NEARCHAIN - Leveraging NFC and Blockchain in Pharmaceutical Supply chain to prevent counterfeiting of drugs

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Abstract—*Counterfeit Drugs in developing countries are increasing at an alarming rate. More than 10% of the Global Pharmaceutical supply chain is impacted by counterfeit drugs. In particular, poor countries are affected on a much larger scale. Data indicates that up to 25% of the medicines used in poor countries are not genuine [1]. The increased number of issues due to counterfeit drugs demands an innovative and scalable solution for the product traceability in the pharmaceutical supply chain. In this paper, we have leveraged NFC and blockchain technologies to track the movement of the drugs from manufacturer to the end consumer in order to prevent the counterfeiting of drugs. We propose an approach that publishes the NFC tag to the Blockchain and establishes the transit path for better tracking and traceability across the pharmaceutical supply chain. The proposed solution focuses on publishing the NFC signature along with product details into the blockchain using smart contracts. Manufacturers can define the exact transit path for the movement of drugs in the supply chain and all the participants in the supply chain can trace and track the product location and details at any moment. Our approach prevents counterfeiting and provides a high level of transparency into the pharmaceutical supply chain in a most reliable, scalable and efficient manner.*

Key words— Blockchain, NFC, Counterfeit drugs, pharmaceutical industry, Tracking, supply chain

1. INTRODUCTION

Counterfeit drugs may contain no active ingredient, incorrect ingredients, or toxins. These medicines compromise the treatment of chronic diseases, causing many health problems, even death. The United States Drug Enforcement Administration seized more than 9.5 million lethal fake pills in 2021. Annually more than $200 billion of counterfeit drugs are supplied in the market [2]. Patients also lose trust in the drug that is supplied in the healthcare industry.

A long and complex supply chain facilitates counterfeits. It is difficult to track the counterfeit drugs due to the intricacy of the supply chain.

The current pharmaceutical supply chain involves many parties from the manufacturer to distributors, repackages and wholesalers before reaching the consumer. There is very little visibility between the organizations involved in the supply chain in order to track the authenticity of the drug.

Traditional supply chains usually adopt centralized anti-counterfeit solutions. That kind of arrangement is subject to the risks of data modification.

We propose a decentralized application framework that records transactions at every stage of the supply chain and provides an efficient method for tracking and tracing the medicines.

The main contribution of this paper can be summarized as follows:

- We discuss the prevailing solutions in the market and the recent research work on preventing counterfeiting products.
- We present an NFC and blockchain-based solution for traceability and visibility in the Pharma supply chain using EOSIO smart contracts.
- We have discussed the method of tracking NFC tags in the blockchain, featuring main interactions between all the participants in the supply chain, with entity relations and sequence diagrams.
- We use EOSIO testnet framework to simulate and test the smart contract algorithms that are used to detect and prevent the counterfeit drugs.

The reminder of the paper is organized as follows.

Section 2 presents the Market and existing solutions in the pharmaceutical supply chain. In section 3, we discuss the current research and related work. Sec4 & 5 explains the importance and capability set of the Blockchain & NFC. Sec 6 describes the proposed solution, sequence diagram and high-level overview. Sec 7 lists out the feature set Sec 8 describes all the algorithms implemented as part of the proposed solution. Sec 9 Describes the feasibility and market adaptability Sec 10 & 11 concludes the study and future development prospects.

2. MARKET AND EXISITING SOLUTIONS

This section describes the pharmaceutical supply chain challenges in detail, highlighting the existing solutions and its limitations. This segment will also explain as to why combining Blockchain and NFC could be a better solution to reduce counterfeit products.

2.1.Current Problems In The Pharmaceutical Supply Chain

THE PHARMACEUTICAL SUPPLY CHAIN

Pharmaceutical supply chain as represented in Figure 1 involves many transit paths between manufacturer and the patient. The manufacturer ships the drugs to wholesale distributors. The wholesale distributor further ships to master retailers and then stocked at retail before it reaches the end consumers. This offers a great opportunity for fraudsters to introduce counterfeit products

SECONDARY WHOLESALE PROBLEM

Secondary wholesalers do not directly purchase the medicines from the manufacturer. They usually buy it from different parties like the primary wholesaler. Primary wholesalers may also purchase the drugs from a secondary wholesaler if the demand is high. The products move between different wholesalers before being repackaged and sold to the patients. This movement of drugs within different wholesalers provides an opportunity for counterfeit drugs to enter the supply chain. While repackaging counterfeit drugs may be given original labels, making the identification of counterfeit drugs even harder.

GRAY MARKET

"When legitimate medication makes its way to distribution channels not authorized by drug manufacturers, this is considered the gray market. Largely, these medications are diverted out of the legitimate supply chain due to price point differentials or availability gaps in different geographies." [3] These diversions from the supply chain provide opportunities for counterfeit drugs to enter the supply chain and these drugs cannot be easily tracked.

2.2 Existing Solutions And Challenges:

Few solutions like Holographic Packaging, RFID, and Mass Encryption are already in the market. In the case holographic packaging, each package will contain the hologram and it is visible to the end consumer. Holographic implementation is expensive. It can be easily cloned. Also, it is difficult to determine the origin of fraudulent activity.

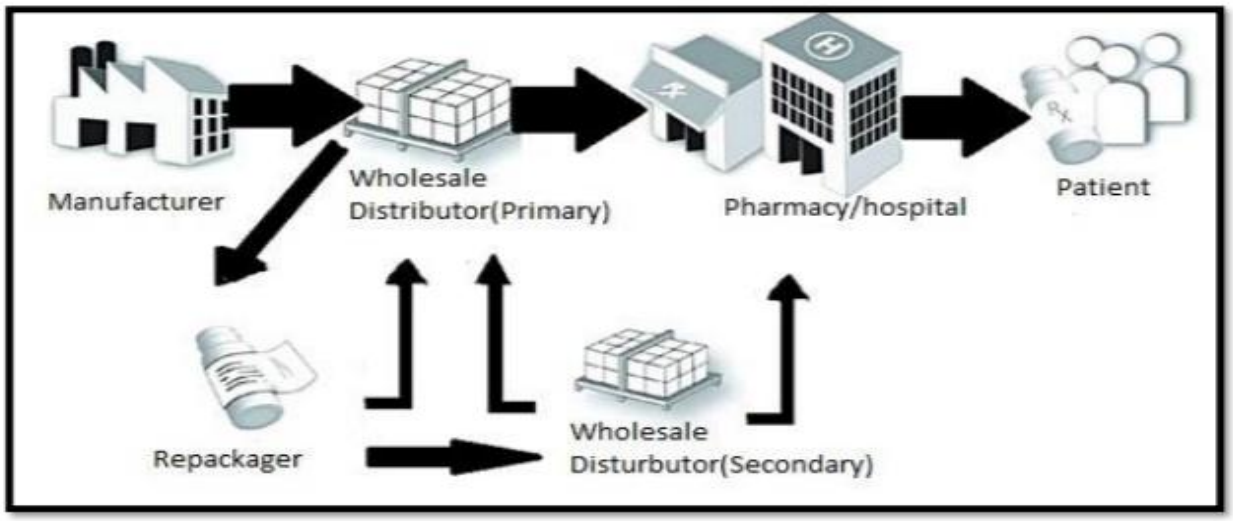

Figure 1 Pharmaceutical Supply Chain

Mass Encryption based solution involves adding an encrypted code and can be decoded at every stage of the supply chain. Mass Encryption techniques require high data storage which increases the cost of implementation.

In RFID based solutions each package is allotted a unique identifier. RFID solutions are expensive to implement and it is not tampered proof.

Most common counterfeit attacks in the existing solutions include (1) Modification of the Medical data in the tag. e.g., Expiry date (2) Cloning of the existing product details into a different tag (3) Insider attack due to the leaked private keys used for signing the RFIDs.

Our solution uses both NFC and Blockchain technologies to track and trace the products from the manufacturer to patients and also verify the authenticity of the drug

3. RELATED WORK

In this section, we will review some of the recent research works on preventing counterfeit and improving traceability of products in the supply chain. Traceability is the ability to follow the materials from the beginning of the supply chain to the customer who purchases the product.

Recently there is a lot of interest in the traceability of products in the supply chain. The most common solutions are based on IOT technology employing RFID and using a central infrastructure to trace the product along the supply chain [11] - [13]. These kinds of centralized solutions lack data protection. Any user who has access to the server can modify the data stored in the server. Further, centralized solutions are not efficient and lack transparency.

Problems like Data Protection and lack of transparency can be resolved using Blockchain technologies. Advantages and benefits of blockchain are explained in Section IV.

Application of Blockchain for traceability of products in the supply chain are addressed across industries like Food Chain, Banking, Finance, Pharmaceutical.

Food supply chain traceability is discussed by Tian using blockchain and Internet of Things [14]. Tse et al compared the blockchain based solutions with the traditional solutions for the food supply chain [15]. Kumar and Tripathi combined encrypted QR codes with blockchain [16]. Saxena et al. did an experimental study and created Pharmacrypt to reduce counterfeit drugs [17]. Peng Zhu al introduces a new blockchain consensus algorithm and access control to improve security and privacy protection.

As evident from the related work, there is a growing trend in adapting blockchain based solutions for information security, traceability and to reduce counterfeit products. However, most of the Blockchain based solutions lack practicality. Most of the paper discusses the conceptual methods of using blockchain in the pharmaceutical industry falling short of specific implementation framework (or) approach. Our proposed solution combines NFC and blockchain and tracks the NFC tag across the supply chain. NFC is tamper proof and has programmable memory to provide more insights about the drugs and origin information. Benefits of NFC are discussed in Section V.

We are proposing a pharmaceutical supply chain framework that reads the data from NFC, defines the exact transit path of the medicines and provides a method for improved transparency. Our solution is using the Delegated Proof of Stake (DPOS) framework that is highly scalable and can be implemented without much complication

4. WHY BLOCKCHAIN?

"Blockchain is an immutable, distributed, decentralized, peer-to-peer ledger replicated across multiple nodes connected in a network", making it possible to record data about any event or transaction as it happens. It consists of blocks in a chain used to record as digital assets using a secure algorithm" [4].

BENEFITS OF USING BLOCKCHAIN

Data in every block is encrypted using the SHA-256 algorithm that makes modification to data very difficult. Any change in the data renders the modified block invalid. This ability of blockchains prevents alteration of transit data of the drugs within the supply chain.

Data once created in the blockchain cannot be altered. Every transaction is recorded as a unique entry and historical records cannot be modified or removed.

This enables patients to view the entire history of the drugs from the manufacturer to the patients and eliminates any opportunity for the introduction of Counterfeit drugs into the supply chain.

The transparent features of blockchain helps in detecting fraud at every stage of the transit.

Records can be accessed using a private key by the owner of that record (manufacturer, wholesaler, distributor and the pharmacy) and with public keys by participants with whom they want to share information (Patients). The system is intended to enable the user to have full control of the data

while allowing patients to gain complete access to the transit data of the product(medicines).

Figure 2 NFC Growth Statistics

5. WHY NFC ?

1. NFC is tamper proof and can only be applied once. Its antenna breaks when attempting to remove it.
2. An NFC Tag can hold essential information like product-ID, unique-ID, Date of Expiry and the status of the product.
3. The data stored in the tag can be protected using a password which offers more security

6. PROPOSED NFC TRACKING SOLUTION USING BLOCKCHAIN

In this section, we will explain the solution that utilizes the EOSIO based smart contracts to publish the NFC details. We will describe in detail our approach to trace and track the pharmaceutical drugs.

Our solution addresses most common counterfeit attacks including (1) Modification of the Medical data in the tag. e.g., Expiry date (2) Cloning of the existing product details into a different tag (3) Insider attack due to the leaked private keys used for signing the NFC.

In addition to the above, our solution enables traceability of the Product and fetching the product details from the blockchain by any entity. At a high level, our solution includes three building blocks: Registration, Transit and Tracking.

Our proposed framework will focus on writing the data to NFC, reading the data from NFC, creating workflow, publishing the medical data to the blockchain and tracking.

6.1. General System Overview

In our solution we are using NFC to store details of the medicine and EOSIO blockchain to track the movement of the item and validate the authenticity of the product in the supply chain.

Each NFC tag has a unique signature, the expiry date of the drug and origin details stored within its memory. These details can be obtained by simply scanning the NFC tag using an NFC reader on a mobile phone.

These details are converted using a hashing algorithm for extra security and then stored on the blockchain which can be accessed using the NEARCHAIN application.

The manufacturer can attach an NFC tag to their electronic goods before shipping, and the end consumer will be able to verify that the NFC tag is original and not tampered with, using NEARCHAIN.

EOSIO is a leading open-source platform for blockchain innovation and performance. [5] The EOSIO platform uses the Delegated Proof of Stake (DPOS) algorithm. In DPOS block producers are selected through a voting system. Anyone who holds a token can be involved in the voting process. [6]

Our proposed framework describes the creation and execution of smart contracts in EOSIO based blockchain.

We have defined smart contracts for Registration Block, Transit Block and Tracking Block. Each smart contract is triggered by various entities like Manufacturer, Distributor, Pharmacy/Retailer and end consumer. Upon execution of smart contract transactions are generated and broadcasted as part of the produced blockchain to other nodes.

In EOSIO, all the state and application data are stored in the multi-Index table. Multi-Index tables provide quick access to the datastore. The blockchain records the transactions while the Multi index tables are used to store data

In our proposed framework for the pharmaceutical supply chain the following entities are involved in interacting with the smart contracts.

Manufacturer - The responsibility of the Manufacturer is to injects the data into the NFC tag and publishes the NFC tag information to the blockchain

Distributor/Retailer - Upon receiving the product, the distributor varies the content of the NFC tag and cross check and update the status in the blockchain.

All entities - At any moment, one or more entities can be involved in tracking the location of the product and validity of the product.

Figure 3 is a representative entity-relationship diagram that defines the table structure of the multi-index table and the relationship between the participating entities.

6.2. General Functional Overview

In EOSIO Blockchain all the entities Manufacturer, Wholesale Distributor, Retailer and Consumer are created an account. Each product item that is shipped in the blockchain has a unique product id. As represented in the Figure 5 Sequence Diagram, there are three major functional blocks: Registration, Transit and Transfer.

For each block there is a list of actions that are defined and triggered on the smart contract as mentioned in the sequence diagram.

Registration Block

In our proposed framework, the Manufacturer has to identify itself in the Blockchain by adding its details like Publisher ID, Owner, address, Email (Action: addManufactureID).

Manufacturer has to identify the total number of NFC tags required for a given product and pushes the total NFC tag (sealCount) along with the public Key into the blockchain. (Action: addSealCount)

Manufacturer writes all the necessary information like Product ID, Sequence Number of NFC Tag (seqNum), Product Details, Expiry Date into the NFC using NFC Writer software. It also signs the NFC Label using a private key.

Manufacturer registers the content of the NFC tag along with the label signature to the blockchain, thus preventing insider attack. (Action: addNFCTag). Now, it is not possible for someone to produce a seal knowing the private key since the sequence number is already registered in the blockchain. seqNum prevents the insider attack problem.

Manufacturer defines the transit flow for the product. Transit flow is the path in the supply chain from product origin till it reaches the end consumer. (Action: createTransitFlow). Upon completion of the above steps, the product is ready for the next transit path.

Transit Block

Now the product is received at the Transit Point. Transit node reads the content of the NFC tag using the public key of the Manufacturer.

Transit node reads the data in the NFC tag and matches the product details with that of the data available in the multi-Index table. Any mismatch in the data indicates that the data is modified in the NFC tag. Transit Node also reads the Label Signature in the NFC and matches with the Signature in the blockchain. Any mismatch in the signature indicates that the product is cloned.

The last step is to verify the transit flow. If there is no mismatch in the transit path, then the Transit node updates the transit status (Action: updateTransitStatus)

The above steps are repeated by all the transit nodes till it reaches the end customer.

Track Block

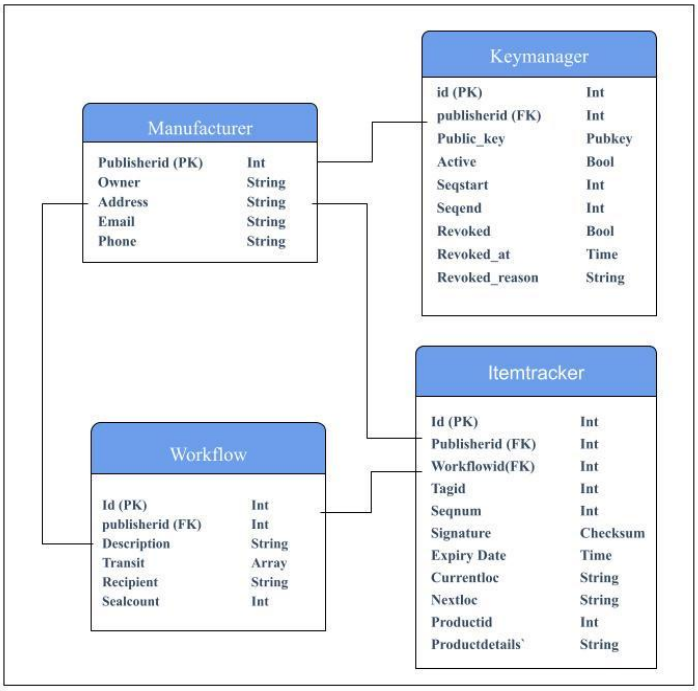

Figure 3 Entity Relationship Diagram

Our proposed framework provides a high level of transparency and security by providing traceability and product details functionality.

Any entity can trigger the following action to track the location of the product and to understand the product details. Once the product is received by the customer, they can scan the NFC tag and understand the product details. They can also send the request to the blockchain to understand the transit path (Action: getTransitStatus)

7. NEARCHAIN FEATURES

Below listed are the features of the prototype developed:

- Asset Creation: NEARCHAIN creates a new asset for every unique product in the supply chain. The product's information is uploaded to the Blockchain on scanning the NFC tag.
- Tracking the asset: When a product is moved on to the next party in the supply chain, the application records the transit and also updates the status.
- View Details: User is able to verify if the drug is authentic and also trace the origin of the drug.
- Security Requirements:

1. A common wallet for account creation with an automated password which needs to be stored.
2. An account is created for the contract creation
3. Every supplier in the supply chain has a private key while the user can use the public chain to view the information of the product.
4. NFC can be password protected for more safety

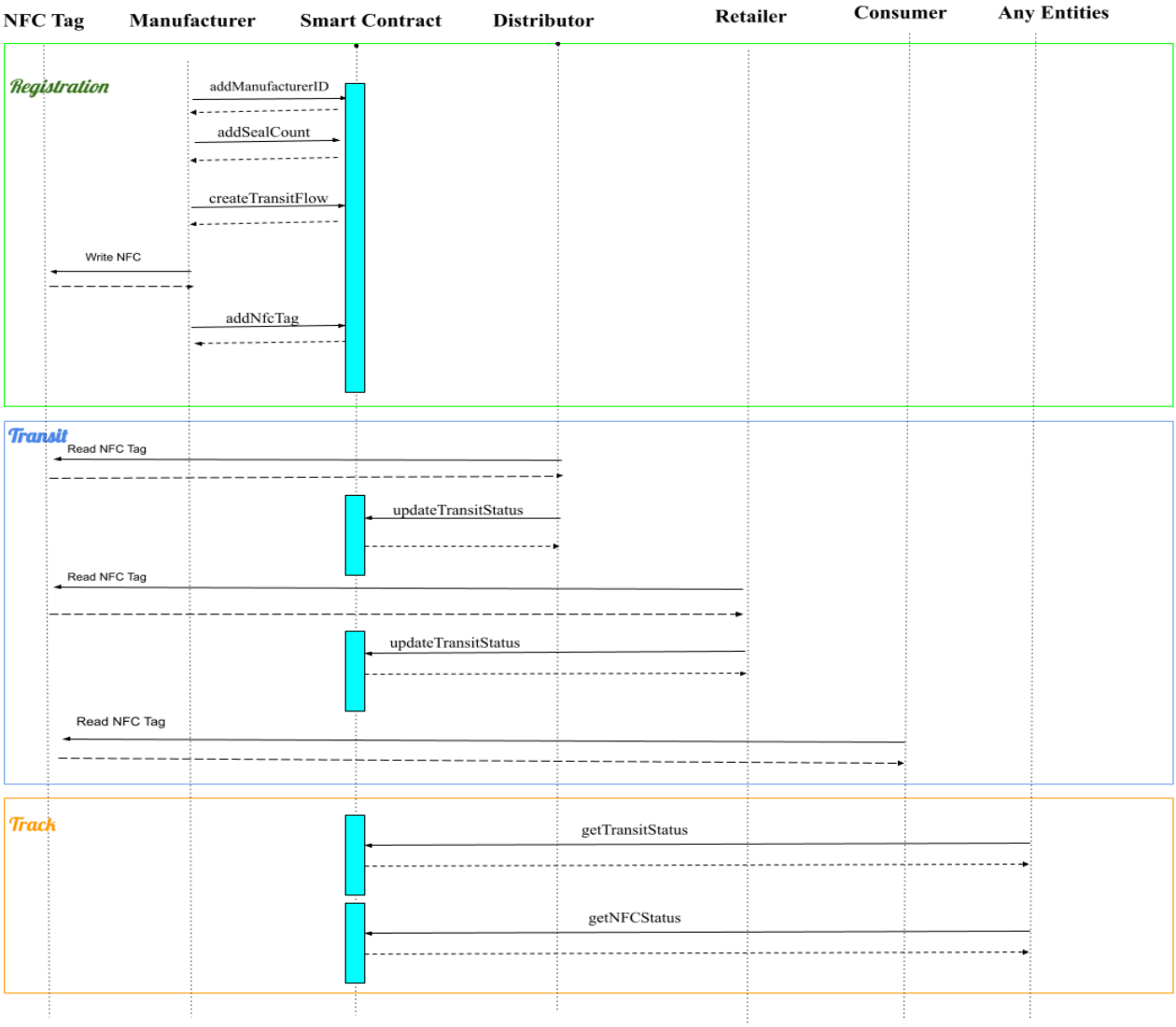

Figure 4 Sequence diagram representing end to end workflow

8. IMPLEMENTATION FRAMEWORK

This section we discuss the algorithms that define the working principles of our proposed approach.

We have simulated the smart contract environment using EOSIO multi-node testnet.

Tools Used

- Ubuntu 18.04 Machine
- EOSIO framework
- NFC pcsc NodeJS library
- NFC Reader / NFC Tags

Below figure 6 depicts the multi-node setup environment using open source EOSIO software. We have setup two nodes on the same computer.

In the figure 6, keosd is the wallet management application.

"Nodeos is the demon that processes smart contracts, validates transactions, produces blocks containing valid transactions, and confirms blocks to record them in the blockchain".

cleos is the command line interface that helps to communicate with the REST API interface of the Nodeos process.

Technically we can have any number of distributors and consumers as part of the supply chain

1. Manufacturer (Issuer)
2. Wholesale Distributor (Transit_1)
3. Pharmacy (or) Hospital (Transit_2)
4. Patient (Recipient)

Create Accounts and Wallet in Blockchain:

- Create 4 User Accounts corresponding to Manufacturer, Wholesale distributor, Pharmacist the recipient for wallet creation.
- Create Wallet in Blockchain Network using account Pharmawallet

Import private keys of Manufacturer, Transit_1, Transit_2, Recipient in Pharma wallet.

Manufacturer creates a smart contract that has defined actions for adding NFC tags, publishing the Product details, creating the transit path in the supply chain, updating the status by all transit points and fetching the transit status from the blockchain.

Upon creation of smart contract, Manufacturer publishes the total seal required for a given project, sequence number of the NFC tags and the publicKey of the Manufacturer as defined in Algorithm1.

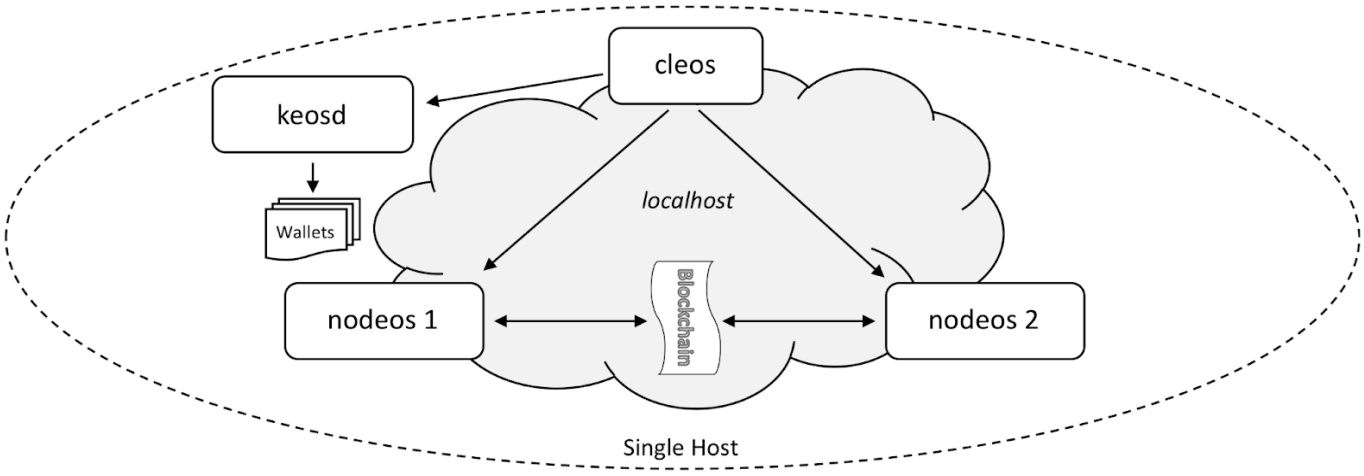

Figure 5 Simulated Environment https://developers.eos.io/manuals/eos/v2.0/nodeos/usage/development-environment/local-multi-node-testnet

In this simulated environment we have assumed 4 majors parties as part of the pharma supply chain as below.

Manufacturer is responsible for creating the complete transit path. As indicated in Algorithm 2,

Manufacturer defines the complete transit path using the action: createTransitflow. Manufacturer defines the necessary and required routes in the supply chain. In this case transit path is defined as Manufacturer, Distributor, Pharmacy and Recipient.

Now all the initial setup is ready for the product to be shipped. Manufacturer writes the required product data into the NFC

tag. Data includes drug information, expiry date, sequence number of the tag, and signature Hash of the NFC tag. Once the writing is completed in the nfcTag, the data from the tag is pushed to the blockchain as explained in algorithm 3. Manufacturer defines the nextLoc using the transit flow information defined in the blockchain.

At this point, the item can be shipped to the next transit path. Upon receiving the item in the next transit location, the information in the NFC tag is read and cross verified with the blockchain. If the drug details in the NFC match with the drug details in the blockchain and if the product has not expired, the transit status is updated in the blockchain as mentioned in the Algorithm 4.

Algorithm 5 and Algorithm 6 explains the transit status and product status details. Any entities can check the current location of the product in the blockchain and understand the product details at any point in time based on the data stored in the blockchain.

Algorithm 1 Add seqstart, seqend and publicKey

Input: ManufacturerID, publicKey, maxSeals

1 ManufacturerID is same as the publisherID corresponding to the Manufacturer as represented in Fig 3 .

2 publicKey is shared by the manufacturer in the blockchain, which provides ownership for Manufacturer to update sealCount, seq number.

3 **if** ManufacturerID exists in blockchain **then**

4 **if** maxSeals > 0 **then**

5 seqStart = 0, seqEnd = 0

6 fetch seqEnd from the blockchain

7 seqStart = seqEnd + 1

8 seqEnd = seqStart+ maxSeals -1

9 Update a record in the table “Keymanager” the following fields seqStart,seqEnd,publicKey .

10 **else**

11 Notify error to the client side for invalid maxSeals

12 **end**

14 **else**

15 Notify error to the client side for “Invalid manufacturer Id

16 **end**

17 **end**

Algorithm 2 create TransitFlow

Input: publisherId,workflowId,transitArray,recipient, description

1 **if** publisher has ownership, **then**

2 **if** workflowId is unique and not exists in the blockchain **then**

3 **if** transit accounts and recipient account exists in the blockchain **then**

4 Update record in the workflow table with the following: workflowId, description, transitArray, recipient

5 **else**

6 Notify to the client “transit or recipient account does not exist”

7 **end**

8 **else**

9 Notify to the client “workflowId already exists in the blockchain”

10 **end**

11 **else**

12 Notify to the client “publisher does not exists”

13 **end**

Algorithm 3 Add nfcTag

Input: publisherId,tagId,seqNum,sighash,expiryDate, ProductID,ProductDetails,workflowId,Manufacturer

1 **if** publisherID exists in blockchain **then**
2 **if** workflow exists in blockchain **then**
3 **if** seqNum OR sighash does exists in blockchain **then**
4 fetch next transitId from workflow Table
currentLoc = publisherID
nextLoc = transitId
Update tagId,seqNum,sighash, expiryDate,currentLoc,nextLocProductID,ProductDetails in the blockchain
5 **else**
6 Notify to client "seqNum OR sighash already exists in blockchain"
7 **end**
8 **else**
9 Notify to client "Workflow does not exists"
10 **else**
11 Notify to client "publisherId does not exists"
12 **end**

Algorithm 4 Update Transit Status

Input: transitId,seqNum,tagId,status,notes,transit

1 **if** transitId has ownership **then**
2 **if** transitId == nextLoc then
3 **if** seqNum exists **then**
4 **if** workflow exists for corresponding seqNum **then**
5 currentLoc = transit
6 nextloc = next transit location from workflow
7 Update record in the itemtracker table with the status, notes
8 **else**
9 Notify Client "workflow does not exists for the given nfcTag"
10 **end**
11 **else**
12 Notify Client "seqNum does not exists"
13 **end**
14 **else**
Notify client "Invalid transit path"
15 **end**
16 **else**
17 Notify client "transtId does not have Permission to update records"
18 **end**

Algorithm 5 Get Transit Status

Input: seqNum

1 **if** seqNum exists in ItemTracker **then**
2 Notify client "current location"
3 **else**
4 Notify client " Not able to track"
5 **end**

Algorithm 6 Get Product Status

Input: seqNum

1 **if** seqNum exists in ItemTracker **then**
2 **if** todayDate <= expiryDate in ItemTracker then

```
3                Notify client "Product Details"
4        else
5                Notify client "Product expired"
6        end
7        else
8                Notify client " No Product details
9                available"
10       end
```

9. MARKET ADAPTABLITY

The Blockchain Technology in Healthcare market is estimated to surpass 6.17 billion USD in 2027, with projected growth of 52.1 Compound annual growth rate. Primary growth drivers include

1. Rise in counterfeit drugs
2. IOT in healthcare
3. Rising need to store and secure medical application
4. Increase in the number of medical data breaches

The Near Field Communication Market in Healthcare is estimated to surpass $278.80 Million by 2025 growing at an estimated rate of more than 11.36% during 2020 to 2025[7].

As the numbers above suggest an increase in the market of both NFC and blockchain in the healthcare industry, our solution is viable and can be deployed to manage a pharmaceutical supply chain.

10. CONCLUSION

Counterfeit medicine or fake medicines as discussed earlier can be fatal when taken and even life-threatening as they contain small or no traces of the active ingredient that is required to keep you healthy. It has been estimated that fake antimalarial drugs contribute to nearly 450,000 preventable deaths every year [8].

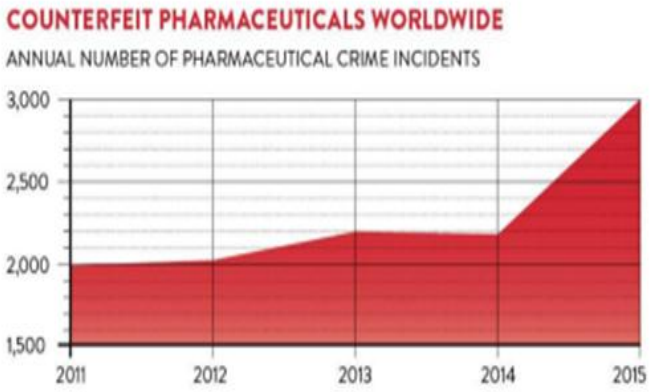

Figure 6 Counterfeit Pharmaceutical graph https://www.raconteur.net/counterfeit-medicines-killing-people-and-brands/

The number of cases of medicines reported falsified or substandard increases every day as represented in Figure 7. While the impact of counterfeit drugs on public health is huge, manufacturers also suffer. The current global market for counterfeit drug sales accounts for $75 billion, according to the National Association of Boards of Pharmacy [9]. Counterfeit Drug Market Grows by 20% Per Year [10]. The production of counterfeit drugs continues to increase due to high profit margin and low detectability especially in the low- and medium-income countries.

Effective supply chain management is a challenge in every industry. However, there is an additional challenge in healthcare as a compromised supply chain can be life – threatening. The involvement of multiple parties in the transportation of the medicines makes the detection of counterfeit drugs very difficult. There is little or no visibility between the organizations involved in the supply chain and the patients cannot verify if a drug is authentic or not.

The increase in the number of users of online pharmacies has widened the global market for counterfeit drugs. Unlicensed, substandard and falsified medicines are sold illegally in online pharmacies and patients buy them due to the high demand and low supply of certain medicines.

We have combined NFC and Blockchain technology to provide a secure, transparent and viable solution to prevent counterfeiting of drugs. Utilizing blockchain and NFC technology can provide a secure, transparent, and distributed network which enables supply chain verification, detect potential counterfeit products, and improve the safety of the public's health. The patients can trace the movement of the medicinal drugs along the supply chain and also read essential information like the product ID, unique item-ID,

expiry date, product information and customer support contact details by reading the NFC tag, using the NFC reader app on the mobile phone.

11. FUTURE DEVELOPMENT

Figure 7 Future app UI

As there are new discoveries made in the pharmaceutical industry and new medicines created that require more complex manufacturing and supply chains compared to small molecule drugs, blockchain may be used as standard in the manufacturing industry to track the drugs through the complex supply chains.

On reflection, we believe that NEARCHAIN has the potential to be developed and used in the healthcare industry as represented in figure 8.

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