Contracts, Counterfeit Prevention.

I. INTRODUCTION

Keeping drugs safe, legitimate, and intact along the supply chain is a major concern for the pharmaceutical sector. Problems including mishandled drugs, counterfeit drugs, and a lack of transparency present major health hazards to patients. Traditional supply chain systems often fail to provide the necessary transparency and traceability, making it difficult to ensure drug safety from manufacturing to end-user distribution.This project presents a blockchain-powered solution that establishes a transparent, decentralized, and immutable ledger to securely track every transaction in the pharmaceutical supply chain. By integrating Ganache for blockchain simulation and MetaMask for account management, the system enables seamless stakeholder interactions while ensuring real-time tracking of drug movement—from raw materials to manufacturing, distribution, and final retail.

At the heart of this system are smart contracts, which automate and enforce verification at every point of the supply chain, reducing human error and assuring secure, timely transfers. The technology improves not only openness and traceability but also regulatory compliance by providing an immutable audit trail for health authorities. This considerably reduces the possibility of fake medications getting into the supply chain.This blockchain-based method ensures accountability at every stage by giving all parties involved—manufacturers, distributors, pharmacies, and regulators—access to real-time, tamper-proof data. The ability to quickly confirm the security and legitimacy of the medications they buy benefits end users and promotes confidence in the pharmaceutical industry. The fragmentation, inefficiencies, and lack of transparency in the current pharmaceutical supply

chain techniques increase the risk of counterfeit goods and create regulatory obstacles. Outdated paper-based documentation and siloed digital systems hinder real-time tracking and data visibility, making it challenging to verify drug authenticity and comply with strict regulations such as DSCSA and FMD.

A blockchain-based solution revolutionizes the pharmaceutical supply chain by introducing a secure, decentralized ledger that enables:

- Real-time tracking of drugs at every stage.
- Enhanced drug authenticity verification to prevent counterfeits.
- Streamlined compliance with regulatory standards.
- Improved operational efficiency across the supply chain.

By securing the entire lifecycle of pharmaceuticals, this system drastically reduces the risk of counterfeit drugs, enhances regulatory adherence, and builds a safer, more reliable, and efficient pharmaceutical supply chain.

To further strengthen security, the project also implements a college student ID-based verification system, ensuring that only authorized students from specific campuses can access the application. This feature prevents unauthorized access to sensitive data, reinforcing security while maintaining a seamless user experience. This blockchain-driven approach not only transforms supply chain management but also sets a new standard for security, transparency, and trust in the pharmaceutical industry.

II. LITERATURE SURVEY

This study introduces an advanced blockchain-based approach for improving transparency, security, and traceability in the pharmaceutical supply chain. The suggested solution guarantees safe medication transportation from the acquisition of raw materials to retail distribution by utilizing Ethereum smart contracts, Ganache for blockchain simulation, and Meta-Mask for account administration. In contrast to traditional frameworks, this decentralized method reduces vulnerabilities, creates an unchangeable audit trail, guarantees regulatory compliance, and increases consumer trust in pharmaceutical products. [1]. The use of blockchain technology in supply chain management has been the subject of numerous investigations. Research on using Hyperledger Fabric for secure transactions has shown promise in enhancing pharmaceutical logistics security; nevertheless, these methods frequently lack scalability and real-time adaptation. [2, 3]. Moreover, technologies such as encrypted QR codes and RFID have been employed for drug traceability; however, they remain reliant on centralized verification mechanisms [4, 5]. Studies such as Drugledger have introduced service segmentation strategies to enhance data authenticity and privacy [6], while Medledger has utilized Hyperledger Fabric to establish permissioned blockchain networks for secure transactions [7]. Despite these advancements, many of these solutions remain theoretical, lack AI-driven automation, and are restricted to Windows-based environments, limiting their flexibility [8, 9]. The proposed system addresses these limitations by incorporating advanced technologies. Unlike prior studies, this research

integrates Dockerization, enabling seamless deployment across Linux, macOS, and Windows, thereby ensuring cross-platform compatibility and enhanced accessibility. Additionally, the system leverages an AI-powered chatbot to provide real-time updates, automate responses, and facilitate decision-making for stakeholders . These innovations contribute to a more scalable, intelligent, and practical blockchain-based pharmaceutical tracking system, establishing a new standard for supply chain management.

III. METHODOLOGY

The blockchain-based pharmaceutical supply chain solution's implementation architecture consists of numerous components that work together to create a safe, efficient, and user-friendly platform for drug tracking. The architecture's modular form makes it easier to scale and maintain. The main elements and their interactions are depicted in the block figure further down, which also shows the application's methodology as shown in Fig. 1.
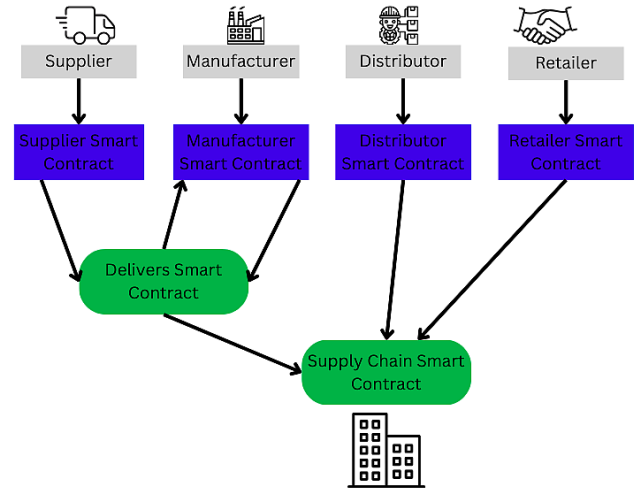

Fig. 1. Workflow of the site.

A. Implement a Secure Tracking System

Develop a blockchain-based platform that securely records every transaction in the drug supply chain, ensuring that stakeholders can verify the authenticity and journey of pharmaceuticals from production to sale. This will enhance trust and accountability in the system [8].

B. Blockchain Perform

The core application is where users (manufacturers, distributors, retailers, and regulators) interact with the pharmaceutical tracking system.

C. User Interface (UI)

Represents the graphical interface through which users navigate the application, view drug tracking information, initiate transactions, and access features like the knowledge base [8].

D. User Authentication

Verifies user credentials, ensuring that only authorized stakeholders can access the system. This includes implementing secure login methods and access control.

E. The system comprises the following actors:

- Raw Material Supplier: Records the source and quality of raw materials.
- Manufacturer: Registers production details and quality checks.
- Distributor: Tracks logistics data and ensures temperature control.
- Retailer: Verifies product authenticity before selling.

The system leverages Ethereum Smart Contracts for secure and automated transactions. The Hyperledger Fabric framework is considered for permissioned networks where stakeholders have defined roles and access controls.

F. Blockchain Database

The blockchain securely stores drug movements, user profiles, and compliance records, ensuring data integrity and transparency across the supply chain[9].

IV. PROPOSED SYSTEM

The flowchart demonstrates the Proposed system as shown in Fig. 2.

A. User Enters the App

The user accesses the app's splash screen

B. Check for Existing Account

- If the user already has an account, proceed with login process.
- If not, display the register user screen.

C. Login Process

- User enters their username/email and password.
- The system validates the credentials.
- If valid, redirect to the home screen.
- If not, display an error message.

D. Registration Process

- User clicks on the registration.
- User provides necessary information (e.g.,name, email, password).
- The system validates the information.
- If valid, create a new account and redirect to the home screen.
- If not, display an error message.

E. Home Screen

After successfully logging in or registering, the user is redirected to the home screen.The home screen displays various roles, allowing users to select their specific functions such as Raw Produce, Manufacturer, Distributor, Retailer, Logout Button.
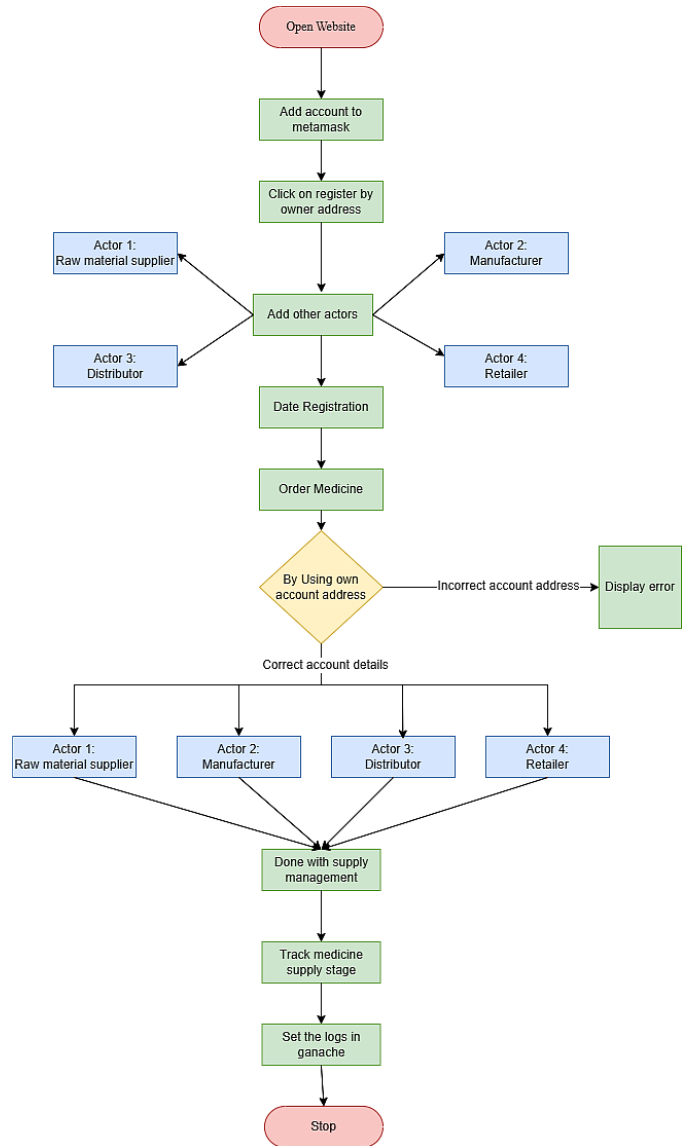

Fig. 2. Process Diagram of site.

F. Tracking Section

In this section, the user can view a list of drugs along with their tracking information. Users can select a specific drug to view its journey through the supply chain, including current status and location.

G. Logout

User can log out from their account by clicking the logout button. After logging out, they are redirected to the login or registration page.

V. RESULTS

To set up the system, first connect Metamask Fig. 4 to the Ganache blockchain by starting the workspace you created, and entering the Metamask password to initiate the connection. Ganache will then display 10 Ethereum accounts as shown in

Fig. 3. In the settings, you can see the workspace details and confirm the connection with Truffle's configuration file, where the server connects to the specified host and port. Only the owner can perform registration by importing accounts from Ganache using private keys. The owner adds various actors like the raw material supplier, manufacturer, distributor, and retailer by registering their details, such as name, location, and Ethereum address.

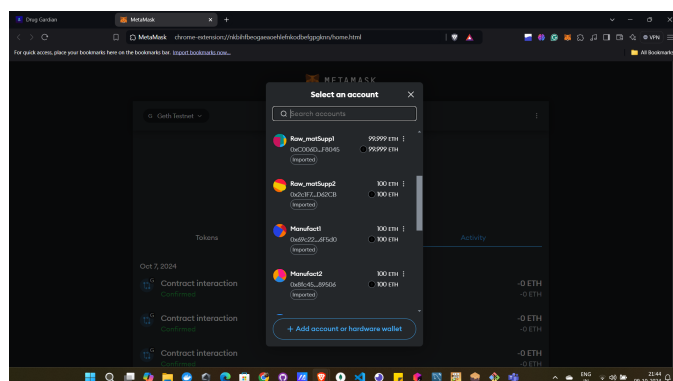Fig. 3.   Ganache Account details page.

Fig. 4.   Metamask Account of actors.

After registering the actors, the owner can add the medicine to be manufactured. Each actor performs their specific task using their respective accounts, such as the supplier providing raw materials by adding the medicine ID. Once all tasks are completed, the medicine can be tracked by entering its ID, allowing any actor to check its status as needed. This setup ensures clear roles and responsibilities among all involved parties while enabling efficient tracking of medicines.

VI. CONCLUSION AND FUTURE SCOPE

The Drug Guardian platform improves the drug supply chain's efficiency, security, and transparency by leveraging blockchain technology. The technology guarantees that all parties involved—manufacturers, distributors, pharmacies, and patients—have access to precise and up-to-date information about the provenance and validity of drugs by utilizing decentralized ledgers. This strategy not only reduces the possibility of fake medications reaching the market, but it also increases user trust. The platform architecture addresses major difficulties in the pharmaceutical business, including traceability, regulatory compliance, and data integrity. Through continuous development, medication Guardian strives to improve the medication supply chain, contributing to better healthcare results and patient safety.

Improving Compatibility with Current Systems Future initiatives will prioritize integrating the Drug Guardian platform with existing healthcare systems, such as EHRs and pharmacy management systems. This will enhance stakeholder collaboration alongside information flow. The Drug Guardian platform will evolve to ensure the integrity and safety of the drug supply chain, benefiting both patients and healthcare practitioners.

For more details, visit the project repository at: GitHubRepository.

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