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A Comprehensive Review of Blockchain Integration in Pharmaceutical Supply Chain Management

[1]Prof. Balaji Chaugule, [2]Sahil Pardeshi, [3]Sanchit Nawale, [4]Sanskriti Shinde, [5]Prajakta Nirale

[1]Lecturer, Department of Information Technology, Zeal College of Engineering and Research, Pune, Maharashtra, India
[2,3,4,5]U.G. Student, Department of Information Technology, Zeal College of Engineering and Research, Pune, Maharashtra, India

***Abstract* - The pharmaceutical supply chain is an organization of interrelated tasks that includes all aspects of the creation, transport, and distribution of medications. The pharmaceutical sector has several challenges to ensure transparency, safety, authenticity, and fraud. Drugs that are counterfeit and traceability are the two most common problems. Blockchain technology can offer remedies like transparency, security, and complete traceability along the whole pharmaceutical supply chain. via joining blocks together using methods of cryptography, a chronological chain comprising data is created through blockchain. Furthermore, it provides a decentralized, immutable ledger for open data and transaction recording. Blockchain technology's primary feature, decentralization, lowers the risk associated with relying on a single point of failure. An Ethereum blockchain-based pharmaceutical supply chain architecture is presented in this article. By automatically enabling and confirming contract agreements, smart contracts allow parties to engage in automated, trustless transactions. The design and development of a web application make use of the React Framework. The Blockchain will be connected to this application, showing every relevant detail about transactions, shipping, and counterfeit medicinal products.**

Keywords: Immutable Ledger, Decentralization, Smart Contracts, Blockchain, Ethereum, and Transparency.

I. INTRODUCTION

The Pharmaceutical supply chain network serves as the intricate mechanism through which manufactured prescription medications are disseminated to patients this supply chain proves exceptionally intricate spanning over several months or even longer across diverse regions globally it encompasses various key entities such as suppliers manufacturers transporters wholesalers distributors retailers and more consequently the task of monitoring each pharmaceutical product throughout this extensive network and tracing its origin becomes a challenging endeavor the issue of counterfeit drugs represents a pressing global concern according to reports from the health research funding organization developing countries grapple with counterfeit drugs with an estimated 10-30% of pharmaceuticals being fraudulent counterfeit products pose a significant threat due to their potential to cause adverse health effects alarming statistics from the world health organization reveal that approximately 30% of all medications sold in Africa Asia and Latin America are counterfeit the overarching concern lies not only in the existence of counterfeit drugs but also in their capacity to induce distinct health complications compared to genuine medications.

The prevailing lack of transparency in the current system presents a formidable challenge for customers and buyers, impeding their ability to accurately assess product value and investigate potential tampering within the supply chain, particularly in cases of suspected illegal or unethical activities. Consequently, these supply chains often experience inefficiencies as vendors and suppliers grapple with the complexity of establishing connections among various entities and discerning their specific needs. Customers and buyers currently face significant hurdles in determining the genuine worth of goods due to the pronounced lack of clarity within the existing system. Moreover, uncovering evidence of improper or immoral conduct within the chain proves exceptionally intricate.

These issues can also lead to unreliability, as retailers and manufacturers wrestle with identifying who requires what, when, why, and how. Blockchain, on the other hand, stands as a revolutionary remedy. It introduces a decentralized and tamper-resistant Hyperledger, free from centralized control. Each transaction etched onto the blockchain remains immutable, safeguarding sensitive data like drug and customer information. Furthermore, blockchain fosters complete transparency, rekindling trust among the principal entities comprising the Supply Chain, encompassing Manufacturers, intermediaries like Distributors and Suppliers, and end-users such as Customers, Retailers, and Hospitals. Additionally, the blockchain facilitates seamless product transfers between authenticated entities through an event request-response mechanism, with smart contracts dutifully recording all transactions among these entities.

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II. RELATED WORK

Due to the introduction of a decentralized and tamper-proof Ethereum Blockchain that is free from centralized control, blockchain stands out as a revolutionary treatment. To identify our challenge, we referenced earlier research articles' methodology and approaches.

The implied system's architecture and algorithms, outlined by K.C.Bandhu et al. [1], are designed to overcome the transparency and tracking issues that traditional supply chains have. It makes use of Solidity smart contracts and has undergone extensive testing using a broad range of inputs, yielding an average gas cost for particular capabilities. This solution allows a continuous flow of medications through blockchain and smart contracts, boosting security and traceability compared to current approaches. It is an important development step for a safe pharmaceutical supply chain application in the blockchain 4.0 era. The track-and-trace mechanism for the healthcare supply chain is presented in this paper as an Ethereum blockchain-based solution that makes use of smart contracts and data immutability.

By providing a standardized method for developing Blockchain solutions in non-financial applications and presenting insights into practical obstacles and opportunities, notably in the context of digital supply chains and logistics, G. Perbouli et al.'s [2] paper bridges the gap. The article illustrates the results of a fresh food delivery use case, showing the difficulties in actually putting a Blockchain solution into reality. Additionally, it looks at how Blockchain technology might help save costs associated with logistics, improve operations, and pinpoint areas for further study and development in this developing industry.

Sherwyn D'souza and coworkers [3] In order to address these pressing problems, this article offers a creative approach that combines the power of two cutting-edge technologies, namely Blockchain and Artificial Intelligence (AI). Through an event request-response system, any product moving through this chain experiences frictionless transfers between authenticated entities. An important step has been reached with the creation of a decentralized application (DApp) utilizing the React Framework.

A proof-of-concept experimental system was created by Kentaroh Toyoda et al. [4] using Ethereum, a platform for decentralized applications based on blockchain technology. created a system for product ownership management that offers post-supply chain protection against counterfeiting of RFID items. By confirming the seller's ownership status, customers are now able to recognize and reject fake goods even when the RFID tag information appears to be accurate.

In their work, Jamil et al. [5] offer a revolutionary strategy: a medication supply chain management system based on the blockchain technology Hyperledger Fabric. By transacting on a blockchain for drug record transactions, it develops a smart healthcare ecosystem. Smart contracts are also included to offer time-limited access to electronic drug records and patient health records. Hyperledger Caliper was used in the study as a benchmarking tool to assess the system's performance.

Q. Zhu and others [6]. Multiple steps in the process of product deletion—including recognition, analysis, evaluation, and implementation—depend on precise supply chain data. Rational product deletion can be seriously threatened by errors in information generation, comprehension, or assessment. In this essay, the potential of blockchain technology is examined in relation to these informational difficulties. Additionally, it offers managerial advice and proposals for integrating blockchain into the decision-making process for product elimination. huang yan et al [7] designed a drug tracking and regulation is introduced in this paper compared to other systems drugledger's peer-to-peer p2p architecture increases robustness it also effectively handles storage producing a reliable and respectable method for storing blockchain data the system uses algorithms that are based on the extended unspent transaction output [utxo] workflow and simulate genuine drug supply chain activities.

J.Ma, S.Ma et al [8] describes characteristics like decentralized and tamper-proof of blockchain technology has become more popular in a variety of applications most notably bitcoin which successfully handles double-spending and transaction record authenticity without counting on centralized control customers can use the system low transaction costs all but removing worries about fake goods manufacturers can transparently keep data about product sales such as sales caps and remaining stock levels on blockchain giving users ability to perform to vendor-side verification in real time digital signatures ensure identity verification increasing security.

III. PROPOSED SYSTEM

Our proposed system aims to use blockchain's power to create a strong network that brings together pharmaceutical companies, contract manufacturers, suppliers, logistics and shipping companies, wholesalers, distributors pharmacies and hospitals. This network firmly rooted in blockchain aims to build confidence and trust in the pharmaceutical supply chain which leaves no room for doubt about the authenticity of every medication and related products in the world of blockchain every transaction between two parties is recorded in a digital ledger that's shared among everyone transparency is the key here every participant in the blockchain network is

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fully aware of every transaction and updates their records accordingly our system connects a diverse group of entities suppliers, transporters, manufacturers, wholesalers distributors and customers or retailers. They all seamlessly work together through a decentralized network each participant has a unique ethereum account that represents who they are and what they do in this complex supply chain this approach represents a groundbreaking use of blockchain technology that has the potential to change the pharmaceutical supply chain by ensuring an exceptional level of transparency and authenticity.

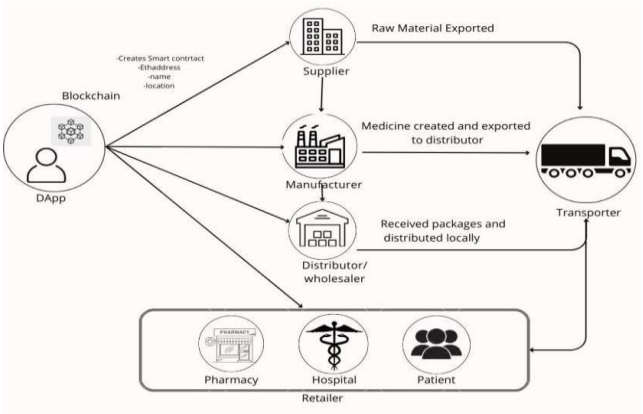

Figure 1: System Architecture of the application

The specific roles and responsibilities of these nodes are meticulously defined:

1. Supplier

- GENERATE: Suppliers possess the capability to generate and introduce novel raw materials into the blockchain, initiating the record-keeping process.
- RETRIEVE: They can access the addresses of the raw materials they've created, streamlining the tracking and management of materials within the system.

2. Manufacturer

- ACCEPT: Manufacturers receive raw materials from suppliers through the intermediary of transporters, commencing the production process.
- CONFIRM: They confirm the source and authenticity of the received raw materials, ensuring quality control.
- PRODUCE: Manufacturers employ verified raw materials to fabricate new medicines, further enhancing the blockchain with product data.

3. Wholesaler

- Receive: Wholesalers take delivery of medicines from manufacturers via transporters, marking a pivotal step in the supply chain.
- Verify: They verify the source of medicines received, confirming their legitimacy and quality.
- Transfer: Wholesalers facilitate the smooth transfer of ownership of medicines, enabling the products to progress along the supply chain.

4. Transporter

- VALIDATE: Transporters assume a pivotal role in validating the packages they handle, assuring the authenticity of raw materials or medicines.
- COLLECT: Depending on the type of transporter (e.g., raw material or medicine transporter), they collect packages from the respective entity, adhering to defined protocols.
- DELIVER: Transporters are entrusted with the responsibility of conveying products to their designated recipients or entities, upholding the reliability and timeliness of supply chain operations.

5. Distributor

- Receive: Distributors receive medicines from wholesalers through the services of transporters, marking a continuation of the supply chain process.
- Verify: They play a role in verifying the source of medicines, upholding the chain's commitment to authenticity.
- Transfer: Distributors, like wholesalers, partake in the critical process of transferring ownership of medicines, ensuring seamless transitions.

6. Customer

- Receive: Customers receive medicines from distributors via transporters, representing the final leg of the supply chain journey.
- Verify: They engage in verifying the source of medicines, safeguarding the integrity of the products they receive.
- Place Orders: Customers have the privilege of placing orders through the Rasa chatbot, streamlining the ordering process for medicines.
- Get Information: Additionally, they can access essential medical drug information through the system, promoting informed decision-making.

Finally, customers, empowered to receive medicines, verify their source, and access essential medical drug information, play a pivotal role in this comprehensive system. This holistic approach stands as a groundbreaking application of blockchain technology, poised to transform the pharmaceutical supply chain by introducing unparalleled levels of transparency and authenticity.

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3.1 Process Flow:

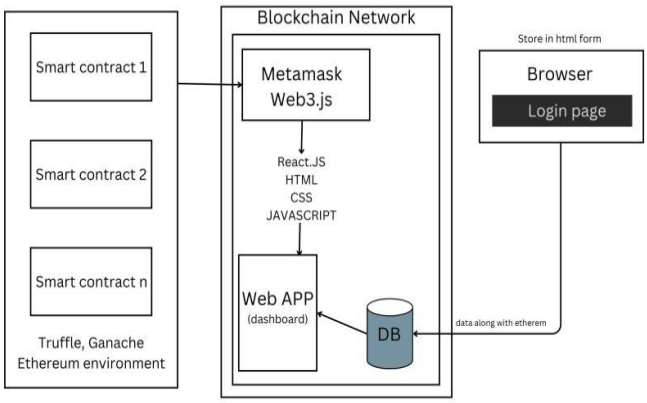

Figure 2: Block Diagram of the application

1) All entities will register on the DApp with necessary details which will trigger an event and notified to all entities.
2) Supplier will add new raw material to smart contracts for sale notifying all entities in supply chain.
3) Supplier updates the product status and creates a transaction in Transaction Contract.
4) Manufacturer verified the source of raw material and updates product status in Transaction Contract.
5) Manufacturer registers new medicine which is added to medicine contract.
6) Manufacturer updates the product status in transaction contract.
7) Wholesaler verifies the source of raw material and updates the product status in Transaction Contract.
8) Distributor verifies the source of raw material & updates product status.
9) Customer verifies the source of medicine through medicine id.

3.2 Methodology:

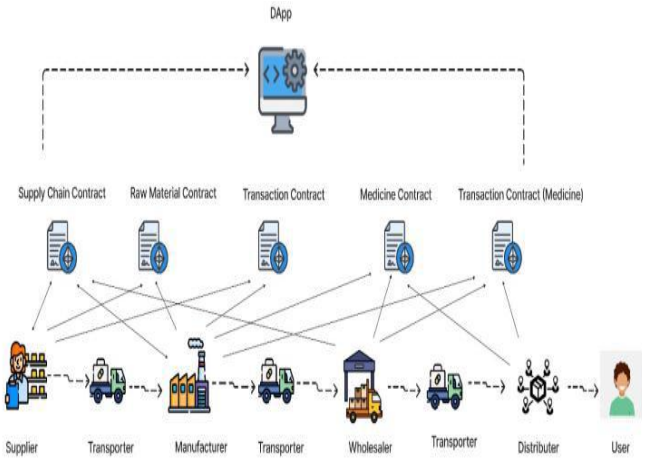

Figure 3: Methodology

3.3 Implementation:

The proposed solution is being created using the Ethereum blockchain technology. Since Ethereum is a public blockchain with no access restrictions, anyone can use it. The smart contract is written in Solidity then assembled and tested using the truffle framework. It provides a selection of tools for using the Solidity programming language for developing smart contracts. Also it enables the execution and testing of smart contracts on the blockchain. In addition to truffle, we also used ganache, which gives us access to a local Ethereum blockchain for testing and development. Ten default accounts with 100 ethers apiece are offered by Ganache. Finally, metamask is employed to conduct transactions on the local blockchain network using decentralized applications.

IV. CONCLUSION

In conclusion, our innovative solution harnesses the power of blockchain to combat the pervasive issue of counterfeit medicines within the supply chain. By employing smart contracts and product registration, our system establishes an immutable ledger of all product transactions, creating a robust defence against tampering. Through meticulous verification of identities and event signatures, coupled with real-time recording on the blockchain, we ensure the authenticity of every participant and transaction. The implementation of a user-friendly decentralized application (DApp) adds an extra layer of protection, enhancing the overall security of the system.

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