IIETA International Information and Engineering Technology Association

Journal Européen des Systèmes Automatisés
Vol. 57, No. 5, October, 2024, pp. 1429-1443
Journal homepage: http://iieta.org/journals/jesa

Leveraging Blockchain Technology to Establish a Transparent and Counterfeit-Resistant Pharmaceutical Supply Chain

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https://doi.org/10.18280/jesa.570518

Received: 8 July 2024
Revised: 29 August 2024
Accepted: 10 September 2024
Available online: 28 October 2024

Keywords:
blockchain, coldchain distribution, ethereum, healthcare, pharmaceutical drug counterfeiting

ABSTRACT

In the past few years, there has been a great deal of concern about medicine counterfeiting. Manufacturing and distributing of fake and falsified drugs are prohibited and pose a risk to public health. Depending on how strictly a nation's laws and processes are adhered to, the severity of this issue varies greatly between nations. Thus, stopping the production of fake medications has become crucial, particularly in developing and impoverished nations. To prevent medicine counterfeiting, this research aims to: (1) Identify the main obstacles facing the current pharmaceutical supply chain system (2) Suggest an Ethereum framework based on blockchain and (3) Assess the suggested framework. Based on the suggested framework, a prototype was created, and the prototype was assessed using an evaluation study. According to the assessment study, the average block time is 15s, and the average block execution time is 4s. Once more, compared to the current system, the suggested framework was judged to be practical, safe, scalable, and customer-focused.

1. INTRODUCTION

A key element of the Internet of Medical Things (IoMT) is the Pharmaceutical Supply Chain (PSC), which guarantees that consumers in need have timely access to necessary medications in the proper quantity and quality [1]. In the current globalized setting, PSC facilitates the seamless execution of operations involving geographically dispersed businesses and redraws practical boundaries to enable the pharmaceutical sector to pursue more cost-effective and successful tactics [2]. Although PSC has many advantages, the various stakeholder's manufacturers, distributors, retailers, mail-order pharmacies, physical pharmacies, Pharmacy Benefit Managers (PBM), health insurance companies, and consumers make the flow of goods, information, and money more complicated. Relationships between these entities fluctuate throughout time according to usage trends and needs.

This PSC component has produced an opaque perspective that makes it challenging to track medications along the supply chain and holds parties responsible for the problems brought up. The introduction of counterfeit goods into the supply chain by nefarious actors is one of the most frequent and urgent risks. These fakes range from ineffective components to placebos or medications produced under unethical circumstances [3]. What's even more dangerous is when they repackage expired medications and reintroduce them into the system. Because of the complicated PSC [4], it is challenging to identify and penalize such unscrupulous participants in the PSC under present methods. There have been numerous instances of this in the past.

One notable instance from recent memory involves the Canadian distributor SB Medical, which was charged with improperly storing medications in inferior condition before its shipment to the US PSC. The World Health Organization (WHO) projects that, before non-monetary damages are deducted, 30 percent of pharmaceuticals supplied in 140 countries are probably counterfeit, with an annual cost of $250 billion. This demonstrates unequivocally the urgent need to redesign the PSC's architecture to increase transparency and ensure customer safety.

Two major issues that the global medical supply chain must deal with are drug counterfeiting and improper management of medications that are sensitive to temperature during storage and shipping. Patients are put in danger by counterfeit pharmaceuticals, which also damage the reputation of the whole supply chain.

Figure 1. The flow of goods in the pharmaceutical supply chain

Similarly, vaccinations and other temperature-sensitive goods may become dangerous or useless if they are improperly stored or transported outside the advised ranges. Public health outcomes are directly impacted by these systemic issues. The system uses blockchain technology as a key component to change the pharmaceutical supply chain. Blockchain guarantees the validity of drugs by maintaining an unchangeable record of their travel. Furthermore, smart contracts automate procedures to guarantee quality control and send out notifications when temperatures rise above acceptable bounds. Our objective is to develop a system that is safe, effective, and transparent to protect pharmaceutical supply chains and guarantee the timely and safe distribution of necessary pharmaceuticals to all. Driven by the pressing need to raise the standard of healthcare and ensure patient safety.

Figure 1 depicts the conventional architecture of the interactions between the various PSC elements [5, 6]. An overview of the pharmaceutical supply chain's major participants is shown in this graphic, it does not cover backorders and certain intricate relationships.

The drugs that are carried through distribution networks are more vulnerable to manipulation and adulteration. A temperature-controlled transportation route including personnel, tools, and facilities is required for certain specialist medications as they move between entities.

1.1 Motivation

Table 1 depicts similar efforts for Blockchain-enabled Pharmaceutical SCM systems that are currently in the concept and design stages.

Table 1. Comparison of related past works

Ref	Idea	Performance	Potential Improvement
[7]	Offers a theoretical foundation for implementing blockchain technology in the pharmaceutical supply chain.	The design of the Blockchain implementation architecture for PSC	Deploy the idea, Automate with IoT, Expand Blockchain for data security as well
[8]	A medication based on blockchain SCM. A consumer medicine recommendation system powered by machine learning	The manufacturer communicates medicine details with distributors, pharmacies, hospitals, and physicians by adding, updating, and removing them from the blockchain. Customers can request medication recommendations for various medical conditions	Apply in real-time to pharmaceutical firms to optimize performance. Automate processes using IoT; use IoT Blockchain to automate manufacturing processes. Safely keep analytics data.
[9]	Ethereum off-chain using smart contracts for a permanent transaction history and product tracking	safeguards transaction data's availability, integrity, and nonrepudiation	Boost efficiency by optimizing smart contracts, Including the manufacturing phase, fully automated with IoT
[10]	Pharma SCM using Blockchain and IoT proposed through a review of the literature	IoT blockchain minimizes infections by reducing workers' direct engagement.	Effective design implementation for time-sensitive real-world use cases
[11]	carries out an IoT Blockchain Pharma SCM Proof of Concept	gives resources for confirming the legitimacy of medications before consuming them.	Expand Blockchain to allow safe cloud storage of SCM data for analytics and customer inquiries
[12]	Each participant has verified credentials and can use the blockchain to check the medication's status.	The Internet of Things technology has been tested for monitoring liquid medication temperature in real-time.	Execute for practical application, Expand blockchain to allow for the safe cloud archiving of SCM data for stakeholder inquiries
Our work	Blockchain-based Ethereum and QR-code security for pharmaceutical SCM	Faster response times, SCM made possible by blockchain technology and safe IPFS data storage	-

There are a few pre-built blockchain-based supply chain solutions (such as VeChain, IBM Food Trust, OriginTrail, and CargoCoin), but they do not include QR code integration. Additionally, research on IoT-Edge Cloud and Blockchain is being done [13], yet it hasn't been tried and tested for SCM applications. IoT and blockchain are being used in a small number of supply chain frameworks [14]. Therefore, there is a need to appropriately adapt IPFS, Blockchain, and QR-code technologies to create a more secure and real-time supply chain management and analytics system.

The work's particular contributions are as follows:

- Demonstrates PSC use case situations along with cutting-edge supporting technologies like Blockchain and IoT.
- Creating a framework with an IoT-IPFS architecture and a quick response code (QR) to enhance the security and reaction speed of pharmaceutical supply chain requirements.
- The deployment and quantitative evaluation of IPFS and Ethereum blockchain technologies, in terms of latency.

Organization of the paper: Section 2 includes a literature review, a brief introduction to blockchain technology, a synopsis of the healthcare supply chain, and a description of the problem statement for pharmaceutical SCM systems. Section 3 presents the suggested method for automating the Pharma SCM utilizing the Ethereum blockchain and IoT. Section 4 presents the paper's results, discussion, and Ethereum implementation process. Section 5 outlines our conclusions.

2. LITERATURE SURVEY

2.1 Preliminaries

2.1.1 Supply chain applications

Supply Chain Management (SCM) is now an integral component in practically all fields. These days, digital technologies like e-commerce, e-payments, and the Internet of Things give SCM automation and speed. It starts with the purchase of components or raw materials, followed by the transfer of a product from the producer to the manufacturer and finally to the distributor. The wholesaler receives it from the distributor. Lastly, customers can purchase it at retail establishments. To offer care, hospitals require a consistent supply of drugs and medical equipment. Distributing prescription drugs to pharmacies and hospitals while adhering to regulations. Stakeholders involved in various phases of the supply chain health care medical facilities are pharmaceutical distributors and patients, and in pharmaceutical production are drug manufacturers, suppliers, and distributors. Perishable products and their SCM requirements are medical supplies medicines, blood, and medical items mandate fast and precise delivery. Temperature-sensitive medications require strict temperature control and fast distribution. The pharmaceutical sector is responsible for the development, production, and distribution of life-saving drugs and other healthcare products. Ensuring the accuracy, security, and transparency of supply chain data is crucial in this particular business. The varied and widely spread pharmaceutical supply chain involves a great deal of stakeholders, including pharmaceutical manufacturers, distributors, retailers, and medical experts. Pharmaceutical firms need to handle a complicated supply chain with efficiency, tackling issues with procurement, storage, shipping, coordination, and regulatory compliance.

Numerous obstacles affect the pharmaceutical supply chain's capacity to provide patients with medications that are safe, effective, and readily available [7, 15, 16]. The following are some of the major problems with the pharmaceutical supply chain:

1) Product tampering and counterfeiting: Prescription medication counterfeits represent a serious risk to patient safety. Patients may be given dangerous or inadequate therapies if counterfeit drugs are produced by criminals and appear to be genuine goods.

2) Cold Chain Management: To retain their effectiveness, many pharmaceutical products particularly biologics and vaccines need to be kept at a certain temperature. Maintaining the cold chain's integrity across the supply chain is essential, and changes to these parameters can result in product spoilage.

3) Data security and cyber threats: Protecting valuable information, intellectual property, and sensitive patient data is essential. Data breaches have major financial and legal repercussions.

4) Drug Traceability: Finding and recalling potentially harmful or fake items depends on ensuring pharmaceutical product traceability from the point of manufacture to the point of distribution.

Supply chain analysis has been more significant in recent years as a means for businesses to enhance their planning for sales, operations, inventory control, demand forecasting, and logistics. The act of analyzing each link in a supply chain, from the point at which a company purchases raw materials to the point at which its final goods are delivered to clients, is known as supply chain analytics. For this reason, safeguarding the data in the supply chain is crucial.

SCM has become an intrinsic part of almost every domain [15]. Nowadays digital technologies like IoT, payments, and e-commerce are providing automation and speed to the SCM. It is initiated with the procurement of raw materials or components, the movement of a product from the producer to the manufacturer, and then it is forwarded to the distributor. The distributor in turn ships it to the wholesaler. Finally, it is available to the customer at the retail stores.

Using blockchain-based traceability to combat drug counterfeiting: An implementation framework for sustainable pharma logistics networks manufacturing to drive the circular economy. The approach aims to combat counterfeit pharmaceuticals in pharmaceutical logistics networks through stakeholder interviews [17].

Enhancing pharma supply chain flexibility and end-to-end traceability with blockchain enhancing pharma supply chain strength and end-to-end traceability utilizing blockchain the study examines the financial benefits of using Hyperledger to establish end-to-end traceability in the pharmaceutical supply chain. The adoption of blockchain for track and trace purposes enhances patient safety by ensuring the legitimacy of pharmaceuticals and lowering the possibility that fake medications may find their way into the supply chain [18].

The process comprised giving each product a unique ID and producing a QR code with the manufacturer's name, the date of manufacture, the expiration date, and the transaction number so that the product could be tracked along the supply chain. The study [19] compared the architectures of Hyperledger Fabric and Ethereum in implementing blockchain for supply chain management, focusing on enhancing product safety and reducing manual operations in the supply chain.

The research paper [20] focuses on combining blockchain technology with the Internet of Things in pharmaceutical organizations to enhance drug traceability. It discusses how blockchain ensures secure drug distribution in the supply chain by providing irreversible, reliable, and transparent information. Additionally, it highlights the role of IoT systems in pharmaceutical drug traceability, leveraging automation and computational methodologies.

The study [21] presents a blockchain-powered cloud-based architecture for the pharmaceutical supply chain, addressing the requirements for data storage, privacy, traceability of pharmaceutical materials, and quality control. This system enables pharmaceutical manufacturers to track product movement, ensuring product integrity and reducing counterfeiting risks. It allows users to classify themselves as different stakeholders in the supply chain, controlling data access and visibility through smart contracts and encryption. The proposed system facilitates the verification of medication origins and manufacturing details through instant QR codes, enhancing transparency and trust in the pharmaceutical supply chain.

The study [11, 22] suggests using distributed ledger technology to fortify the network of drug distribution. To improve consumer safety and industry efficiency, the research paper proposes PharmaChain, a blockchain-based solution that creates a safe and transparent pharmaceutical supply chain through Distributed Ledger Technology (DLT). PharmaChain addresses problems like data fragmentation, counterfeit medication, and distribution delays.

The paper [23] suggests the use of PharmaChain for real-time information retrieval, enabling participants to access details like current ownership, timestamp of ownership transfer, and drug authenticity, thereby enhancing visibility and trust among stakeholders. To prevent medicine counterfeiting in the pharmaceutical supply chain, it suggests putting in place a blockchain network that would provide real-time traceability and tracking of medications from beginning to finish, boosting system security and transparency.

The study [24] employs a single case-study methodology that expands upon transaction cost economics theoretical foundations. To determine the potential of blockchain technology for pharmaceutical delivery in Egypt, a total of twenty-five semi-structured interviews were performed with personnel of the case firm as well as pharmacies. The authors go into more detail about connections between the observed practices by examining the frequency of the codes. The study uncovered the possible advantages of implementing blockchain technology. Reductions in lead times, processing fees, and contracting expenses all have a positive effect on transaction costs while guaranteeing the safe delivery of pharmaceuticals. But the results also show challenges with operating expenses, awareness, and corporate culture. Blockchain technology can improve cooperation between key players and the supply chain as it relates to supply chain governance.

To improve traceability and security, the research paper [25] suggests an Internet of Things (IoT)-based traceable medicine anti-counterfeiting management system that incorporates blockchain technology. The anti-counterfeiting system is designed using the Elliptic Curve Cryptography Digital Signature Standard (ECDSA), which guarantees data integrity and non-repudiation. A customized labeling device is employed in the drug packaging process to generate identification codes using an algorithm for asymmetric encryption. While private keys are used by end users to confirm authenticity, public keys are utilized for drug distribution and data recording.

To guarantee data integrity inside the distributed system and improve security and partition tolerance, the study [26, 27] employs a zero-knowledge-proof methodology. It is a smart system because it uses a smart consensus process based on a kind of zero-knowledge proof to facilitate network decision-making. The prototype system predicts node trustworthiness in consensus decision-making by using the Markov model to track each node's reputation score based on interactions. To improve the integrity of the prototype system, error detection in the blockchain and block content is suggested by utilizing the Merkle tree; however, time restrictions prevented this feature from being implemented.

The work [3] proposes an Ethereum blockchain-based method for effective product tracing in the healthcare supply chain that makes use of decentralized off-chain storage and smart contracts. The smart contract gives all parties access to a safe, unchangeable history of transactions, ensures the provenance of data, and does away with the need for middlemen. We outline the system architecture and specific algorithms that underpin our suggested solution's operation. We do testing and validation, as well as provide a cost and security analysis of the system to assess how well it works to improve traceability in supply chains for pharmaceuticals.

To prevent fraud, paperless systems, and blockchain technology provide a reliable, decentralized solution. According to one definition, smart contracts are blockchain-based platforms that permit the importation of traceable, non-modifiable data from the manufacturer to the final consumer along the whole drug supply chain. Compatibility with several technologies and real-time accessibility throughout the whole pharmaceutical supply chain are two of blockchain's distinctive features. A decentralized distribution system that offers low-cost statistics storage and accessibility, dependability, and integrity to smart contract stakeholders can be advantageous for the pharmaceutical supply chain. Smart contracts that make use of RFID tags can allow someone to adjust fake returns to the supplier and manufacturer [28].

The body of research highlights how blockchain technology might improve pharmaceutical supply networks' traceability, security, and efficiency by tackling problems including data fragmentation, supply chain delays, and counterfeit medications.

2.2 Synopsis of the articles: The literature survey presents a summary of the research results from the chosen papers

1. Due to the serious risk that the surge in pharmaceutical drug counterfeiting poses to public health, innovative solutions to secure the pharmaceutical supply chain are necessary.
2. Within the pharmaceutical industry, cold chain distribution security and counterfeit drug problems are major issues.

2.2.1 Problem statement

The pharmaceutical supply chain is responsible for acquiring raw ingredients, manufacturing pharmaceuticals, and distributing them to patients. The following are the steps and data mobility in Pharma SCM.

1. Getting raw materials: Check suppliers' validity and quality, put information on the blockchain, such as the batch number and supplier details.
2. Manufacturing: Use blockchain to track manufacturing milestones.
3. Labeling and packaging: Log packaging details onto a blockchain.
4. Distribution to retailers and wholesalers: Manage delivery and terms of payment, monitor shipment progress on blockchain.
5. Retail sales: Maintain payments and inventory updates, log sales transactions on blockchain.
6. End user: Use blockchain to access product details (such as legitimacy and provenance). Post comments or report problems on the blockchain.

2.2.2 Objectives

1. Establish a blockchain-based system for pharmaceutical product authentication and end-to-end traceability.
2. Design an automatic IoT and increase data quality and openness to improve cold chain distribution and lessen the spread of fake medications.
3. Reduce the hazards to health posed by improper temperature control and fake drugs, thereby enhancing public health results overall.

3. PROPOSED SOLUTION

This section addresses the issues with traditional PSC and the creative fixes that the blockchain-based Pharma Chain architecture offers.

3.1 Issues covered in this paper

- Complex interactions between dispersed entities can result in order processing delays, which can create delays in the delivery of critical medications to the final consumer.
- Due to the distributed structure of the system, information fragmentation may occur, making it more difficult to identify and fix problems.
- Participant entities lack accountability because of difficulties tracking down problems in such a complicated ecosystem.
- In traditional PSC, blind parties can lead to

invisibility and significant processing delays at the manufacturing and distribution stages.

3.2 Innovative fixes put out in the Pharmacy supply chain

The Novel approach in the proposed scheme is given below.

- We create an innovative Ethereum-based architectural design that ensures security, traceability, immutability, and accessibility of data provenance for the pharmaceutical supply chain in India.
- We define read-write control access and guarantee both on and off-chain storage allocation methods.
- We are developing a smart contract that handles different kinds of exchanges between participants in the supply chain for pharmaceuticals.
- Provide end-to-end traceability and verification for pharmaceutical products by implementing a blockchain-based system.
- Improve data integrity and transparency to lessen the flow of fake medications and strengthen the cold chain distribution.
- Reduce the health risks brought forth by improper temperature control and fake drugs, therefore enhancing public health results in general.

3.3 Blockchain technology

Blockchain is a distributed, decentralized ledger system that makes record-keeping safe, open, and impervious to tampering. It functions as a series of blocks, each of which block has a transaction list within it [29]. Cryptographic hashes are used to connect these blocks, creating a continuous chain. Because it is decentralized, there is no need for a central authority because the ledger is kept up to date by a network of nodes. The consensus method guarantees agreement on the legitimacy of transactions and is frequently based on proof-of-work or proof-of-stake. Blockchain technology has become more well-known than cryptocurrencies, with applications across a range of industries thanks to its efficiency, security, and transparency features. A fundamental tenet of blockchain technology is decentralization, which disperses power over a network as opposed to depending on a single entity. Another important characteristic is immutability, which refers to the fact that data is resistant to alteration once it is recorded in a block. The consensus mechanism and the cryptographic linkages between blocks make it computationally impossible to change previous transactions. Immutability upholds the blockchain's integrity and increases confidence in the data that has been recorded. Ethereum is a decentralized platform that enables the creation of autonomous apps and self-executing contracts by using distributed ledger technologies from supply chain management to finance (DeFi). The digital money that drives the Ethereum network and permits access to its computational services is called ether, or ETH. Ethereum is a leading platform for blockchain-based innovation because of its programmable and open nature [30].

3.3.1 Working of blockchain

Transactions in blockchain technology are recorded and validated anonymously [31]. It is a publicly shared record of occurrences among numerous nodes or parties. According to the study [32], blockchain technology operates as follows: Users log on to the network using credentials and record the transaction in a structure called a "Block," depending on the type of blockchain. Groups of transactions that have been hashed and encoded into a Merkle tree are kept in blocks. Every block in the network contains the cryptographic hash of the block that came before it, linking the two. The links between the blocks create a chain. This recursive process verifies the integrity of each block starting with the genesis block and going all the way down to the preceding block. The links between the blocks create a chain. This recursive process verifies the integrity of each block starting with the genesis block and going all the way down to the preceding block. To guarantee the integrity of the data stored inside a block, it is common practice to digitally sign it. Any attempt to add a transaction to the chain will require validation from every member of the network. It is accomplished by applying a consensus method to confirm the authenticity of the transaction. A majority of the parties must then ratify the transaction. A block containing all the approved transactions is then sent to every node in the network. They respond by confirming the new block. A hash, or the distinct fingerprint of the previous block, is present in every block that comes after it.

Selecting the blockchain type that is best suited for the project is the first step in creating a Blockchain solution. As a result, it's critical to comprehend all the possibilities for Blockchain structures. The study [33] classifies blockchain as either permissioned (private blockchain), permissionless (public blockchain), or hybrid (combining the two).

• Permission-less public blockchains that are accessible to the whole public are known as public blockchains. According to [33], a public blockchain is a decentralized platform that enables anyone to participate in the network and approve transactions there. As an illustration: Ethereum, Litecoin, and Bitcoin.

• Private Blockchain: A Blockchain that functions exclusively within a closed network, a private blockchain is restricted or permissioned. It is typically applied in settings where a Blockchain network is exclusive to a select group of users within an organization [33]. For instance, Hyperledger and Ripple.

• Blockchain Hybrid: A blockchain hybrid combines the features of a public (permission-less) and private (permission-based). Hybrid blockchain is designed to meet industrial demands and is based on a variety of business requirements. It enables businesses to establish a public, permission-less system in addition to a private, permission-based one, giving them control over who can access data stored on the Blockchain and what information can be made public.

• Consortium Blockchain: This type of blockchain uses both public and private blockchains to carry out transactions. They do not allow third-parties to validate transactions and are run by a limited group of members. Transactions can be read by everybody, but only members of a certain group can write [33]. As an illustration: Hyperledger.

3.3.2 Importance of blockchain

In study report [32, 34] covered a wide range of possible features of Blockchain technology that set it apart from other technologies. Figure 2 illustrates a few of the most significant traits.

• Immutability: Data cannot be changed or altered after it has been stored. Block information is protected using a hash value or a cryptographic mechanism.

• Transparency: An identical duplicate of all the data is held by each member. No transaction block may be added to the ledger without the consent of most nodes. This enables companies to track every aspect of the system, increasing openness and removing fraud.

• Decentralized Technology: The network is decentralized, meaning it is not governed by a single entity or individual. Rather, a collection of nodes manages the network, which makes it decentralized.

• Security: No one can easily alter the network's properties to their benefit thanks to blockchain technology, which does away with the need for central authority. Every piece of information on the Blockchain is cryptographically hashed, which fortifies the system even further.

• Distributed Ledgers: Within a decentralized network, a distributed ledger is a kind of database that is shared, copied, and synchronized by its participants. Each node involved will own an identical duplicate of the ledger.

• Consensus: Consensus is an algorithmic procedure that makes sure that every node has access to a single copy of the record. Records are kept honest and true according to consensus procedures.

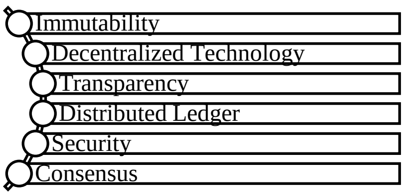

Figure 2. Characteristics of blockchain

3.3.3 Pharmaceutical supply chain powered by blockchain

Preserving people's health and ensuring the constant availability of medical products (such as medications, equipment, services, etc.) are the main objectives of the healthcare supply chain. To deliver great customer satisfaction at a reasonable cost, a supply chain must supervise the relationships between vendors and consumers. Purchasing resources, managing supplies, and delivering goods and services to patients and medical staff are all included in the supply chain. The supply chain organization shown in Figure 3 has been emphasized [35, 36]. A producer or manufacturer makes the pharmaceuticals and sends them to a distributor or a distribution hub (business warehouse) at the start of the healthcare supply chain. One or more vendors provide the raw ingredients to the manufacturing [37]. Distributors make sure that everything prescribed by your doctor is delivered safely and securely to your pharmacy, healthcare providers (including clinics and hospitals), or in the event of an emergency, directly to the patient.

3.3.4 Decentralized inter planetary file system (IPFS)

The IPFS is a distributed file system that stores healthcare industry segment-specific data via a one-to-one network protocol. Each department is uniquely identified by IPFS via data-addressing in a global namespace that is available to all department staff. Every department is dealt with separately so that the provider, files can be stored and accessed by manufacturers, warehouses, distributors, pharmacies, healthcare practitioners, and patients. The decentralized system can be employed with the IPFS system. In this case, the manufacturer may examine the details in a different or comparable country, but the patient saves the issue in the IPFS system, which may reflect on the IPFS system. The manufacturer could understand the requirement schedule for the decentralized IPFS system. The best part about the decentralized system is that, even in the case of a server outage or virus attack, data can still be accessible from any system that has IPFS. In contrast to other systems, it provides greater advantages [38].

In Figure 3 the green and purple color lines illustrate the two ways that stakeholders (pharmacy, distributor, manufacturer, medical professionals, and patients) may interact in a traditional supply chain. Once the product is made, it is often kept in the manufacturer's warehouse. In the role of middleman, a distributor distributes goods to other parties after retrieving medications or other items from a warehouse [39, 40]. In Figure 3 the green line depicts this situation. The other scenario highlighted in red allows stakeholders pharmacies, medical experts, and patients to purchase medications straight from the producer, eschewing middlemen like wholesalers.

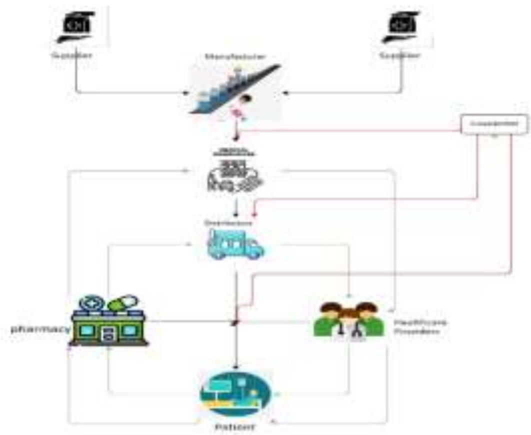

Figure 3. Blockchain-based healthcare supply chain

Serving the patient is our priority because they are the center of the system. Supply networks for the healthcare industry are intricate, varied, and ever-changing. Counterfeiting through intermediaries is feasible on several fronts, as Figure 3 illustrates. Among these are the following: 1) When drugs are transported to the warehouse from the manufacturer; 2) When drugs are stocked in the warehouse and 3) When drugs are shipped to other parties like the distributor, pharmacy, patients, and healthcare providers. Supply networks for the healthcare industry are intricate, varied, and ever-changing. It is extremely difficult for anyone, at any level, to recognize and track the counterfeit. We need a strong technology, like blockchain technology, to enable faultless tracking and monitoring. Many of the problems with conventional supply chains may be resolved by blockchain, a distributed, transparent, and traceable ledger technology [41]. Every single transaction from the supplier to the end user will be recorded due to the immutability feature of the Blockchain network, meaning that no one can alter the same. These blockchain network specifics are used by data analysis and management systems. A fully decentralized healthcare supply chain built on blockchain connects doctors, chemists, patients, and other stakeholders to every step of the process.

3.4 System design

Figure 4 explains, the work's methodology, it is divided into a two-pronged approach. First, a robust blockchain system will be implemented in place to fully document and validate the pharmaceutical items and the entire supply chain journey, guaranteeing total authenticity and traceability through their lifecycle. Second, automated processes will relate to quality control and real-time temperature monitoring. Automation increases productivity and security, and blockchain technology will produce a record of the pharmaceutical supply chain that cannot be altered. On the Ethereum blockchain, transactions will be managed by smart contracts that ensure transparency and prevent unauthorized alterations. With QR codes pointing to pertinent information, front-end development will produce an intuitive user experience that will enable stakeholders to view and retrieve information on pharmaceutical products that is recorded on the blockchain. Temperature and humidity will be detected using Internet of Things (IoT) sensors, securely transmitting data to the blockchain for real-time tracking and anomaly alerts. This integration effectively combats counterfeiting while ensuring the quality and authenticity of pharmaceuticals through enhanced cold chain monitoring.

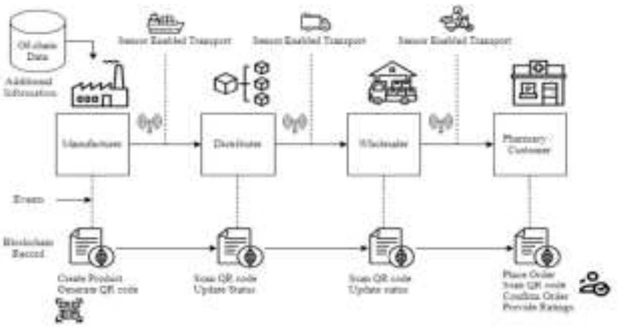

Figure 4. System design

3.4.1 Sequence of working

1. Manufacturer
a. Events
i. Create product
ii. Generate QR code
b. Blockchain Record
i. Records the creation of the product and the QR code generation.
c. Transport
i. Sensor-enabled transport is used for shipping the product.
2. Distributor
a. Events
i. Scan the QR code
ii. Update status
b. Blockchain Record
i. Logs the scanning of the QR code and updates the product status
c. Transport
i. Continues with sensor-enabled transport to the next entity
3. Wholesaler
a. Events
i. Scan QR code
ii. Update status
b. Blockchain record
i. Logs the scanning of the QR code and status updates
c. Transport
i. Utilizes sensor-enabled transport for final delivery
4. Pharmacy/Customer
a. Events
i. Place order
ii. Scan QR code
iii. Confirm order
iv. Provide ratings
b. Blockchain Record
i. Records the order placement, QR code scan, order confirmation, and any ratings provided by the customer
5. Additional Information
a. Off-chain data
i. Represents any off-chain data that may be used or recorded during the process

The model makes use of modifiers, including only_Manufacturer, only_Distributor, only_Retailer, and only_Consumer. In Figure 5, an entity activity diagram is displayed.

Figure 5. Entity activity diagram taken into account in the Pharma supply chain solution implementation

3.5 System architecture

Figure 6 details the front end for user interaction using jQuery, the Ethereum blockchain for safe product tracking, and IoT devices for in-the-moment cold chain monitoring are all seamlessly integrated into the system architecture. Smart contracts on Ethereum guarantee open data recording, and the front end's ease of use encourages participation from stakeholders. Sensor-equipped Internet of Things (IoT) devices send data about the environment to the blockchain, improving real-time cold chain monitoring. This comprehensive strategy ensures security, traceability, and transparency throughout the pharmaceutical supply chain to combat drug counterfeiting and maximize distribution. At the application layer, customers used jQuery JavaScript to develop an intuitive interface that allowed them to connect consistently with the framework. This application layer connects client engagement with the underlying blockchain innovation, enabling partners to query and display real-time information about pharmaceutical goods.

To improve cold chain verification, the IoT framework simultaneously operates and tampers with the blockchain. Internet of Things gadgets with sensors continuously gather natural information crucial to the intelligence of medicinal items. The arrange layer promotes the secure transfer of this data to the blockchain, creating an immutable record of the cold chain circumstances. Figure 6 depicts the system architecture of the proposed Ethereum DApp application. The foundation of the system is formed by the blockchain layer, which makes use of Ethereum's smart contracts to ensure easy and impenetrable recording of data related to the pharmaceutical supply chain. When combined, these coordinating layers and modules strengthen the pharmaceutical supply chain's transparency, traceability, and security while reducing drug fraud and maximizing cold chain dispersion. Partners can engage consistently and naturally with the client interface module, which enables quick access to real-time information about pharmaceutical products and a straightforward path. The user interface, which was created with jQuery, and JavaScript, promotes trust and well-informed decision-making in the pharmaceutical supply chain by facilitating transparency and traceability. The blockchain module records and verifies the complete lifespan of pharmaceutical items, establishing security and transparency using Ethereum's technology.

Figure 6. System architecture of the proposed ethereum DApp application

3.6 Summary of the proposed plan

The part that follows goes over the planned PharmacyChain's architectural layout. The pharmacy chain can be broken down into five logical parts: (1) Internet of Things sensing nodes installed in transport vehicles; (2) An IPFS component for off-chain data storage; (3) a Chainlink component that connects real-time monitoring parameters from the sensing nodes to Ethereum smart contracts; (4) an Ethereum blockchain component that creates an immutable and transparent ledger for all the entities; and (5) a web DApp that allows entities to interact with the blockchain to carry out various tasks in addition to confirming the legitimacy of the drugs at any point in the supply chain along with scanner installed to scan the QR code for updation. Figure 4 presents a high-level overview of the PharmaChain application. The suggested mechanism's DHT11 sensor is used for sensing. They are made with the least amount of power, scalability, and form-factor possible because tracking every carrying vehicle requires a lot of sensors. The sensors are intended to track temperature, humidity, and all crucial conditions for the transportation of pharmaceuticals. Before being transferred to the IPFS component, monitoring data from sensing nodes will be analyzed and converted into a JSON file. The lightweight Message Queuing Telemetry Transport (MQTT) protocol is used by sensing nodes, and the data is published to a pre-made topic. Any fresh data posted on the created topic by authorized sensing nodes will be absorbed by the IoT hub through event listeners. The sensing node and cloud component communicate in the following ways.

1. Sensing Node (Data Collection)

a. Sensors attached to the drug containers or transportation units continuously monitor critical environmental parameters like temperature and humidity.

b. Data Collection: The sensing node gathers this real-time data at regular intervals.

2. Data Encryption

a. Encryption: Before transmitting, the sensing node encrypts the collected data to ensure its security.

b. Output: The encrypted data is now ready to be securely transmitted.

c. Data Transmission to IPFS

a. IPFS Upload: The encrypted data is uploaded to the InterPlanetary File System (IPFS).

b. Content Addressing: IPFS generates a unique hash that serves as an identifier for the stored data.

4. Blockchain Integration

a. Recording: The unique hash of the encrypted data is recorded on a blockchain. This creates an immutable and auditable record of the data's existence and integrity.

b. Smart Contracts: Automated smart contracts might trigger alerts or actions if certain conditions (e.g., temperature thresholds) are violated.

5. Secure Access and Sharing

a. Access Control: Authorized stakeholders (e.g., drug manufacturers, and regulators) are provided with the decryption keys.

b. Data Retrieval: Stakeholders can retrieve the encrypted data from IPFS using the unique hash and then decrypt it with their keys.

6. Data Validation

a. Integrity Check: The blockchain record ensures that the data has not been tampered with. Stakeholders validate the data against the blockchain to confirm its authenticity.

b. Audit Trail: Every access and transaction is logged on the blockchain, creating a transparent audit trail.

7. Cold Chain Monitoring

a. Monitoring: Throughout the entire process, the cold chain is monitored to ensure that temperature-sensitive drugs are maintained under the required conditions.

b. End-to-End Security: The combination of encrypted data transmission, decentralized storage on IPFS, and blockchain recording ensures the integrity and security of the supply chain.

To ensure the robustness and dependability of the application, the blockchain network must receive tamper-proof and dependable data from on-field sensors. Because Ethereum smart contracts aren't designed to communicate with Application Programming Interfaces (APIs), Raspberry Pi is utilized to supply trustworthy data from sensing nodes to the contracts. Verifiable data is sent from sensor nodes to smart contracts via the PharmacyChain model's decentralized inbound hardware.

4. RESULTS AND DISCUSSION

4.1 Experimental setup

The PharmacyChain solution for the Pharmacy supply chain in counterfeit identification and avoidance is implemented in full in this part.

- Create the blockchain's network configuration and smart contract implementation, as well as track the movement of drugs.
- Use blockchain and Internet of Things sensors to monitor the cold chain's temperature and other environmental parameters.
- Use Solidity to implement backend logic for the generation of smart contracts.
- Create React-based front-end interfaces to manage and

grant stakeholders access to data on medicine distribution.

A prototype that can track and trace a shipment from beginning to finish in the pharmaceutical supply chain is built using just one sensing node. Its tiny form factor and power-efficient module, which has built-in WiFi and can connect to wireless networks, is used in its design. It also includes other interface technologies, such as SPI and I2C. The necessary sensors are connected to the module in the current architecture. A DHT11 sensor is used to measure the relative humidity and ambient temperature in the area surrounding the cargo. Figure 7 gives an overview of the deployment of cold-chain distribution.

Figure 7. Deployment of cold-chain distribution

4.2 Tools and technologies

4.2.1 Blockchain development in proposed work

Our pharmaceutical supply chain system uses the browser plugin Metamask as a safe wallet for Ethereum transactions. An IDE called Remix.org is made specifically for Solidity programming, which is the language used to create Ethereum blockchain smart contracts. In our Ethereum-based system, Etherscan is a blockchain explorer application that transparently shows and validates transaction and smart contract data. Table 2 gives the details of block time data.

Table 2. Data for block time

Block Number	Mined at (seconds)	Block Time (seconds)
1	10	-
2	25	15
3	38	13
4	51	13
5	67	16
6	80	13
7	95	15
8	110	15
9	125	15
10	141	16

To calculate the block execution time, use Eq. (1). To calculate the block time use Eq. (2). Average block execution time can be calculated using Eq. (3). Average block time can be calculated using Eq. (4) graphical analysis is given in Figure 8.

$$\text{Block Execution Time} = \text{ETBE} - \text{STBE} \quad (1)$$

where, Start Time of Block Execution(STBE): The time at which the first transaction in the block begins execution; End Time of Block Execution(ETBE): The time at which the last transaction in the block is fully executed.

$$\text{Block Time} = \text{TCB} - \text{TPB} \quad (2)$$

where, Timestamp of Current Block(TCB): The timestamp at which the current block is mined or validated; Timestamp of Previous Block(TPB): The timestamp at which the previous block was mined or validated.

$$\text{Average Block Execution Time} = \frac{\sum_{i=1}^{n}(\text{End Time of Block } (i) - \text{Start Time of Block } (i))}{n} \quad (3)$$

$$\text{Average Block Time} = \frac{\sum_{i=1}^{n}(\text{Timestamp of Block } (i) - \text{Timestamp of Block } (i-1))}{n} \quad (4)$$

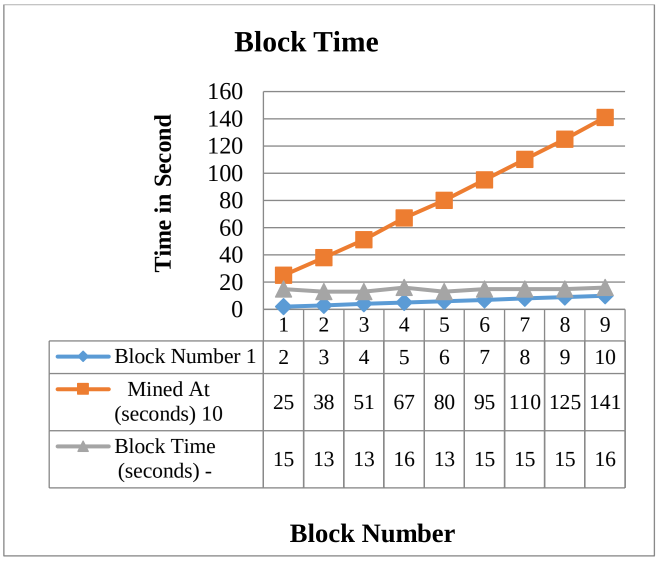

Figure 8. Block time variation

4.2.2 Front-end

Reactjs: The blockchain platform's user interfaces are constructed using Reactjs. Reactjs's component-based architecture makes it possible to create dynamic and interactive interfaces that make it simple for stakeholders to view and engage with the platform's pharmaceutical supply chain data. A JavaScript library for Ethereum Blockchain development is called Etherjs. It offers a straightforward and user-friendly interface for communicating with Ethereum smart contracts. It facilitates event handling, function calls, and contract deployment.

4.2.3 Hardware

The DHT11 is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and provides a digital signal on the data pin (no analog input pins needed). It's simple to use but requires precise timing to grab data.

Figure 9. The suggested coldchain solution's designed sensing node

Figure 9 shows the designed sensor node module. The Blockchain IPFS component receives the data from the sensing node over a secure link. The environmental parameter data from the sensors DHT11, along with additional shipment information, is encoded into JSON string data once the secure connection has been made.

Table 3 provides information on deployed smart contracts as well as the test accounts used for testing in the Rinkeby Testnet. The following actions are taken in the drug's life cycle within the pharmacy chain that has been put into place.

1. When a producer develops a new product, it is given a special identity.

2. Following the production process, the medicine lots are put up for sale and the manufacturer's inventory is updated with newly generated products.

3. Depending on the needs, a distributor will buy the manufacturer's large quantities of medication.

4. Following a successful transaction, the distributor will get the merchandise from the manufacturer.

5. The distributor processes and repackages the received product and updates inventories. The distributor offers to sell updated inventory.

6. A store will purchase the medicine shipments from the distributor following demand trends.

7. The distributor will ship successfully purchased items to the retailer's location.

8. The retailer updates the inventory and acknowledges the shipments that were received.

9. When a customer buys prescription pharmaceuticals from a retailer, they should be able to track the medication's legitimacy by consulting the logs that were made along the way.

Table 3. Cost calculations

Sl.NO	Function Description	Transaction Cost (gas)	Gas Fee (ETH)
1	Deploy Contracts of our system	1377273	0.0020848
2	Registration of Manufacturer	259066	0.0003959
3	Registration of Distributor	259394	0.0003948
4	Registration of Wholesaler	259422	0.0003921
5	Registration of Pharmacy	259506	0.0003942
6	Adding of Medicines by Manufacturer	291506	0.000447787
7	Ordering of Medicines by Pharmacy	163965	0.00024974
Total=0.0004359327 ETH			

Table 4. A comparisions between the current options and our suggested one

Sl.NO	Ref	Decentralized	Blockchain Network	Integrity	Tracking and Tracing	Security	Transparency	End-to-End Traceability	Off-Chain Storage	IoT	QR-Code	Type of Supply Chain
1	[42]	√	Ethereum	√	×	√	√	×	No	×	×	Generic
2	[43]	√	Hyperledger	√	√	√	√	×	No	×	×	Drug
3	[44]	√	Hyperledger-Fabric	√	√	√	√	×	No	×	×	Drug
4	[45]	√	Bitcoin	√	√	√	√	×	No	×	×	Drug
5	[3]	√	Ethereum	√	√	√	√	×	No	√	√	Drug
6	Proposed	√	Ethereum	√	√	√	√	√	Yes	√	√	Drug

Table 5. Details of the deployed PharmacyChain smart contract

Specifications	Value
Contract_Address_Deployed	0xabcd1234567890abcdef1234567890abcdef1234
Owner_Address	0xA8cA23ab89ea84f930910c05474305C1cDea4540
Manufacturer_Address	0xF85A4C63003eC3ef2342d0fe66498f498b4038b2
Distributor_Address	0xB6a4721acd794b5b105d88BDB65a46456Cb92C33
Consumer_Address	0x25e80995e85CBBaA9165722326cC1b90A55047f7
Contract_Creation_Transaction_Hash	0x5b8e5a665c43a6f6589b5bb6eb4a2ec994a5d5e7f3e8c4d57c2d18e80e09f1a6

Table 6. Throughput

Time (seconds)	Transactions per Second (TPS)
1	5
2	7
3	6
4	8
5	7
6	9
7	10
8	9
9	8
10	11

Like any service, the process of submitting data to the Blockchain has an associated cost. We refer to this expense as a transaction fee. Think of blockchain miners as toll collectors on a motorway. They give higher-fee transactions priority so that the network can process and confirm them promptly. Gas is the unit of measurement used for these transaction costs. Consider gas as the necessary fuel for a Blockchain transaction. A transaction requires more gas to operate the more complicated contract. To show the precise gas requirements for the different system functionalities, we've supplied Table 3 [42]. Table 4 gives a comparison between the current options and our suggested one. Analyzing our system's expenses let's take a closer look at the transaction costs related to our suggested approach. To ascertain these gas requirements, we investigated and calculated the fees using Remix, an online development platform made especially for creating decentralized applications (DApps). Details of the deployed PharmacyChain smart contract is given in Table 5. This platform offers resources to calculate the amount of gas required for various system functions. Furthermore, we consulted CoinMarketCap, a well-known website for monitoring cryptocurrency values, to convert gas cost expenses in a more approachable manner. We were able to convert the gas fees which were expressed in Ethereum, or ETH the native currency of the platform into US dollars by using this resource. Our calculations show that the cost of deploying the contract on the Rinkeby Test Network is

0.0020848 ETH, or around 6.80 US dollars (given the current exchange rate). By dividing the transaction costs into these more manageable chunks. The Figure 10 shows the overall transaction cost used among different functions. The Figure 11 shows the overall gas fee utilized among different functions. Figure 12 focuses on adding new medicine, and the details of the medicine are accepted. The Figure 13 shows different stakeholders. The Figure 14 describes the transaction details of a medicine added to the blockchain.

Figure 15 will be a linear plot because the transaction fees are assumed to increase proportionally with the size of the data uploaded. The purpose of the figure is to visually demonstrate that even for relatively small file sizes, the transaction fees in Ethereum can accumulate, making it impractical to upload larger files. How many transactions are processed over a specific period is called throughput. Throughput is typically measured in transactions per second (TPS). Follow the steps to create a throughput Graph. Figure 16 shows the number of transactions processed per second over 10 seconds and the corresponding details can be found in Table 6.

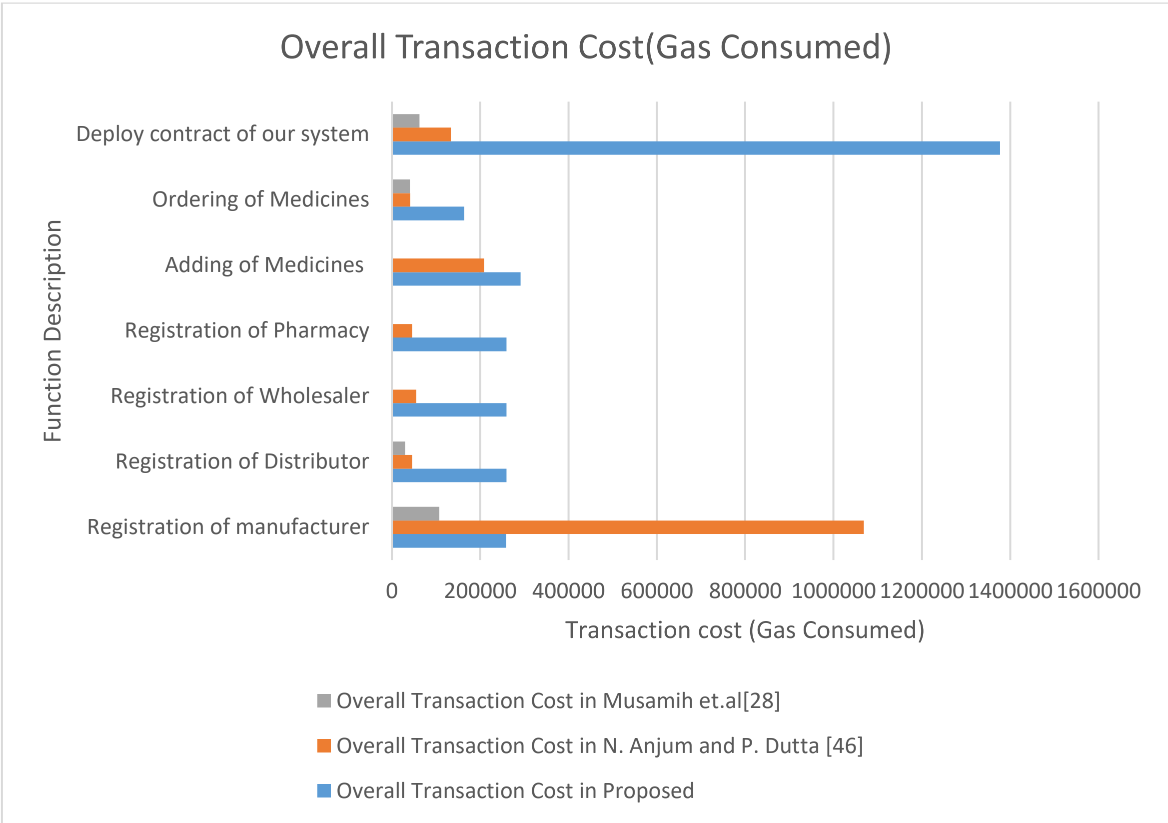

Figure 10. Transaction cost graph

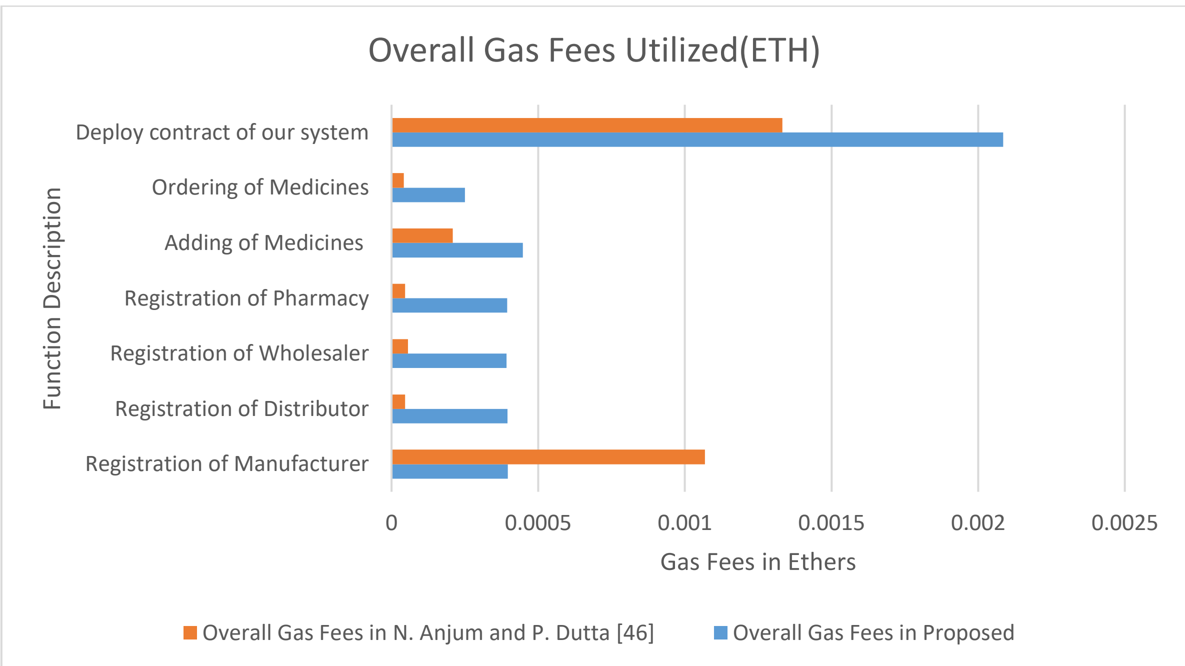

Figure 11. Gas fee graph

Figure 12. Add medicine interface

Figure 13. Home page

Figure 14. Transaction details of medicine added

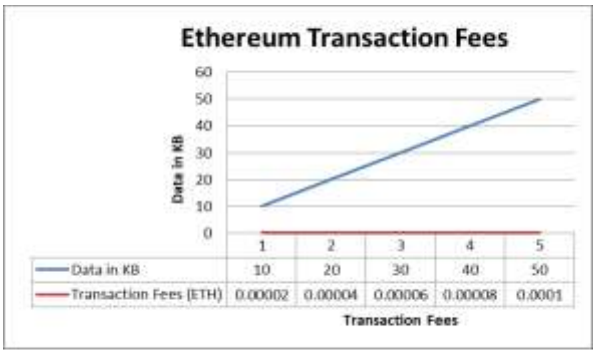

Figure 15. Ethereum transaction fees

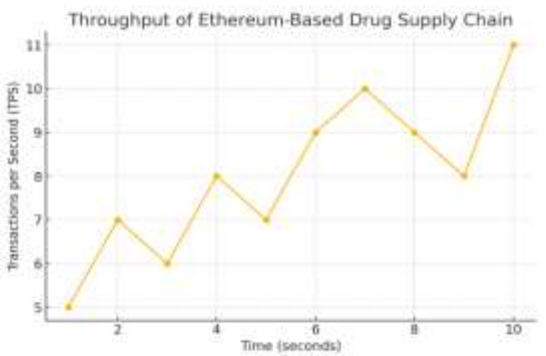

Figure 16. Throughput per second

1. Deploy the Smart Contracts:

Deploy the drug supply chain smart contracts on an Ethereum network (e.g., a private Ethereum network, Ganache, or a testnet like Rinkbey).

2. Simulate Transactions:

Simulate or send a series of transactions that would typically occur in the drug supply chain (e.g., adding new drug batches, updating the status of drugs, transferring ownership between entities, etc.). Record the time each transaction is submitted and confirmed.

3. Measure Throughput:

Calculate the number of transactions processed within a certain time frame (e.g., every second, every minute). For accurate results, run multiple tests under different network conditions (e.g., varying network congestion).

4. Deploy the Smart Contracts:

Deploy the drug supply chain smart contracts on an Ethereum network (e.g., a private Ethereum network, Ganache, or a testnet like Rinkbey).

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Simulate or send a series of transactions that would typically occur in the drug supply chain (e.g., adding new drug batches, updating the status of drugs, transferring ownership between entities, etc.). Record the time each transaction is submitted and confirmed.

6. Measure Throughput:

Calculate the number of transactions processed within a certain time frame (e.g., every second, every minute). For accurate results, run multiple tests under different network conditions (e.g., varying network congestion).

4.3 Algorithms

Account Creation of Manufacturer

Input: Man_Name, M_EmailId, M_Phone, M_Password, Function.

Output: The manufacturer is added to the blockchain, and a unique ID is generated.

Start:

Fetching Private key from ganache, creating an account in metamask.

Call the function add_manufacturer (Man_Name, M_EmailId, M_Phone, M_password)

Read Man_Name, M_EmailId, M_Phone, M_Password, Function

Update the blockchain with a unique address (the account address is used for deploying the same smart contract)

Updating Man_login=false

//Manufacturers are added successfully, and a unique ID is generated.

End

Including Medication

Input: Med_prefix, Med_Name, Med_Description, Med_Price, Med_EOD

Output: An indication that the medications have been successfully added

Start:

Increase the number_of_medications by one.

Revise the owner ID

Updating the owner's address by calling the function

Owner_address(the account that the smart contract is calling from)

Update med_id=number_of_medications

Update med_name, med_description, med_price, med_EOD and med_state

Checking the status of the medicine(medicine state refers to the state of medicine within the supply chain network at a specific point in time)

Calling the function medicine_history it returns successful addition of medicine.

End

Buying of Pharmaceuticals

Input: Slr_id, Vys_id, Med_id, Sold_date, New_Price, Cur_st_code, Up_st_code.

Output: Announcing the purchase of medication.

Start:

If Slr_id = = med_own_id then

If the med_id is present, then

If the patient has sufficient ethers to purchase the medication, then update the med_own_id

Update the address of the owner

Call the medication history record function to update the medication's status code depending on the development of the expected status code and to record the purchase of medication into the decentralized apps for future use.

else

Declare the acquisition of medication by emitting an event.

else

Reverse the status of the contract and show an error.

else

Flip the contract's status and show an error message.

End

5. CONCLUSION

In summary, this research aims to combat medicine counterfeiting and enhance the cold chain distribution of vital drugs by utilizing blockchain technology, Internet of Things devices, and automation to transform the pharmacy supply chain. Implementation of end-to-end traceability, less medicine counterfeiting, and enhanced temperature control across the supply chain will result in an environment that is more open, safe, and effective. Through the reduction of health hazards linked to fake drugs and improper handling of temperature, this work plays a crucial role in guaranteeing the security and effectiveness of pharmaceuticals, ultimately leading to better public health outcomes worldwide.

The suggested PharmaChain enhances seamless operation and effective communication between dispersed businesses by utilizing smart contracts and the blockchain to create a transparent ledger. Additionally, this makes participating entities more accountable, which facilitates the tracking and removal of rogue entities from the network. As a result, there will be fewer fake goods entering the supply chain. Additionally, PharmaChain offers users the ability to confirm the legitimacy of medications prior to taking them in order to guarantee their safety and create a track and trace system that is focused on them. In order to monitor the environmental characteristics of the medicine shipment in real-time and send notifications to relevant entities, the suggested system is additionally integrated with the Internet of Things network. This gives organisations control over shipments throughout the supply chain and the ability to act quickly to protect the integrity of shipments before they reach the customer. When extracting and using data from the sensing IoT network into blockchains, false data injection is a significant issue that can tamper with shipment integrity and give incorrect information to customers and other entities. The proposed PharmaChain avoids this.

ACKNOWLEDGMENT

I would like to express my heartfelt gratitude to our supervisor, Poornima A.S., for her unwavering support and guidance throughout the research process. Her expertise, insights, and encouragement were invaluable in helping us to complete this work. Finally, I would like to thank my family and friends for their love and support throughout the research process. Without their encouragement and support, I would not have been able to complete this research.

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