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Blockchain Technology in Pharmaceutical Supply Chain Management

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***Abstract*— The coronavirus pandemic caused global health and economic disruption of an unknown scale. Several issues with the pharmaceutical supply chain such as the counterfeiting of drugs came to light in these dire times. While continual efforts are being applied in order to effectively treat and annihilate the coronavirus, so are the efforts of supply chains to prepare for patient care in case of a recurrence. The requirement of superior quality medicines has sky rocketed, subsequently, so has the influx of counterfeited drugs. The security of the pharmaceutical supply chain is unquestionably necessary due to the large scale increase in demand for drugs. Tampering of the supply chain is not easily detectable when unethical practices are suspected currently. A radical and innovative method that contains the potential to overcome the challenges of securing the pharmaceutical supply chain is the blockchain technology. So, our proposed solution amalgamates blockchain technology into the drug supply chain to make it tamper-proof. This study proposes a system that harnesses blockchain's properties to ensure supply of safe and traceable pharmaceuticals from end to end. The smart contracts designed have been deployed on a local blockchain using Ganache. Results of our experimentation indicate with certainty that not only is this solution feasible but it is more secure than the present day scenario of the pharmaceutical supply chain.**

Keywords—Blockchain, Smart contracts, Etherium, Supply chain, Drug traceability

I. INTRODUCTION

Supply chain management in the pharmaceutical domain is the mechanism by which medications successfully reach patients [1]. Typically, a supply chain consists of several participants such as suppliers, manufacturers, transporters, wholesalers, distributors, retailers, etc. making it complex, spanning over space and time [2]. This inherent complexity makes it difficult to trace products like a drug throughout the supply chain. Drug counterfeiting arises from this lack of traceability and is a global concern. Such counterfeited medications have adverse effects on the health of consumers. Owing to a severe lack of transparency in the drug supply chain management system, it is exceedingly difficult to know the true value of a medication [3]. Such tampering in itself is difficult to investigate. The advent of blockchain has brought about a revolution. The proposed system harnesses the abilities of blockchain to enable us to maintain a ledger without a centralized point of control [4]. This ledger is immutable; meaning no tampering of sensitive data is possible. There is complete transparency due to blockchain, ensuring trust and accountability amongst the various stakeholders in the supply chain [5]. Each product within the chain can be transferred between the different authenticated entities of the chain using an event request-response mechanism. All transactions between the different entities are recorded into the blockchain using smart contracts. The smart contracts designed have been deployed on a local blockchain using Ganache.

To develop a Blockchain integrated smart anti-counterfeit pharmaceutical supply chain management application that is trackable, transparent, consistent and reliable while eliminating the need for trusted intermediaries, making interactions among stakeholders fast, convenient and cheap. In order to guarantee access to medicines as a basic human right by providing the correct medicines in an adequate condition to the right customer, at the right time and place, and at a minimum cost, our objectives currently are-

- To analyse existing developments using blockchain technology in pharmaceutical supply chain so as to propose a decentralised application harnessing blockchain's properties such as immutability, transparency and trackability.
- To design a solution providing a better managed supply chain experience to the various stakeholders, encompassing them all under the same connected network.
- To harness the power of Smart Contracts and improve traceability and verifiability of handovers of all packages in the supply chain.

II. REVIEW OF LITERATURE

Several discussions have been done by scholars and research papers published regarding how to incorporate blockchain technology into the supply chain to make it more efficient and secure. We reviewed several such papers and the ones we found most relevant have been briefly described here. A study by Casado-Varaa et al. [5] proposed a framework using Multi Agent System (MAS) with Circular Economy Model that enhances the performance of the

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system on the basis of efficiency and reliability of system. Another study by Chang et al. [6] described the inherent capabilities of an embedded smart contract framework like increased transparency as well as traceability in tracking activities like cash flows and logistics. The timely controls facilitate a speedy payment process while they improve convenience and reduce the cost of maintaining a money reserve. One more study by Ahmadi et al. [7] highlights the problems in the existing pharmaceutical supply chain. The stakeholders involvement in the drug supply chain are reviewed and scope of blockchain in the reduction of counterfeiting is studied. Details of the applications of IoT are discussed in detail to help identify the lacking technical aspects in the pharmaceutical supply chain. Alshahrani et al. [8] used quantitative methods to collect data and analyse those using self-administered questionnaires. Each item was tested on certain criteria and the 5-Point Likert Scale was implemented. Johny et al. [9] conducted an exhaustive investigation of comprehensive exploratory reports of several blockchain based supply chain systems. The focus was on the drug supply chain and the working of its blockchain implementation is elaborated.

III. METHODOLOGY

A. *Proposed system*

The proposed system used the decentralisation and data immutability of blockchain technology which helps in the product traceability process. The process of the formation of a product for a transaction works on the event request-response mechanism. The request-response mechanism makes sure that the users involved in the execution of a transaction agree on the transfer of medical drugs [10]. The data stored on the ledger is tamper proof since blockchain is immutable. Fig. 1 shows the various entities that the proposed system consists of.

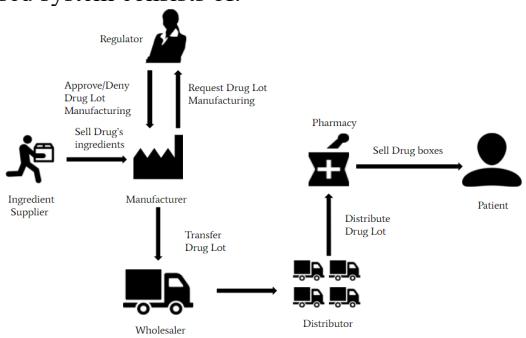

Fig. 1: Drug supply chain stakeholders and their relationships

The various entities are the regulator, supplier, manufacturer, wholesaler, distributor, pharmacy and finally the patient. All these entities are connected by the decentralised network. Each of these stakeholders has an identifying characteristic, which is its Ethereum Address. These are all nodes on the blockchain. The specific roles are discussed in TABLE I.

TABLE I: Supply chain Entities and functions

Entity	Function	Description
Regulator	CREATE	New user added
Regulator	READ	Read the information of user
Regulator	UPDATE	Update the roles of any user
Regulator	DELETE	Delete a user from the chain
Supplier	CREATE	Creates a raw material on the chain
Supplier	GET	Get the address of the raw material created previously
Transporter	VERIFY	Verify the package being transferred
Transporter	PICK	Pick up the product to be transferred
Transporter	DELIVER	Deliver the product
Manufacturer	RECEIVE	Receive raw material through the transporter from the supplier
Manufacturer	VERIFY	Verify source of raw material received
Manufacturer	CREATE	Create a medicine using raw materials previously received
Wholesaler	RECEIVE	Receive drug through transporter from manufacturer
Wholesaler	VERIFY	Verify source of medicine received
Wholesaler	TRANSFER	Transfer medicine's ownership
Distributor	RECEIVE	Receive the medicine through the transporter from the wholesaler
Distributor	VERIFY	Verify the source of the drug obtained
Distributor	TRANSFER	Transfer medicine's ownership
Patient	RECEIVE	Receive the medicine through the transporter from the distributor
Patient	VERIFY	Verify the source of the drug ordered
Patient	GET	Get information about a medicine

The high level architecture of pharmaceutical supply chain is depicted in Fig. 2.

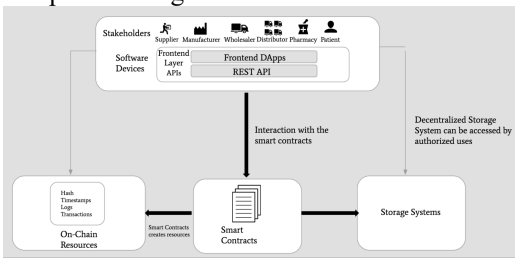

Fig. 2: A high-level architecture for the blockchain based system for pharmaceutical supply chain

Users will interact with smart contracts to execute functions that will allow them to access data from the storage system interacting with the On-Chain resources that provide access

to transaction data and logs. The details about the architecture components are-

- Stakeholders: Suppliers, Manufacturers, Wholesalers, Distributors, Pharmacies and Patients are all stakeholders. Stakeholders participating in the supply chain smart contracts have specific functions assigned to them. These stakeholders have access to the On-Chain resources to track supply chain transactions.
- Storage systems: The data related to the transactions in supply chain are stored using the storage systems to ensure reliability and accessibility of the stored data.
- Smart contracts: The smart contract is crucial for recording the history of transactions and managing data from storage server, which allows participants to access supply chain data. Furthermore, the smart contract defines the functions of the various stakeholders in the supply chain, and access to these functions is granted to approved parties via modifiers.

B. *Smart contract design*

The smart contract design consists of the following components.

- Transaction contract: Transaction contract is automatically deployed when raw material and medicine smart contract are created. The contract takes data as input such as date and time of execution, ethereum address of sender, ethereum address receiver, location and the hash of both current and previous transactions. The last transaction's hash allows stakeholders to verify the origin of a product.

- Medicine contract: This contract is deployed by the manufacturer. This happens after a medicine is created and added to the blockchain. While creating medicine to be added to the chain, data such as raw materials ethereum address that used to create medicine, date and time of execution, transporter's ethereum address, transaction contract address are all requested and consequently sent by the manufacturer. The medicine contract consists of events that report the status and whereabouts of a package. The wholesaler's ethereum address, distributor's ethereum address, and customer's ethereum address are modified according to the feedback mechanism of request-response. The whereabouts of the package (here, medicine) are stored in the form of status, informing us about which entity currently has the package.

- Raw material contract: This contract is deployed by the supplier of raw material once it is created in reality and then added to the blockchain. Before creating a raw material, data such as supplier's ethereum address, date and time of execution, transporter's ethereum address, transaction contract address are all requested from the supplier. The raw material contract consists of events that report the status and whereabouts of a package. The receiver's ethereum address (here, manufacturer) is modified according to the feedback mechanism of request-response. The whereabouts of the package (here, raw material) are stored in the form of status, informing us about which entity currently has the package.

- Supply chain contract: Deployed by the owner of the chain which consists of all entities like owner, supplier, transporter etc. that are involved in the supply chain. Constituents in this smart contract are several events in solidity used to communicate among entities. It also consists of various solidity events used to communicate with the front end in real-time. Each function in the contract can only be accessed by its respective role assigned to it. This is done with the help of "modifiers" in solidity. This increases the security as well as the accessibility of the information stored on the ledger.

C. *Traceability and verification of drugs*

The dialogue of the event request-response mechanism is what is responsible for traceability and source verification of the product which adds an extra layer of security. Fig. 3 shows the event request-response mechanism.

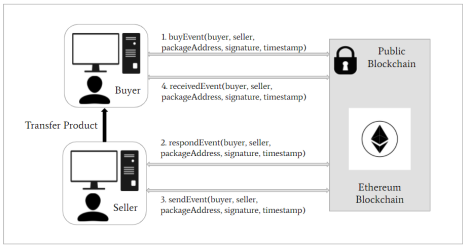

Fig. 3: Event request-response mechanism

This mechanism is discussed elaborately below:

1) The buyer requests the purchase of a drug using the buyEvent() event of the supply chain smart contract. The parameters include the buyer and seller's ethereum address, address of the item to be purchased and a signature which is signed using the private key of the entity that is buying the product and the time and date of the event being requested.
2) The entity selling a product will firstly validate the signature. Afterwards it will trigger the respondEvent(). This event is passed by a signature which is signed with the private key of the entity selling the product.
3) A transporter transfers the product to the entity who bought it. sendEvent() is automatically called to verify that the drugs/item requested have been transported. This includes the ethereum addresses of both the buyer and seller, the address of the product and a signature which is signed using the private key of the seller and the time and date that the product was put into shipment.
4) Finally, receivedEvent() is triggered by the buyer once the item is received and verified.

IV. RESULTS AND DISCUSSION

In the subsequent sections we discuss the results obtained upon deployment of the smart contracts. To test as well as validate the system we show the execution of the smart contracts on the Remix IDE, the achieved compiling and deploying of the smart contracts on Ganache. Some implementation details of the local blockchain on Ganache are also delineated. We also discuss a high-level comparison of the system that is proposed and existing solutions. The limitations of using blockchain in the Drug Supply chain are elaborated next.

A. Testing and validation

For the validation and analysis of the smart contracts written, Remix IDE is used as a testing environment. Fig. 4 shows the snapshots of successful compilation and deployment of Transaction smart contract.

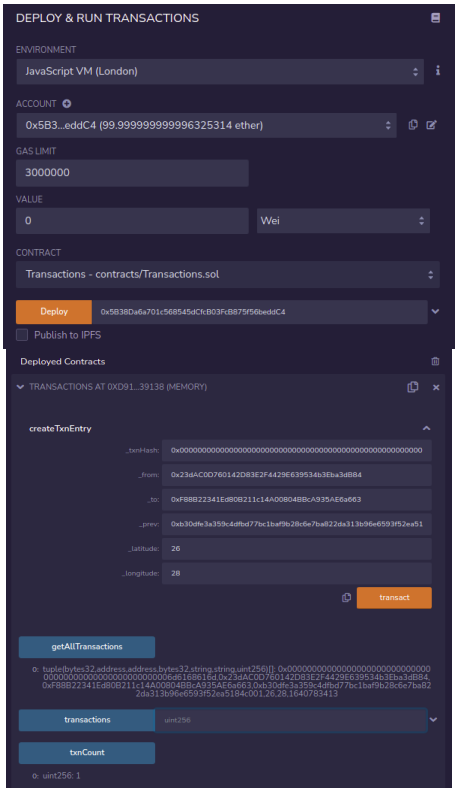

Fig. 4: Successful execution of Transaction Contract

Transaction contract takes attributes like hash of the previous transaction, location, address of source and destination entities. The Transaction smart contract has the functions like- getAllTransaction, that fetches all the executed transactions in the contract and create- Transaction that creates a new transaction. Fig. 5 shows the snapshots of successful execution of medicine smart contract. The medicine contract consists of events that report the status and whereabouts of a package. The current whereabouts of the medicine are stored in the form of status, informing us about which entity currently has the package. The medicine smart contract has the functions like- getMedicineInfo, that fetches information of a particular medicine; pickMedicine, that pick medicine from seller according to transporter type; receivedMedicine, that updates status of medicine upon receipt depending on receiver type; getBatchIdStatus, that fetches current status of a particular batch of medicine; sendWtoD, that sends shipment from wholesaler to distributor; sendDtoC, that sends shipment from distributor to customer; receivedWtoD, that verifies receipt of shipment from wholesaler to distributor, and receivedDtoC, that verifies receipt of shipment from distributor to customer.

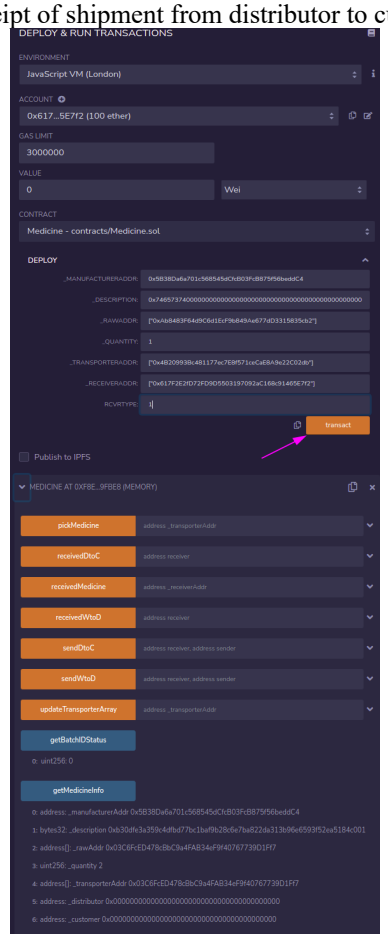

Fig. 5: Successful execution of Medicine Contract

B. Comparison

TABLE II show the comparison between the system we have proposed and the state-of-art techniques like security, integrity and verification of the stored data as mentioned in [11]. From the comparison table, the betterment of our proposed system is clear.

Table II: Comparison of proposed and existing chain

Base of comparison	Proposed solution	Existing solution
Integrity of stored data	Immutable	Mutable/Changeable
Security of stored data	Protection through decentralization	Central security mechanism
Verification of stored data	Successful	Unsuccessful

C. Limitations

Though the results of our proposed system are better, yet there are some limitations. Although data integrity and security is facilitated by blockchain's property of immutability, this may also pose a challenge in the case of the drug supply chain. There would be no mechanism to correct wrongdoings such as inaccuracies on the blockchain. Immutability of blockchain may pose a threat to the privacy of patients. Patient data such as what drug someone purchased and when, is forever stored on the blockchain. Most healthcare and drug supply chain systems that exist are not leveraging blockchain in their implementation. This causes issues with interoperability.

V. CONCLUSIONS

The impact of leveraging blockchain technology in the pharmaceutical supply chain was reviewed. Analysis of the same was accomplished. Methodology was discussed that helps further elaborate on how the proposed system works. Workflow of the application and involvement of various stakeholders was depicted as required. A decentralised Pharmaceutical Supply Chain Management application was elucidated, incorporating aspects of blockchain aimed primarily to make interactions among stakeholders faster and more convenient and reliable. The design for Smart Contracts was decided upon. Two essential smart contracts were deployed and tested. The planning for the rest of the contracts was commenced. With the use of smart contracts, traceability and verifiability of all products being transferred is achieved. The transfers are all registered in an immutable ledger. The collaboration of smart contracts gives us the ability to track the status of a package from end to end. The immense potential of smart contracts shows up here, since no trusted third party is necessary for the execution of transactions among stakeholders. Blockchain and subsequently Smart Contract application in pharmaceutical supply chain management contains the potential of radically changing the traditional healthcare and drug supply industries for the better.

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