

Combating Drug Counterfeiting by Tracing Ownership Transfer Using Blockchain Technology

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ABSTRACT

Supply chain management in healthcare sector plays significant role in the lives of people. Presence of intermediaries and lack of traceability has lured it towards drug counterfeiting, which reduces drug efficacy, thus hampering patients' trust and putting their lives in danger. Blockchain has emerged as a groundbreaking technology which provide a system that is immutable and transparent without the requirement of a trusted third party. This paper depicts how blockchain can provide a solution to reduce drug counterfeit in the pharmaceutical supply chain. This is achieved by creating a Blockchain Network in which each participant and the drug is registered to maintain transparency of transactions among all the participants. Realtime transfer of ownership in the blockchain creates all-round visibility among the registered participants to retrieve information like the current owner, timestamp of ownership transfer and authenticity of drugs. This paper implements PharmaChain for real-time traceability and trackability information of drugs from end-to-end of the pharmaceutical supply chain.

KEYWORDS

Blockchain Technology, Counterfeit Drugs, Ownership, Drug Provenance, Pharmaceutical Supply Chain, Traceability

INTRODUCTION

According to the World Health Organization (WHO)(2006), a counterfeit drug can be defined as one that is *deliberately and fraudulently mislabeled with respect to identity and/or source*. Such pharmaceutical products either have wrong ingredients or may have correct ingredients but in the wrong quantity. Penetration of such counterfeit drugs in the authentic pharmaceutical supply chain

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is evaluated by Mackey et al. (2015) and they observed that no single entity alone is able to combat this menace.

Counterfeiting is one of the major concerns faced by the pharmaceutical industry. According to the Center for Medicine in the Public Interest, sales of counterfeit drugs are increasing globally at about 13 per cent annually, nearly twice the pace of legitimate pharmaceuticals, as examined by Pfizer's Global security(2017). This has prompted regulators and pharmaceutical firms across the globe to take the requisite measures to tackle the increasing trade in counterfeit drugs. For example, product serialization continues to be a driving force for reform in the segment of pharmaceutical packaging in the battle against, duplication, fraud, deviation and misleading returns to manufacturers. Serialization requires a robust program to monitor and control the flow of prescription medications across the entire supply chain in order to reduce the supply of counterfeit drugs. The process of serialization and labelling involves printing 2D barcodes directly onto the medicines, packets and boxes. It allows the manufacturers, pharmacies and hospitals to track their pharmaceutical products. With the use of Automatic Identification, a customer can verify whether a product is genuine or not, via labels. Vision identification is also implemented for the real-time validation of barcodes that can be printed on products in compliance with the Specific Product Recognition specifications of the FDA. Radiofrequency Identification (RFID) is another sophisticated serialization technology used, as studied by Kumar(2019).

The growing threat of spurious drugs has forced the US Food and Drug Administration(FDA) to drift their focus to the Indian pharmaceutical industry. The measures taken by the Indian government such as 'Make in India' and 'Skill India' are binding together with the healthcare firms at a global level to provide comprehensive packaging solutions and improve the quality of drugs manufactured. A government portal called Drug Authentication and Verification Application (DAVA) based on GS1 standards has been developed for authentication and traceability. Its objective is to boost India's status as a world leader in production. But there are some loopholes in the system like it is not necessary that each transaction is transparent to all the stakeholders in the supply chain. Furthermore, it is not able to locate and regulate the product in the entire supply chain, as mentioned in niti.gov.in (2020). Banerjee and Bali, (2019) has Designed a Bioinformatics Feature Based DNA Sequence Data Compression Algorithm for enhancing the security of the algorithm.

At present, around 1.9 million of the total world's population has been affected by the Novel Coronavirus (COVID-19). The coronavirus pandemic has resulted in the increasing demands of a wide variety of products that aren't readily available to the general public, like the self-testing kits at home. To avoid the growing gaps in the market, selling of fake drugs in developing countries like Africa became more profound. Falsified claims have been made for the treatment and prevention of COVID-19, essential healthcare products like face masks, hand sanitizers have been counterfeited in the supply chain. Selling of substandard drugs as well as the medical devices is a matter of grave concern, which needs to be addressed in this time of crisis, as studied by Newton et al. (2020).

The issue of counterfeiting is more prevalent in developing countries, like India and China due to the limited use of track and trace technology. Therefore, there is an urgent need for transparency and intervention in drug data provenance and how they have been managed throughout the entire course of the supply chain, as studied by Kumar(2019).

The direct supply of medicines from a manufacturer's end can be relied upon. However, when it gets transferred among the various levels of the hierarchical supply chain(i.e wholesalers, distributors or pharmacists), there is a possibility of drugs being contaminated. Drugs may be diverted, falsified and substituted at each transfer point from the factory to the patient. The result of such malpractices leads to financial loss to the drug makers, and more importantly, a significant risk to patient safety as investigated by Singh(2020).

Need for Traceability

Traceability of the pharmaceutical supply chain in healthcare is becoming an important concern due to lack of efficacy. The supply of the product from the manufacturer to the consumer has various stages:

manufacturer, wholesaler, retailer and the consumer. Things can go wrong during these stages, from a simple human error to counterfeit of drugs. In our conventional system, it is difficult to identify where the problem has occurred.

There can be an error while transportation of drugs, storage facility, handling as well as distribution to the retailers. All the intermediaries in the supply chain are restricted to share data to the participants before and after them, therefore causing a lack of transparency among other participants. Records stored in the form of hardcopy can be easily tampered causing unauthorized activities.

Pharmaceutical companies suffer losses in huge amounts annually due to counterfeit drugs. Shortages of key medicines create new possibilities for illicit traders, while ever-longer manufacturer supply chains are opening the doors to diversion and frauds. Therefore, affecting the lives of thousands of people on a day-to-day basis.

In a longer run, it is necessary to have a system wherein the consumer should be capable to trace the origin as well as the path of the medicine in the supply chain, this is to have the authenticity of the medicine he/she has consumed.

Overview of Blockchain Technology

Blockchain is a decentralized distributed system(invented by Satoshi Nakamoto in 2008), in which the data is registered, preserved and managed through a P2P network of personal computers called nodes. It is a sequence of blocks which are immutable, time-stamped and linked using cryptographic hashes. Each new block added to the end of the chain contains a unique code or a reference(known as hash value) to the content added to a previous block. This associated hash value is obtained from the one-way encrypted hash function(for eg: SHA 256) as researched by Holbl et al. (2018).

Every node in the network has two keys: a public key that is used to encrypt data sent to a node, and a private key that is used to decrypt messages and allows a node to read messages. It is one of those emerging technologies that can create a revolutionary impact in today’s digital era. Thus, promising a transparent, efficient and secure system for performing transactions without the need of intermediaries, as researched by Holbl et al. (2018).

Table 1 highlights the key features of blockchain technology, as surveyed by Siyal et al.(2018) Blockchain is a consensus-based mechanism that requires the approval from more than half of the participants or nodes before performing any transaction. Though a transaction conducted in the blockchain is public, however, if the information is sensitive, the accessibility to each transaction gets restricted. In the current scenario, the applications of blockchain can be seen in a wide variety of areas like banking, cryptocurrencies, smart contracts, voting etc.

Some of the use cases of blockchain in healthcare include patient record management, traceability of drugs in the supply chain, prescription management, Electronic Health Records, medical research.

Table 1. Key features of blockchain technology

Key Features	Description
Decentralized	A digital public ledger open to all the users present on the network. The data can be controlled or managed on various systems.
Traceability	Provides an audit trail at each stage of the supply chain including the historical records, which helps to validate the authenticity of a drug.
Immutability	Information remains secured forever and is difficult to be altered unless a node has full access to it at the same time.
Autonomous	Each node functions independently in a blockchain network, making it reliable and devoid of any interference.
Transparency	This unmatched property of blockchain allows access to every node connected on the network, publicly. Therefore, anyone can verify/track the asset’s information.

Blockchain technology is of paramount importance in the healthcare sector, as blockchain is a public ledger containing constantly updated and highly encrypted cryptographic records which are unalterable, as reviewed by Rawal et al. (2011).

Necessity of Blockchain Technology in Pharmaceutical Supply Chain

The implementation of tracking and tracing with the use of blockchain technology has the potential to transform the pharma chain. It was found that blockchain technology can substantially improve transparency, efficiency and reliability of transactions in a heavily unregulated pharmaceutical industry. Using blockchain, manufacturers and other supply chain participants can gain real-time data access and greater visibility throughout the supply chain, starting from the point of manufacture (raw material/API suppliers' product codes) to the point of sale (pharmacy stores dispensing prescription/OTC medicines to patients). Most importantly, consumers will have the ability to verify the provenance of the drugs at the point of purchase and ascertain their originality. Major benefits highlighted below are studied by Tanwar et al.(2020):

- **End-to-end traceability of pharmaceutical drugs:** Provide streamlined visibility of the movement of drugs or medicines at each stage/stakeholder in the value chain. This improved traceability facilitates the optimization of drug flow and an efficient inventory management system, leading to considerable improvement in the planning of stocks.
- **Transparency to enhance accountability:** The shipped drug can be traced throughout the supply chain at each point of its ownership. Furthermore, the ledger is transparent which makes it easier to trace the actors or stakeholders involved in the chain of shipment. Blockchain is capable of identifying the source of problems which may arise during the supply of drugs or medicines. Blockchain also enables real-time tracking of medicines at each point of transaction and allows for 'batch reminders' to be sent out efficiently which enhance the accountability of the pharmaceutical supply chain.
- **Distributed ledger:** Transactions are added into the distributed ledger in append mode. This ledger resides in a peer to peer network because of which everyone has the same copy of the ledger at all times. This enables the system to be more fault-tolerant by eliminating a single point of failure or a centralized entity.
- **Consensus:** The blocks are created only when the transactions are validated and verified by all the peers in the network. This is a consensus that governs the truthfulness of the information stored in the ledger. For instance, proof of work, proof of stake, distributed consensus mechanisms like raft and Kafka are normally utilized in current blockchain implementations.
- **Provenance:** The origin of pharmaceutical drugs can be traced quite easily using blockchain since the ownership transfer is stored in real in the ledger immutably. So, the trace of the drug data provenance is kept tamper-proof from hackers and other malicious entities trying to infiltrate the system with foul information.

The introduction of blockchain technology in the supply chain will enable pharma companies to reduce dependence on intermediaries, ensure transparency in stock movement, control quality, and improve the overall reputation of the industry. The government can play a lead role in enabling a common public infrastructure built on top of an underlying blockchain system. This would also greatly benefit various government schemes in the health sector.

Organization

The rest of the paper is organized as follows: Section 2 formulates the problems of drug counterfeiting and drug data provenance. Section 3 talks about the related work in the field of blockchain applications in healthcare systems. Section 4 presents the proposed approach and methodology of solving the

problems discussed along with application architecture design and data flow diagram. Section 5 presents the implementation of PharmaChain with screenshots and working of all the functionalities of the solution. Section 6 concludes with answering the research questions along with challenges and future direction of the solution.

PROBLEM FORMULATION

The authors attempt to solve the following research questions in this paper.

RQ1: Validating the Authenticity of Drugs and Devices

Counterfeit drugs and devices are a big problem. Pharmaceutical companies are attracted towards creating duplicate medicines leading them to high profits, causing a threat to human lives and waste of their income. Detecting fake drugs and faulty devices is not an easy task. These drugs can be fully duplicate or they can be potentially dead (does not produce a desired result or ineffective). Consequences like delay in treatment to various dangerous side effects can be caused by consumption of these fake medicines. Consumers do not have the equipment to test fake medicines at home but there are ways by which counterfeit medicines can be identified and avoided. Negative impacts of fake medicines have no boundaries as there are thousands of fake medicines flooding in the market.

These consequences make it a major concern that a solution is required to the problem of how a consumer can validate the authenticity of the drug consumed? A system capability that should be accessible to every consumer.

RQ2: How to Track Drug Data Provenance?

With the existing conventional system, It is difficult for the consumer to know the provenance of the drug which makes it easier to counterfeit the supply of drugs. Nowadays, there are techniques from which we can track the provenance of the drugs but it might either be complicated or it is not accessible to everyone to know where the drug has come from. There is no reliable record for the consumer to validate the authenticity of the medicine. Another challenge is that it is not perceived as profitable by many businesses as the reputation of the company could be damaged because the end customers can know the product's provenance.

How a track-and-trace system will allow the consumer to follow a specific drug from the manufacturer to the consumer? The authors have discussed the problems faced by the end consumer and how this solution will make it more difficult for counterfeit drugs to enter the legitimate pharmaceutical supply chain.

RELATED WORK

Maouchi et al. (2011) proposed a blockchain-based traceability system for a supply chain in the paper called TRADE, which proves that it is feasible and a better option to apply blockchain technology to obtain transparent and trustworthy traceability in the supply chain. Participants including consumers can access all the information required to track and verify the products in the supply chain. Each participant or actor can create a transaction according to a product identifier (PID), also known as a token, with respect to asset transfer that consists of the full product data. Issued transactions are signed digitally in order to maintain integrity. Consumers are able to view the full life cycle of a product, from its provenance to its consumption.

Griggs et al. (2011) suggested the use of smart contracts based systems, to protect the healthcare records of the patients stored in a private blockchain. These systems allowed monitoring of a patient's

information from remote places, by informing the medical practitioners and patients about any mischievous activities, thus strengthening the security of the systems.

Yue et al. (2016) proposed a blockchain-based data gateway, to ensure the privacy and safety of a patient's information, by giving them the right to access, regulate and supervise their own data.

Xia et al. (2017) developed a blockchain-based system, Medshare, to solve the problem of healthcare record sharing in a *trust-less environment*. With this system, cloud service providers keep a track of the data provenience, control the accessibility and prevent the violation of data.

A permissioned blockchain model has been proposed for end-to-end traceability in the supply chain by Khanna et al. (2020). In their view, the researchers perceive the whole trace of the product in the supply chain as a chain of ownership transfer transactions that have happened on the product from the start of the supply chain. Bali et al. (2021) has suggested a framework for Blockchain Application Design and Algorithms for Traceability in Pharmaceutical Supply Chain

To ensure better healthcare services in our country, proper prescription management is very important. According to Skolnick (2011), improper use of the prescription has been unbridled in recent years leading to many problems such as stimulants crisis. To remove the improper management of prescription, many solutions based on blockchain have been proposed.

Liang et al. (2017) deployed a mobile application for storing the medical records in a cloud database, using blockchain technology to prevent privacy issues using channel formulation scheme.

An Ethereum based platform, BlockMedx (2018) securely manages the prescriptions, where all the prescriptions and transactions are stored in the blockchain securely.

The Blockverify(2018) is a solution for transparency in the supply chain. This platform has four main use cases which are i) pharmacy, ii) diamonds, iii) luxury items, and iv) electronics. The main aim is to verify counterfeiting of products, diverted products, stolen merchandise and fraudulent transactions.

Mediledger(2017) is the supply chain network for medicinal products. It is a centralised permissioned blockchain for the actors that are participating in the supply chain. The main focus is on tracking and tracing of products. The project allows users to trace and track the products from its origin to its consumption.

PROPOSED APPROACH

Architectural Design Components

1. **Hyperledger Fabric:** Hyperledger Fabric is a distributed ledger, an enterprise-grade platform which gives modular and flexible solutions for use cases of various industries. Modularity in the architecture of Hyperledger Fabric helps through the plug and play components such as membership services, consensus and privacy, to a diversity of enterprise use cases, examined by Androulaki et al. (2018).
2. **IBM Blockchain Platform (IBP) Extension:** It is an extension in Visual Studio (VS) code, which was developed by IBM to help developers to write smart contracts or chaincodes, for Hyperledger Fabric environments, and it helps to build applications that can transact on this network. This extension gives developers the choice of among three programming languages to write chaincodes, these are Java, JavaScript and Go. In the proposed solution JavaScript has been used by Novotny et al. (2018).
3. **Nuxt App:** Nuxt is a framework that follows official Vue guidelines to provide a strong architecture design. Incrementally adoptable, it uses complex enterprise-ready web applications to create static landing pages. Nuxt supports various targets (server, serverless or static) and server-side rendering is switchable, making it dynamic in design.
4. **Node.js:** Node.js is a free open source server environment. It runs on various platforms like Linux, Unix, Mac OS X, Windows, etc. Node.js uses JavaScript on the server eliminating the wait time, and

further continues with the next request. Node.js is very memory efficient as it runs asynchronous programming, single-threaded and non-blocking, studied by Wittern et al. (2016).

5. **Fabric-Network:** It is a Software Development Kit for writing node.js applications that interacts with Hyperledger Fabric. It is a package that encapsulates the APIs to connect to a Fabric network, perform queries and submit transactions against the ledger.
6. **Two separate packages are also provided:** See below:
 - a. Fabric-client supports interactions with Peers and Orders of the Fabric network to install and instantiate chaincodes, perform chaincode queries and send transaction invocations.
 - b. Fabric-ca-client interacts with the fabric-ca to manage user certificates.
7. **Fabric contract API:** The fabric-contract-API provides the contract interface a high-level API for application developers to introduce Smart Contracts. Working with this API offers a high-level entry point to writing business logic. Within Hyperledger Fabric, Smart Contracts can also be called as Chaincode. The term chaincode is used to refer to the overall container that is hosting the contracts.

The fabric-shim contains a chaincode GUI, a lower-level API for the implementation of “Smart Contracts”. It is also being implemented to support communication with Hyperledger Fabric peers for Smart Contracts written using the fabric-contract-API, to verify that this is often comparable to the fabric-shim in previous versions of Hyperledger Fabric, studied by npmjs.com(2020).

8. **Docker:** Docker is a container-based tool that makes it easier to create, deploy, and run applications. In order to deploy it as a single package, containers allow the developers to encapsulate an application with all the parts it requires, such as libraries and other dependencies. Unlike a virtual machine, instead of creating an entire virtual OS, docker allows applications to use the same Linux kernel because the system that they are working on, only requires applications to be shipped with the things that are not already running on the host computer. This gives a significant boost to performance and reduces the size of the application, as researched by Combe et al. (2016).

Process Flow

Figure 1 shows the process flow of ownership of medicine in the supply chain. The blockchain network is owned and managed by the pharmaceutical organization. Ownership transfer occurs with every sale-purchase transaction that happens in the supply chain. Drug data provenance can be accessed by any participant from the blockchain.

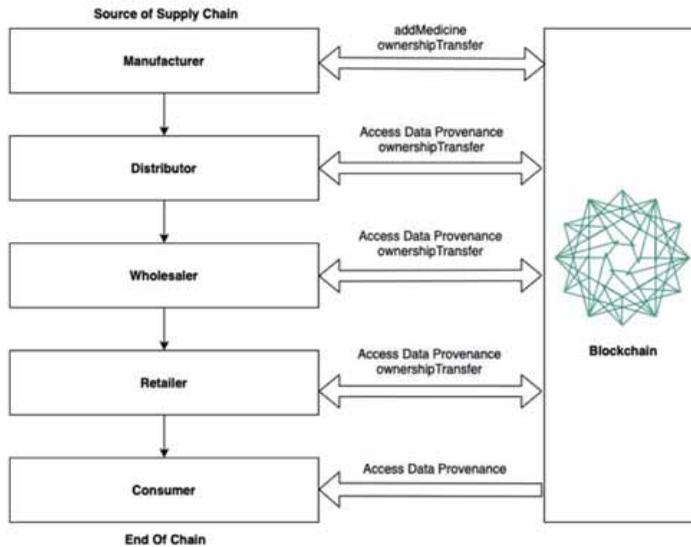
Actors involved in the supply chain process are as follows:

1. Manufacturers
2. Distributors
3. Wholesalers
4. Pharmacy / Retailers
5. Patient / Customers

The proposed system consists of a supply chain which includes some participants as described in figure 1. Every participant except the patient or customer in the blockchain needs to get registered on the network first. They can be registered on the network by the key as a licence number, which is a unique id provided by the government to each participant. This will make sure that the participants are authorised to do their relevant jobs in the supply chain, and they can be trusted.

This Supply chain begins from Manufacturers, Manufacturers will have to register the batch of the medicine on the blockchain with a unique batchID, which is assigned to every batch of product

Figure 1. Process flow of blockchain-based pharma chain



manufactured, to supply the product forward in the supply chain, and they will transfer the ownership of that batch to the next participant whoever is purchasing that particular batch. Only those products can be sold or supplied across the chain which is registered on blockchain to maintain the genuineness of the product.

Manufacturers are the only participants authorised to register the medicine on the blockchain to stop any other participant adulterating the chain with a counterfeit medicine manufactured from fake or unauthorised manufacturers.

Every other participant can trace the provenance of the medicine and can transfer the ownership to the next participant purchasing the medicine. This process will repeat till the medicine reaches retailers/pharmacies, where customers after purchasing the medicine from the pharmacy can trace the provenance of that medicine (and the batch containing that medicine) using the unique batchID provided and be sure that the medicine they are purchasing is genuine.

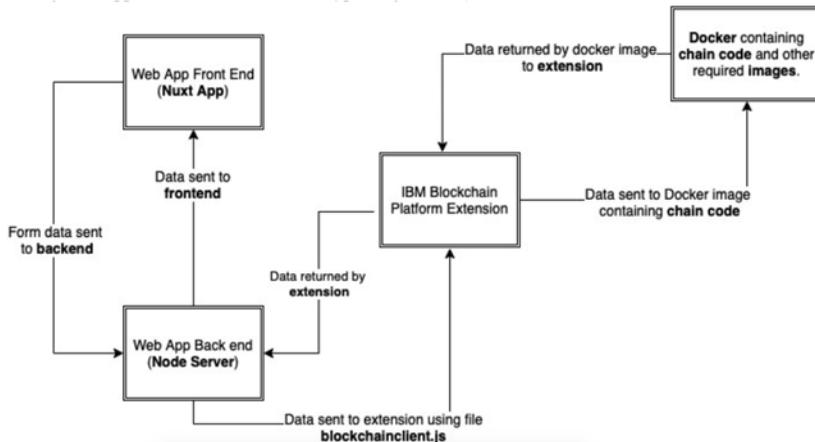
Data Flow

Figure 2 represents the Data Flow Diagram of the application. The front end of the application is served by a nuxt web app which will be interacting with participants or users. This web app will act as a junction between blockchain and users. It will take input from users as web forms and transfer the data in JSON (JavaScript Object Notation) form. Once a user fills the form and submits, the form data will be converted to JSON, and this JSON will be sent to the backend of the web app, which is a node server.

This node server and the blockchain needs to be connected to have some form of communication or to transfer data to each other. In our product, blockchainClient.js is the file that contains the code to connect the web app with the blockchain network using a module called Fabric-network (an SDK for writing node applications to interact with hyperledger fabric).

From the Node server, this JSON will be transferred to ledger (database of blockchain) via IBP or IBM Blockchain Platform Extension. It helps developers to create applications on hyperledger fabric network and to transact on them. Now this IBP extension needs some images to serve its purpose. These images are Hyperledger Fabric, Orderer, Peer, Certificate Authority, CouchDB (database of blockchain) and the image containing chaincode. These images can be provided locally or on the

Figure 2. Data flow diagram



cloud as well. For our project, we are providing these images locally for now, with the help of Docker which will serve the images for necessary components like fabric and the image containing chaincode.

This JSON data will reach the image containing the chaincode. This IBP extension lets us transact on the chaincode that we have written previously, a separate image is already present in docker for chaincode. This is how JSON data will reach the chaincode with help of IBP, now IBP will invoke the transaction and based on that transaction, the ledger will create the record or return the record. Docker image of CouchDB serves for the ledger. This is how the user's input will reach the blockchain network and to the ledger.

Now if some data is returned from the chaincode (network), It will also be in the form of JSON. This returned JSON will backtrack the same route as before to show the response to the user in the nuxt web app, i.e, from chaincode to IBP, IBP to node server, node server to the front end, i.e, this JSON will be visible to the user. This is how users will interact with the product.

Functionalities

Add Participants

All the actors that are manufacturers, wholesalers, retailers who have legitimate license number can register on this blockchain. The license number is verified by the central database that has been provided by the central drug authority. Since a unique license number registers the user, there can't be two participants with the same license number.

There can be three cases at the time of registration:

1. User is added by putting all the valid details on the site.
2. User details are invalid, and he would not be allowed to access the network.
3. The user was already there on the blockchain so no need to re-register him in the network.

Anyone who wants to get into this ecosystem has to register himself on the IBM Blockchain network first by hitting on *addParticipant* button, this button is available on the landing page of the proposed solution. This *addParticipant* will open another tab where one can add the details to get the user on the blockchain.

This function is invoked when the *addParticipant* function is invoked:

```
addParticipant(ctx, participantType, licenseNo, organisationName, address)
```

After that new user as per his type is added to the blockchain. How registration will curb down counterfeit drugs? The whole process of adding the actors is first and most crucial towards counterfeit as blockchain won't allow any malicious parties to get into the ecosystem and introduce falsified medicine. Only privileged actors are allowed to do transactions in this ecosystem that makes it safe.

Add Medicine

Add medicine maintains the integrity of the system as this brings authenticity. When there is an update query by the user so that the medicine batch number can be introduced in the blockchain. Each medicine batch is registered with all the related details like Expiry Date, Batch Number, Manufacturer License Number, Current Owner, Medicine Name, Medicine Formula, Mfg. Date, Place of Mfg.

It gives this more credibility to the system as no batch of counterfeit drugs can not be introduced. All the actors of the system are verified and hence any falsified drug introduction in the ecosystem would be reflected in all the nodes and hence one can trace down the exact node where malpractices are done and this will result in the removal of that actor and finally the whole system is tamper-proof. Trackability is enhanced as *addMedicine* also adds the manufacturer's name with the current owner. With the logic of the previous block hash that is scripted in the blockchain, all the actors that are responsible for drug handling can be easily identified.

Ownership Transfer

One of the breakthroughs that blockchain provides is a realtime and efficient way to distribute the ownership of complex assets, and in our solution also this is present. When the drug transaction occurs from one node to another, this invokes the ownership function where batch id and upcoming owner name is sent to the backend. The batchID helps to get the drug history that is there in the ledger and then parse the byte stream to JSON.

JSON helps us to identify the current owner of the batch, and then we change the credentials. The upcoming owner replaces the current owner and a new block forms with all the credentials on it. This new block has a link with the previous block where the last owner was present, and this brings traceability to the system.

Search

A blockchain operator has a feature to search for details on the blockchain. Search can be done by three methods that can be by batchID, participant name, medicine name. The first search is by unique id search is used to get information regarding that batch of medicine in case the key is for medicine and if the key is licence num then participant details are displayed.

The second search is by the details of participants, and one can find the participant on the blockchain if the user needs his details by entering any detail or combination of the details:

```
{  
  "participantType": "",  
  "licenseNo": "",  
  "address": "",  
  "name": ""  
}
```

The above JSON with all the filled details is then sent to the backend to retrieve the related records as per the operator query. The Third search is by details of medicine, and one can find the medicine on the blockchain if the user needs its details, by entering any detail or combination of the details regarding the medicine:

```
{
  "current owner": "",
  "current location": "",
  "organization": "",
  "manufacturerLicenseNo": "",
  "address": "",
  "Mfgdate": "",
  "Expdate": "",
  "Batchnum": "",
  "formula": ""
}
```

The above JSON with all the filled details is then sent to the backend to retrieve the related records as per the operator query. The fourth search is to retrieve all records on the ledger. This feature is used to get all the details that are present onto the ledger. For this functionality *queryWithQueryString()* function is invoked, the developer provides this function in *contract.js* for search.

When the operator invokes this function by passing a string that he has to search, the *getQueryResult* function that is the inbuilt function to fetch details using CouchDb from Fabric. The *getQueryResult* function returns the [Object, object], and with the help of iterator, traversal occurs. All the values that are fetched by the operator get into a string. The frontend of our proposed solution then displays this JSON to the user. Hence searching brings more integrity to our solution as it fetches the values from a tamper-proof system.

Trackability and Traceability

With search by batchID feature in the author proposed solution empowers the blockchain operator to fetch the details of the medicine whosoever have handled it. Fetching of all the details regarding that batch is done when the operator sends batchID as input JSON to the *retrieveHistoryForBatchID()* function. The *getHistoryForKey()* function that is an inbuilt feature of the blockchain gives all the details of that key. The iterator object then gets the data from this function. The iterator object then puts all the value in the JSON form and sends the details to the user of the blockchain. batchID feature brings traceability into the system as all the related details one needs to get regarding that batchID can be found. Hence one can find information regarding the medicine, and in case one encounters counterfeit drugs, then all the responsible actors for handling that batch of the drug can be identified.

IMPLEMENTATION

Landing Page

Figure 3 is the first page/landing page of the solution called PharmaChain. That is built by using nuxt.js framework. It has all of the features to navigate throughout the solution. The admin can add participants and retrieve records based on batchID. The actors can transfer ownership of drugs amongst themselves and the consumers or auditing agencies can trace the drug data provenance.

Add Participants

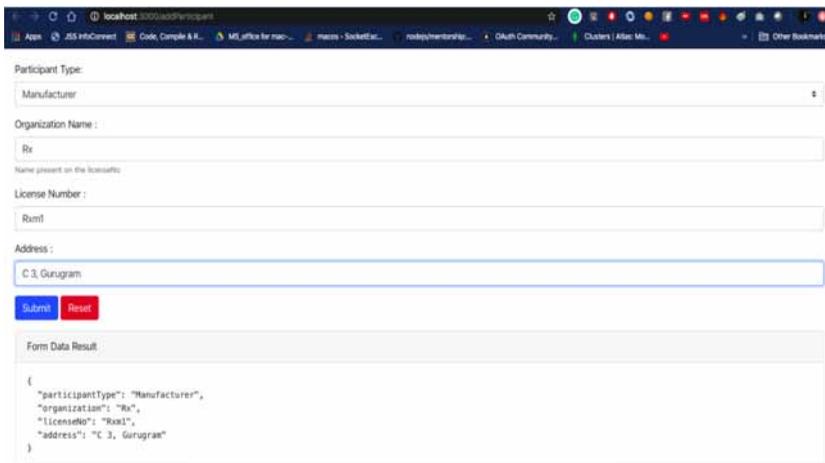
When the operator hits the add participants button, the add participant page appears as shown in figure 4. This will enable you to write in a request body. Click on the Participant Type to choose the type of participant.

In case of manufacturer choose manufacturer from the dropdown. Fill other details like organization, licence number, address. This is input JSON that will be sent to the server-side. It can

Figure 3. PharmaChain landing page



Figure 4. The Add Participant page



be understood with an example. Here Participant Type is Manufacturer, Organization is Rx, License No is Rxm1, Address is C 3, Gurugram.

The final JSON for this will be as:

```
{
  "participantType": "Manufacturer",
  "organization": "Rx",
  "licenseNo": "Rxm1",
  "address": "C 3, Gurugram"
}
```

After adding this data to the blockchain we get details printed on the console as shown in the terminal output in figure 5.

Similarly, wholesalers, distributors and retailers are added as participants of the pharma supply chain.

Figure 5. Terminal output after the manufacturer is added

```

Connected to mychannel.
Done connecting to network.
initiating addParticipant transaction
added participant
{"id":"Rxm1","licenseNo":"Rxm1","participantType":"Manufacturer","name":"Rx","address":"C 3, Gurugram"}

```

The final JSON for wholesaler will be:

```

{
  "participantType": "Wholesaler",
  "organization": "Rx",
  "licenseNo": "Rxw1",
  "address": "A 2, Panchkula, Chandigarh"
}

```

The final JSON for distributor will be:

```

{
  "participantType": "distributor",
  "organization": "Rx",
  "licenseNo": "Rxd1",
  "address": "Sector 62, Noida"
}

```

The final JSON for retailer will be:

```

{
  "participantType": "retailer",
  "organization": "Rx",
  "licenseNo": "Rxr1",
  "address": "Saket, New Delhi"
}

```

Add Medicine

In figures 6, 7 and 8 Panadol medicine batchID- batch1 is being introduced into the system by the manufacturer by adding all the relevant details of the medicine and batchID is the primary key for medicine. This makes the system tamper-proof as only valid participants can add medicine into the system and any change in the status of drugs is available to all the nodes. This solves the issue of trackability as a unique batchID is allocated to all the medicine batches to enhance the traceability process.

Searching

Retrieve Everything in a Ledger

Figures 9 and 10 represent the search functionality which retrieves all records on the ledger. This feature is used to get all the details like the participant, medicine information, etc onto the system. It displays all the transactions that have occurred in the system. All the details of medicine(batch1), etc everything that has been introduced in the system has been displayed.

Search Among Participants

The second search is by the details of participants, and one can find the participant on the blockchain if the user needs his details by entering any detail or combination of the details. Figure 11 shows the output of the searching for a participant in the blockchain.

Figure 6. The Add Medicine Page - 1

The screenshot shows a web browser window with a form titled 'Add Medicine Page - 1'. The form contains the following fields and values:

- Batch number or id: Batch1
- Medicine Name: Panadol
- Medicine Formula: Paracetamol
- Organization Name: Rx
- License Number of Manufacturer: Rxm1
- Place of mfg: Gurugram
- Mfgdate: 01/04/2020
- Expdate: 01/04/2022

Figure 7. The Add Medicine Page - 2

The screenshot shows the 'Add Medicine Page - 2' with the form data result displayed below the 'Submit' and 'Reset' buttons. The form data result is as follows:

```
{
  "batchId": "Batch1",
  "medicineName": "Panadol",
  "medicineFormula": "Paracetamol",
  "organization": "Rx",
  "manLicenseNo": "Rxm1",
  "mfgPlace": "Gurugram",
  "mfgDate": "01/04/2020",
  "expDate": "01/04/2022",
  "owner": "Rxm1",
  "currentLocation": "Gurugram"
}
```

Figure 8. Terminal output after the medicine is added

```
initiating addMedicine transaction
added medicine
{"id": "Batch1", "batchId": "Batch1", "manLicenseNo": "Rxm1", "medicineName": "Panadol", "organization": "Rx", "medicineFormula": "Paracetamol", "owner": "Rxm1", "mfgDate": "01/04/2020", "mfgPlace": "Gurugram", "expDate": "01/04/2022", "currentLocation": "Gurugram"}
```

Search Medicines

The Third search is by details of medicine, and one can find the medicine on the blockchain if the user needs its details, by entering any detail or combination of the details regarding the medicine. Figures 12 and 13 are the outputs of the said functionality.

Search by Key in a Ledger

The search by unique id search is used to get information regarding that batch of medicine in case the key is for medicine and if the key is license num then participant details are displayed. Figure 14 displays the output retrieved after medicine has been queried from the blockchain.

Figure 9. Search everything in a ledger

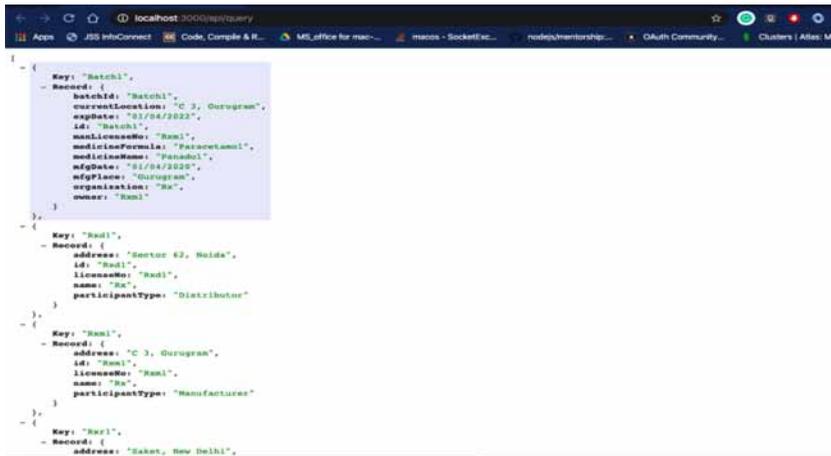
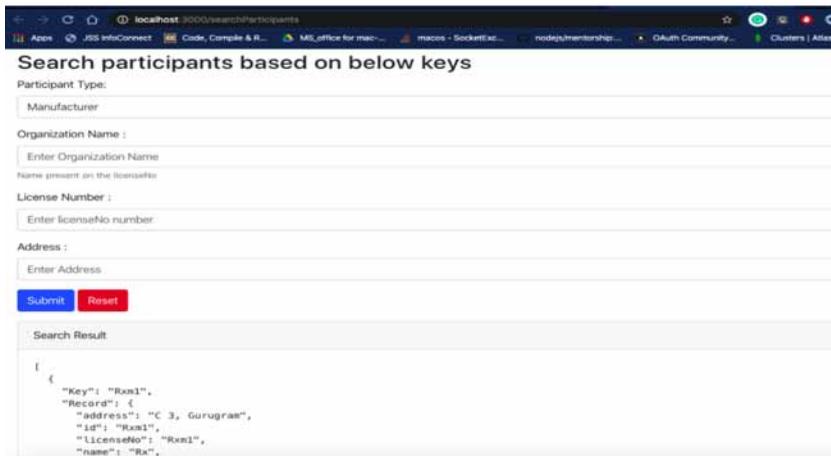


Figure 10. Terminal output after all the is data fetched from ledger



Figure 11. Search participants



Ownership Transfer

When a drug transaction occurs from one node to another, this invokes ownership function where batch id and upcoming owner name is sent to the backend, in this case, it is for Manufacturer to Wholesaler. As the author has transferred the entity (Batch 1) from Rxm1 to Rxw1. This can be viewed from the screenshot in figure 15.

When a drug transaction occurs from one participant to another, this invokes ownership transfer function where the batchID, and in this case, it is for Wholesaler to the distributor and the data

Figure 12. Search medicine - page 1

The screenshot shows a web browser window with the URL 'localhost:3000/medicineSearch'. The page title is 'Search Medicines based on below keys'. Below the title, there is a section 'Batch number or id:' with a text input field. This is followed by several other input fields: 'Medicine Name:', 'Batch name:', 'Medicine Formula:', 'Enter formula:', 'Organization Name:', 'Enter Organization Name:', 'License Number of Manufacturer:', 'Enter licenseNo number of manufacturer', 'Place of mfg:', 'Enter Place of Mfg', 'Mfgdate:', 'Enter date of mfg', and 'Expdate:'. Each field is accompanied by a small downward arrow icon.

Figure 13. Search medicine - page 2

The screenshot shows a web browser window with the URL 'localhost:3000/medicineSearch'. The page title is 'Search Medicines based on below keys'. Below the title, there is a section 'Current owner:' with a text input field. This is followed by a section 'Current Location:' with a text input field. Below these fields are two buttons: 'Submit' (blue) and 'Reset' (red). Below the buttons is a section 'Search Result:' with a text input field. Below this is a section 'Form Data Query:' with a text area containing a JSON object:

```
{
  "batchID": "",
  "medicineName": "",
  "batch name": "",
  "licenseNo": "",
  "mfgdate": "",
  "expdate": "",
  "place": "",
  "mfg": ""
}
```

Figure 14. Search by ID

The screenshot shows a web browser window with the URL 'localhost:3000/queryById'. The page title is 'Enter id to search the value from the ledger (Database of blockchain)'. Below the title, there is a section 'id:' with a text input field containing the value 'Rax1'. Below this field is a text input field with the placeholder 'unique id to retrieve the value from ledger'. Below these fields are two buttons: 'Submit' (blue) and 'Reset' (red). Below the buttons is a section 'Search Result:' with a text area containing a JSON object:

```
{
  "address": "C 3, Gurugram",
  "id": "Rax1",
  "licenseNo": "Rax1",
  "name": "Rax",
  "participantType": "Manufacturer"
}
```

 Below this is a section 'Form Data Query:' with a text area containing a JSON object:

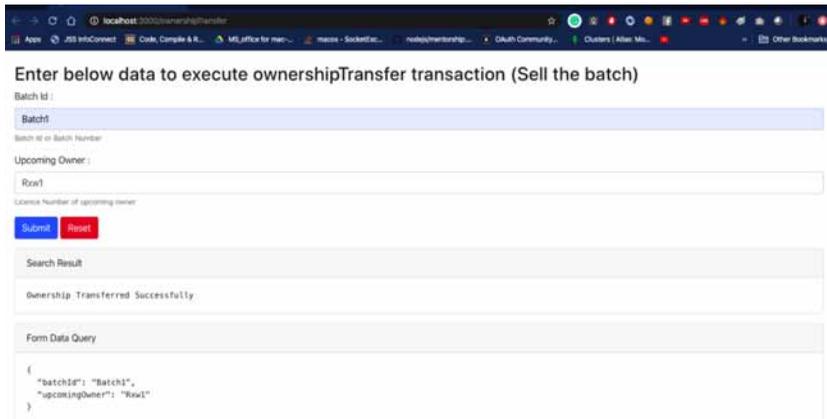
```
{
  "id": "Rax1"
}
```

inputs. Batch1 gets transferred from Rxw1 to Rxd1 Further, it gets transferred from Rxd1 to Rxr1 (distributor to a retailer).

Traceability and Trackability

With search by batchID feature in the author proposed solution empowers the blockchain operator to fetch the details of the medicine whosoever have handled it. Hence one can find information

Figure 15. Ownership transfer from manufacturer to wholesaler



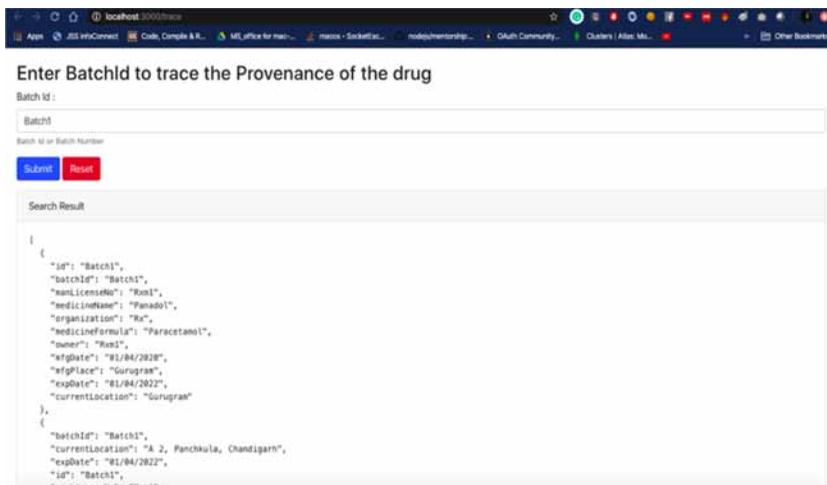
regarding the medicine, and in case one encounters counterfeit drugs, then all the responsible actors for handling that batch of the drug can be identified.

In figures 16 and 17, batch1 details are fetched by the blockchain operator in which he can find all the transactions in which batch 1 is involved. In all the cases it is observed that the same batch is transferred with a change in the owner of that batch and the related details. This feature enhances the trackability in the system as one can track all the users involved in our system.

CONCLUSION

The implementation of PharmaChain has attempted to resolve the research questions pertaining to counterfeit drug problems and drug data provenance. The application of blockchain in the healthcare sector has a vital role in the market. PharmaChain represents a different approach of implementing a traceability system which can be used by auditing agencies as well as consumers to ascertain the genuineness of any pharmaceutical drug.

Figure 16. Trackability and traceability by batch id - page 1



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