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Blockchain based IoT platform optimized for data analytics

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ABSTRACT The Internet of Things (IoT) industry is revolutionizing the physical world into a new digital space. However, the exponential growth of the number of IoT devices has raised number of issues to be addressed. The blockchain technology can provide a solution to the scalability, security and privacy issues of IoT technology with its decentralized, immutable, secured architecture. Rapidly growing IoT systems generate huge amount of data which can be used to derive useful insights and predictions. In this study we introduce a blockchain based IoT platform which provides access management with the use of blockchain technology. Moreover, a novel approach to integrate Machine learning and Artificial Intelligence with blockchain technology is presented as the Block Analytics Tool (BAT).Massive amount of data produced by the IoT devices and systems can be stored, analyzed and learned to make predictions about the future in a secured, privacy preserved environment with the use of the BAT. In this paper, we design and implement the proposed system. In addition to that, Pharmaceutical supply chain is used as the use case scenario to show the functionality of the proposed system. A model to forecast the demand of pharmaceutical drugs is built using a real-world data set to demonstrate the use of BAT while analyzing the performance of the proposed platform.

INDEX TERMS IoT, blockchain, data analytics, smart contracts, Access management

I. INTRODUCTION

INTERNET of Things (IoT) plays a significant role in the convenience of human daily life at present through various innovative applications and services. Further, it empowers the concept of autonomous systems creating new social paradigm. The enormous amount of data generated by these services and systems usually are stored in on premises servers and cloud servers depending on the context. However, these types of systems are vulnerable to several issues, including single point of failure due to its centralized architecture. Gartner [1] has predicted that there will be 21 billion IoT devices at the end of 2020. The traditional client-server architecture of the current storage system will not be able to withstand the growing large number of IoT devices. These systems communicate and store critical, secure and privacy sensitive data such as medical records, financial records [2]. Moreover, this recorded data could be used to identify patterns and anomalies as well as make decisions about the future. Unauthorized access to these data could lead to many security and privacy concerned issues. There are many incidents which have recorded violation of the privacy of the users of IoT devices [3]. The users have little or no control over the access management to the data. [4]. Furthermore, the data could be modified, deleted from the systems without the concern of the users which has raised issues such as counterfeit of medicine in pharmaceutical supply chains.

This paper presents a blockchain based IoT platform which makes use of the blockchain technology with other state of the art technologies in solving the above given problems. The decentralized, peer to peer architecture of blockchain can address problems related to centralized architecture. Access control mechanisms are used to protect data and prevent unauthorized access. The tamper proof mechanisms of blockchain provides data integrity making the system resistance to unapproved modifications. Smart contracts are used to invoke the communication between IoT devices verifying the authenticity of data sources.

This study introduces a novel approach to converge machine learning, Artificial Intelligence (AI) applications and blockchain technology with the Block Analytics Tool (BAT). The blockchain based platform enables decision making and predicting future on trusted, secured data which are stored in a decentralized manner without an involvement of third parties. The proposed system facilitates learning on huge amount of data produced in the systems integrated with IoT devices.

We evaluate the performance of the proposed architecture using various criteria. In addition, we implement a real-life case study on the platform to show the functionality of the proposed system. Drug counterfeiting is a critical issue in pharmaceutical supply chains as it impacts human life. While integrating IoT devices such as RFID tags and temperature sensors with the proposed platform, functionality of the supply chain is modeled. Using this architecture, counterfeiting of drugs can be stopped while making sure favorable conditions for drugs such as temperature is maintained throughout the supply chain. Furthermore, a predictive model to forecast the demand of pharmaceutical drugs using the data stored in the platform is implemented using the BAT service provided by the proposed architecture.

The rest of the paper is organized as follows. Section II gives a brief description about blockchain technology. A brief introduction about the contributions towards blockchain based platforms is given under related works in section III. The design architecture is explained in section IV. The design of the Block analytics tool is explained in the section V. The implementation of the case study is found in section VI with the performance analysis of the proposed system. Section VII discusses and concludes the paper with future work.

II. BLOCKCHAIN

One of the most critical problems in the computer world which is building trust among untrusted parties without an involvement of a third-party is solved by using blockchain technology [5]. Bitcoin was introduced by Satoshi Nakamoto as a pure decentralized peer-to-peer electronic cash in 2008 which marked the initial implementation of blockchain [5]. Blockchain is a distributed database or a ledger which contains timestamped records. These records are known as blocks. Blocks are protected by cryptographically and linked to previous block [6]. A transaction in blockchain is verified by peers in the network. Without knowing each identity a peer can verify a transaction and add it to the blockchain. A transaction can be individually identified by its cryptographic hash. Transaction history is visible via public keys but participants are anonymous. Peers need to verify a block before adding a transaction to the blockchain and distributed peers should agree on the order of the transactions before the block is added into the blockchain to maintain the integrity. This is known as the consensus mechanism. This ensures blocks are valid within the network. There are different types of consensus mechanisms used by blockchain technologies such as Proof-of-Work [7], Proof-of-Stake [7], voting-based consensus [8]. Blockchain can be categorized in to three main categories according to the permission type namely permissionless, permissioned and consortium blockchains [9].

Blockchain opens a new paradigm for decentralized, uncensored computations which build trust. Applications like Smart Contracts, Cryptocurrencies leads to new digital transformation of assets. Blockchains can be applied to industries such as supply chains, medical institutes, insurance companies and many more to build trust among partners as well as users. Blockchain technology is evolving to provide a more secure, trusted, tamper-proof, decentralized systems.

III. RELATED WORKS

Developing of IoT platforms using blockchain technology has been attracted by many researchers and developers due to many reasons.

The existing IoT platform architecture is highly centralized and with the rapidly developing IoT industry, the centralized architecture will not be efficient or scalable to embrace the growing number of IoT devices [10]. Hence the decentralized architecture will be efficient and it will be able to manage the increasing number of IoT devices. The system will be able to resist a single point of failure as it is decentralized.

Access control is the ability to control who has access to the data. There was a huge data breach when using apple fitbit [3] where the data of the users were accessed by 3rd parties without the consent of the users. With the blockchain technology the user can be sure that their data is not used without proper authorization. The data becomes tamper proof which secure the integrity of data. If the data is changed or altered, the blockchain technology can figure out where the data has been changed and the timestamp of the block change which makes the system tamper proof.

Most of the blockchain IoT based platforms are focused on the access management control. FairAccess [11] is one of the platforms which improve access control by using a novel type of blockchain. Seyoung H. et al [12] also has proposed a platform using blockchain for the access management of IoT devices. Ethereum [13] is used as the type of blockchain and access management is controlled using smart contracts. Lei H. et al has created a blockchain platform [14] with a novel method of access control. The platform introduced is created in a layered architecture where modifications can be done to each layer without affecting the other layers. Methodology used has decreased the computational time which enables real-time IoT device access management. Oscar N. [15] propose a platform which mainly focuses on the access control of distributed network sensors which are connected geographically. The scalability of the system is increased using a specific type of node called management hub nodes as it would enable connection of networks simultaneously.

LSB [16] is a novel blockchain which is light and scalable which is specially designed for constrained IoT devices which addresses many security and privacy issues. It is a time-based algorithm which is used as consensus instead of using PoW and PoS which make the blockchain more lightweight. The introduced blockchain will reduce the overhead of the blockchain which is very useful in real time applications. Separate storage, access and monitoring protocols for the blockchain is designed in a manner which would handle data in real time. PlaTIBRART [17] is a platform which is designed for data management. It is also using layered architecture. Different tiers are created in the same structure where centralized IoT platforms do not use blockchain technology. Hence the different layers could have a hybrid architecture with the influence of both technologies. DPoS [18] is a platform which utilizes blockchain technology. Xinxin F. et al describe how it can be used for IoT with modifications.

Researchers have shown interest in utilizing the blockchain technology specifically for the industrial IoT (IIoT). BPIIoT [6] is a blockchain platform for industrial internet of things which can be used to create distributed applications (Dapps) for manufacturing. Using the Dapps provided by the BPIIoT platform a machine can perform transaction with another machine or a consumer without a third-party control. The processes performed in factories and supply chains could be automated and all the transactions could be recorded in the ledger in a secured manner. It can be specially used in the applications of supply chain tracking, on-demand manufacturing, product certification, tracking supplier identity and reputation.

There are many studies conducted to explore the data storage management of the blockchain technology. Hossein S. et al [19] have taken the basic cloud architecture and decoupled the data plane and control plane of the architecture and restructured the architecture to be used as an IoT platform. The usage of blockchain technology in the control plane has enabled the control of data and access control by the proposed system itself without a centralized authority. BeeKeeper [20] is an IoT platform which is used for homomorphic computation and secure storage. The architecture of the beekeeper is based on a beehive. The devices are considered as bees and the blockchain network together with the servers, act as the beehive. The system creates more beehives with the addition of more devices to the network. The data collected is processed with homomorphic computations [21] without learning. Sapphire [22] is an IoT platform which is specially proposed for data storage management. This system is designed in a manner where the storage architecture could be specifically used for the data analytics application of IoT. The hashing mechanism used by the system is Location and Type Sensitive (LTS). Dynamic load balancing is proposed as the hashing mechanism would create the storage to be unbalanced. The classification of IoT devices as super nodes, regular nodes and light nodes with the computational power and memory space makes the data analytics process easier. IoTA [23] is the most popular IoT blockchain platform which is using its own blockchain tangle. It is using a novel blockchain architecture and the platform has proved to be working with the best performance. The method of consensus used by the platform only takes a few seconds which increases the performance of the system. The lightweight architecture increases the real time performance and also increase the scalability of the system. Tangle, the type of blockchain used by the IoTA also act as a cryptocurrency.

Apart from these blockchain based IoT platforms, studies have been conducted to improve the data analytics application of blockchain [24]. Massimo B. et al [25] describes a mechanism to integrate blockchain data with other existing databases. Hoang T. et al explain the way to use blockchain technology for micro insurance. In this study blockchain acts as a secured database [26]. IPFS [27] is a creation of new internet protocol with the use of blockchain technology. This novel protocol defines a new mechanism to store data on the internet in a more convenient way. Paul T. [28] describes the way blockchain and big data could be used to store medical data in a more secure manner. Also, the paper elaborates about the advantages and disadvantages of using blockchain technology to store medical data.

However, the studies conducted to integrate data analytics application to the blockchain technology still have many constraints and drawbacks. Section V provides an overview of these drawbacks while introducing a new approach to address these issues.

IV. DESIGN ARCHITECTURE OF THE PROPOSED PLATFORM

In this section, we present the proposed architecture of the system with basic details about the components of the platform. The section IV-A provides detailed explanations of the way each component connected for the basic functionality of the platform. For this study Hyperledger [29] is chosen as the blockchain candidate technology. Hyperledger is chosen as the blockchain as it is the most suitable type of blockchain for handling business logic currently [30].

Figure 1 shows the overview of the basic architecture of the proposed platform. A modular architecture is adapted with a layered structure which makes sure that each layer could be designed separately without altering the basic architecture. The design is basically divided into 4 layers. Each layer is interfaced with the other layer through a communication medium.

The bottom layer of the platform consists of the device layer which consists of the devices which can be connected to the network. The device layer is connected through a local gateway to the network layer.

The network layer manages the device layer. The security and the network management of the device layer is performed by the network layer. Basic security protocols are implemented for the transmission of data and control

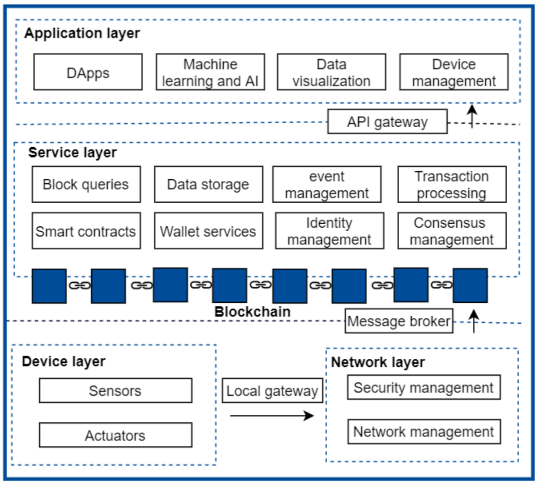


FIGURE 1. Overview of the proposed platform.

between the device layer and the blockchain such as data encryption to prevent unauthorized listening and understanding of the content. In the proposed system MQTT [31] is used as the protocol for communication of IoT devices as it is lightweight and more suitable for the communication between constrained devices as it has a small header [32]. Furthermore, the network layer uses Transport Layer Security (TLS) [33] for the encryption of data. The network layer is connected with the blockchain network through a message broker. In the proposed implementation, MQTT broker is used as the message broker.

The blockchain network is the main actor in the platform. The service layer is found on top of the blockchain layer. Smart contracts are one of the most important services provided by the service layer. A smart contract is a special code/ program where there are few conditions mentioned [34]. When the conditions are met by a specific user or a device, mutual authentication or access could be granted. A transaction occurs when the input variables are satisfied with the logic function given. From one instance to the other the specific logic function changes. The use of a smart contract removes the necessity of use of a central authorization mechanism or a 3rd party access of the system. The platform creates different smart contracts according to the specific situation. i.e. if the transaction occurs between the device and the blockchain, the smart contract is different from a smart contract where the smart contract is used to give access to a user of the system.

Wallet services help the platform in the process of identity management of the platform. These wallets are produced by each Certification Authority of the blockchain network. A wallet contains digital certificates and security keys which can be used for the identification of a component connected to the network. The validation of the certificates provided by the components are performed by the particular organization which issued the specific wallet to the user. This makes sure that the identity management service of the platform is decentralized between the organizations of the blockchain. Furthermore, each component connected to the platform can be granted with levels of privileges with access control. A user can have privileges of an admin, writer or a reader [30]. This reduces the control each user has over the platform. A client user of the platform will not be able to alter the configurations of the platform.

The transaction processing is one of the major uses of the platform. A consensus mechanism is used for the ordering and validation of transactions. The platform uses a permissioned voting-based consensus mechanism as explained in the section II.An endorsement process is performed [35] for the validation of the blocks. The endorsement policy defines which organization needs to approve the transaction. In our proposed platform, all the organizations connected to the network should validate the transaction. Event management is another service found on top of the service layer. In the proposed platform the data is requested from the device layer with a triggering of an event.

Blockchain stores data of all the transactions processed in the platform. Data related to peer to peer communication is stored as blocks without the control of a central authority in the data storage. Hence blockchain acts like a data warehouse [36] which stores data from different sources (IoT devices, DApps data, management data…). This data is very useful especially for industries and business. With the proposed system data can be retrieved and data visualized easily specially for business analytics.A novel approach to query the blockchain is introduced in the section V.

On top of the services provided by the blockchain, the application layer which exposes these services to the external users can be seen. This layer is interfaced with the service layer using an API gateway. The transaction processing and interacting with front end applications are developed through the decentralized applications (DApps).

In the proposed system, a special architecture is created to develop machine learning and artificial intelligence applications using the data stored in the blockchain as explained in the section V In the architecture each IoT device is registered before data transmission from the device. The end application of device management in the application layer is used to handle IoT devices. The registration and management is done through a smart contract specifically created for that purpose. Each device is also provided with a wallet to prove its identity. Hence this mechanism will make sure that unauthorized devices cannot communicate in the system. This provides a solution to the problem of integrity of IoT devices.

A. EXECUTION PROCEDURE OF A TRANSACTION

The figure 2 shows how the different services of the layers in the architecture collaborate together to perform a transaction.

First of all, when a user wants to interact with the proposed platform, the user should first provide the identification certificates which are stored in the wallet of the user to the blockchain network. The wallet is issued to a user by a specific organization established in the network.This process

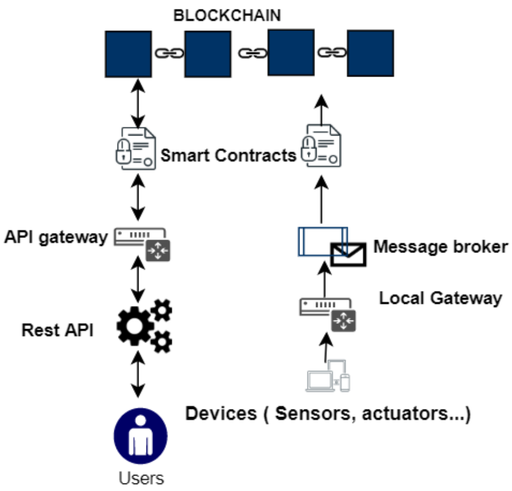


FIGURE 2. Transaction execution procedure .

is done through the API gateway connected to the rest API. If the user fails to produce the proper credentials, the users will not have access to the platform.

After the authentication, the request for the specific transaction or the process is submitted to the API gateway through the application. The smart contract will be invoked once the request is received by the blockchain network. If the necessary conditions are fulfilled, the endorsement peer will approve the transaction and commit the transaction. The other entities of the network are informed about the transaction through the orderer of the network and all the peers will update their ledgers about the transaction. Then, the response of the transaction is sent back to the application through the gateway.

If the particular smart contract requires readings of the IoT devices connected to the network, an event is triggered through the chaincode and the network subscribes to the message broker (MQTT broker) of the system. Through the local gateway, the sensors and actuators will publish the encrypted data as explained in the section IV.

V. BLOCK ANALYTICS TOOL (BAT)

The storage system on the blockchain is specifically designed to handle blocks of data and store the transactions as objects. The storage system is specially optimized to increase the efficiency of transactions in the blockchain. It is neither optimized to perform complex queries nor as an efficient data retrieval schema. Hence in most of the studies that have been conducted off chain database which contains the same data stored in blockchain is used instead of using the on-chain database. In studies, mirror storage facility has been used that would run concurrently with the blockchain storage system which would replicate all the data in both locations. But that would be a huge waste as it would double of all the resources used to store and analyze data. The mirror storage would store redundant data that would not be useful for any future reference. Moreover, updating the storage system at two locations concurrently, reduces the processing time of a transaction which affects in reducing the performance of the platform. In some studies the on-chain network is used to store the security key and the data would be stored in the off-chain database [37] . In this mechanism, everytime a transaction is processed, the data stored in the off-chain network has to be retrieved to identify the state of the block. For instance, in a supply chain transactions, the current owner of the specific object has to be identified to perform the transaction between the current owner and the new owner of the object. For this purpose, off-chain database has to be queried. Hence, the performance of transaction processing will be reduced drastically.

Owing to the reasons explained about the constraints in the state of the art approaches in converging data analytics application with blockchain technology, we designed a novel approach which would reduce the cost of a mirror storage or an off-chain database and would optimize the querying mechanism of blockchain.

The figure 3 shows the basic functionality of the Block Analytics Tool (BAT) tool. The user provides the necessary configuration files through an API which would define the user specific requirements. The BAT can process different data analysis tasks parallel without affecting the other task. The tasks can be separately run in different environments as specified by the user through the configuration files.

The user interactions are always performed through smart contracts. Hence, even if a user tries to change the data of the blockchain though the BAT, it cannot be executed as the queries are performed in only one of the ledgers in the blockchain network. Other ledgers and peers in the network would not be updated about the change of data which would fail the endorsement/consensus of the transaction which results in denying the alternation.

A. BLOCK INDEX

As mentioned earlier rich queries can degrade the performance of the blockchain system. Furthermore, to query a single block, all the blocks in the blockchain have to be searched. Acquiring the data from the blockchain acts as a bottleneck of the proposed system. Hence, we propose a novel approach that can be used to optimize the data acquiring process from the blockchain.

A special indexing system called block index is proposed in this architecture to reduce the search time in the blockchain. This index system would be more suitable when blockchain is used for transactions especially in business logic. Blockchain technology is used to handle transactions between two parties. A unique ID is given for all the transactions recorded in the blockchain. In transactions what happens is the change of the ownership of this specific object while the other details about the object remains the same.

For an example, in vehicle trading between two parties what happens is that the ownership of the vehicle changes

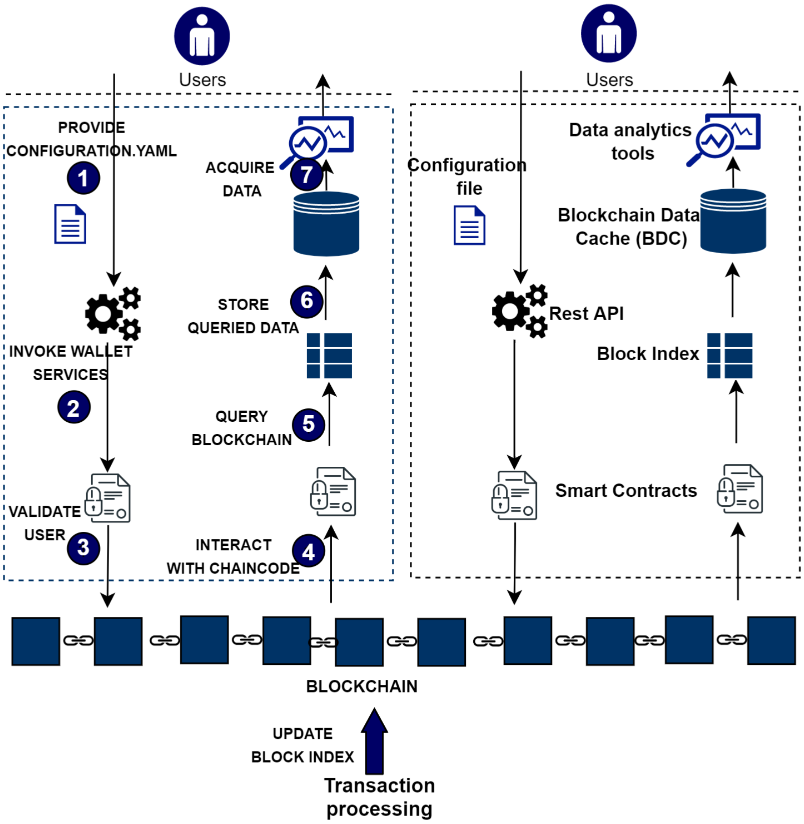


FIGURE 3. Overview of the Block Analytics Tool (BAT).

while specifications about vehicle such as engine capacity, fuel capacity, dimensions, power remains the same.

Moreover, when we want to search through a blockchain, if we want to get details about a particular object, the search pointer goes through many blocks that contain the same details which increase the search time to a large extent.

To address these drawbacks, we propose the block index system. In the block index system, the first transactions that occur related to a particular object are stored in the first column of the index. When more transactions occur related to the same object, they are stored in the second, third ... columns of the index.

In the architecture of the blockchain, transactions are recorded in a manner where all the data would be duplicated into the newly created block with the changed parameter. Thus, in our index system, if we want to query details that would not change over transactions, we can easily go through the first column of the index and find the necessary block.

For instance, the figure 4 shows a part of a blockchain which is used to store data about trading of cars produced by a company. The blockchain is used to keep track of the current and previous state of the cars. Imagine that we want to find a car with specific details. In the given example, block P represents a car with the given specifications. If it queries through the same blockchain architecture, the pointer would have to go through all the blocks. But in the proposed block index system, the pointer only has to go through the first column to acquire the information.

This reduces the time complexity (T(n)) of query time from O(n) to O(m) where n is the input size and n>m. In the index system, the width of a row represents the number of transactions related to a specific object. The adjacent columns of the index contain the details about the same object with ownership and few other details changed. This becomes very efficient once the number of transactions for objects are higher. After initially creating the blockchain network, every time a transaction occurs, an event is triggered to update the block index. Instead of updating a database with the same set of details, updating an index would save processing time as well as the storage.

1) Implementation of the block index

In the proposed blockchain based IoT platform, Hyperledger is used as the blockchain. In the implementation, CouchDB [38] database is used as the state database. CouchDB provide an index system which can be used to query the database easily. The proposed block index makes use of this system. The algorithm 1 shows the pseudo code of the block index. When a block is created in the blockchain or transfer object, through the chaincode the block index is updated. If the block contains details about a newly created object, the block index would store the transaction of

Algorithm 1 Pseudo code to add a block to the block index

```
Input: x[ID] - ID of new block
Output: column of the index, row of the index
    Initialization:
    nRows0 = number of rows in column 0
    nColumnsi = number of columns in row i
    IndexColumn = 0
    for $i = 0$ to $nRows0$ do
        if $(i[ID] = x[ID])$ then
            for $IndexRow = 0$ to $nColumnsi$ do
                IndexColumn = IndexColumn+1;
            end for
        end if
    end for
    return $IndexColumn, IndexRow$
```

the object under the column 0. When the object undergoes another transaction, the transaction would be recorded in the second column through the chaincode. When querying the blockchain, the couchDB make use of this block index created to retrieve the information.

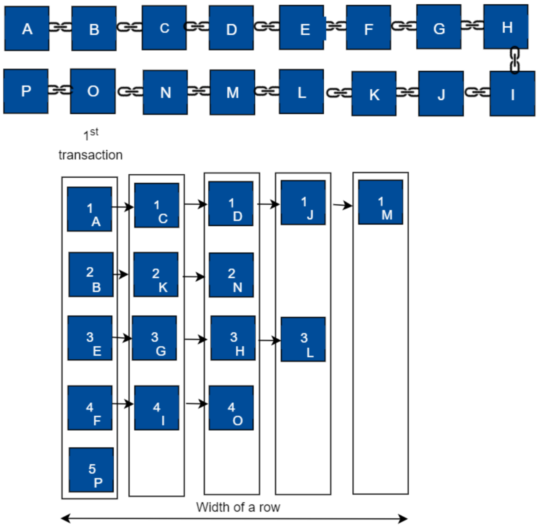


FIGURE 4. Architecture of Block Index.

B. BLOCKCHAIN DATA CACHE

Through the configuration files the user has the capability of requesting a specific set of data according to the requirements. Then, through the BAT the data is queried from the blockchain using the Block Index and the retrieved data is stored in the Blockchain Data Cache. The Blockchain Data Cache acts as a temporary storage for the retrieved data. In our study we support both on-premise and cloud storage systems to be used as the BDC. In the creation of the BDC, the event manager and the ordering service of the blockchain network makes sure about the synchronization of the blockchain network with the BDC to maintain the ACID properties [39] of the blockchain database and the BDC. The created BDC can be pulled down with the destruction of the resources phase in the BAT.

C. DATA ANALYSIS TOOLS

The data analysis tools and frameworks (Tensorflow [40], Pytorch [41] . . .) as specified by the user through the configuration files, can be integrated with the BDC. Unlike the blockchain data storage system, the tools can perform rich queries, preprocess data stored in the BDC.

VI. CASE STUDY

A. USE CASE CONCEPTUAL SCENARIO

A pharmaceutical supply chain is used as the use case scenario to present the architecture of the proposed system. Drug counterfeit is a severe problem in pharmaceutical supply chains. This occurs due to the lack of transparency in the transportation of drugs through the supply chain. Certain medicines also require to have proper conditions maintained. These details also remain hidden and no trusted method to monitor these conditions. According to the World Health Organization, more than 10% of medicines worldwide are counterfeited [42]. Counterfeiting happens in several ways such as manipulating the expire date, producing with no active chemical ingredients, wrapping in forged packages. [43]. After distributing these ill-treated drugs, users are unable to identify these counterfeit medicines. There is no proper mechanism to verify the integrity of whether the original package is distributed by the 3rd party logistics company [42].

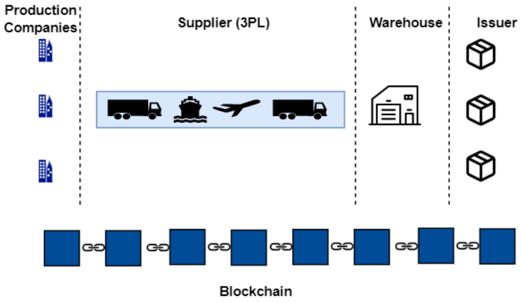


FIGURE 5. Use case scenario.

Most of the above-mentioned problems can be addressed by establishing trust and transparency between the parties in the supply chain. A blockchain based IoT platform can be used to process transactions that occur in the supply chain. RFID tags are used to prevent tampering expire date, manipulating dosage information in the medicine package. Drug manufacturers add initial package data into the Blockchain and RFID tags which can be used to verify the details at any given point using the proposed platform. To track whether the drugs were transported using correct conditions sensors could be used. For example, temperature sensors are used to check whether the temperature of drugs was maintained during transportation or during storage while processing the transaction. It is assumed only sealed packages with RFID tags are accepted by the parties in the supply chain.

Figure 5 shows the scenario of the use case chosen. In the use case, the production companies produce medicine, 3PL (3rd party logistics) supply the medicine to the warehouse. Through the warehouse, the medicine is distributed to the pharmacies or the issuers. Most of the time drug counterfeiting occurs through the suppliers and the warehouse.

B. SYSTEM ARCHITECTURE OF THE CASE STUDY

The implementation and analysis of the platform was performed in the gcloud virtual machine instance (configuration of Name- c2-standard-4, Zone- us-central1-f, CPUs-4, Memory- 16GB). The main actors of the scenario are the supplier, warehouse and the issuer organizations. The network is initiated by the warehouse organization and the initial configuration of the network is configured by the warehouse entity. The network is controlled according to the rules imposed by the network configuration. The channel of the blockchain is named as the NCK channel. The channel order is maintained by the orderer connected to the channel. The channel is governed by the channel configuration which has the policies related to all 3 entities. Separate certificate authorities are maintained by each entity for the validation of the transactions processed in the blockchain. Each organization consists of 2 peers and 1 peer is used as the anchor peer which is used to communicate with the other entities. In each peer a copy of ledger containing details about all the transactions are installed. The peers contain copies of smart contracts installed in the network. 4 different applications are created as decentralized applications (DApps) which are used by different organizations for transactions and processing of data. 2 smart contracts are mainly used by the applications.

- Create batch - a manufacturing company uses this application to create a batch to be delivered to one issuer company. Details about the batch of drugs such as name, dosage, quantity, manufactured and expiry date are added as a block to the blockchain. An RFID tag is assigned for this particular batch.
- Transfer batch - This is used when a batch is transferred from one entity to the other.

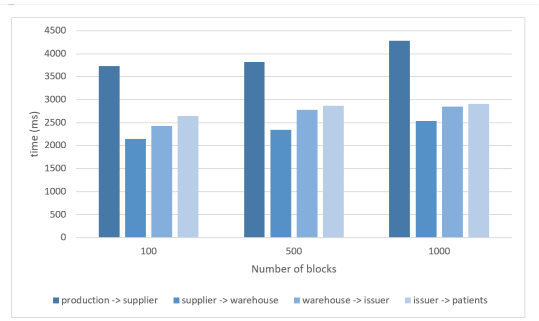
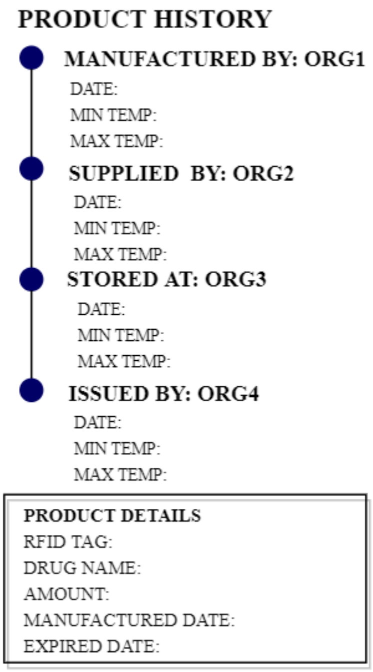


FIGURE 6. Total transaction processing time

Through the application, when an RFID tag is read by a specific entity, the value of the temperature sensors is read to the system and it is checked whether the batch has maintained favorable temperature up to that point. If the temperature has not been maintained at the range or if there is any breach in the data related to RFID tag, the smart contract will automatically be invalidated. The smart contracts and the endorsement policies will make sure that the data is read or added by an authorized person who has necessary wallet configurations.

4 different applications are used by production companies, suppliers, warehouse and issuers for the transactions. The figure 6 shows the total transaction processing time taken by different applications for creating and transferring batches with the help of sensors and devices. With the addition of new blocks. the transaction processing time increases and highest transaction time is taken for the creation of the new batch. This is due to the device registration time related to RFID and temperature sensors. Through another application, an end user can examine where a specific batch is located on that occasion. Eventually, the end user at the issuer can see how the batch has been transported, stored and issued by the organizations while maintaining the favorable conditions for the batches with complete transparency. Figure 7 shows a sketch of the application.


PRODUCT HISTORY

MANUFACTURED BY: ORG1
DATE:
MIN TEMP:
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SUPPLIED BY: ORG2
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ISSUED BY: ORG4
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PRODUCT DETAILS
RFID TAG:
DRUG NAME:
AMOUNT:
MANUFACTURED DATE:
EXPIRED DATE:

FIGURE 7. User output of product history at the end of transferring through the supply chain.

C. DEMAND FORECASTING OF PHARMACEUTICAL DRUGS

All the transactions occur in the supply chain are recorded in the blockchain. Blockchain also acts as a data storage system for transactions. These data can be used for data analytics of the supply chain. The difference between the supply and demand in supply chains is known as bull whip effect [44]. Maintaining this effect in pharmaceutical supply chains is very important. Demand forecasting in the pharmaceutical industry is critical as the availability of drugs at the needed time, impact on patient's life [45]. Furthermore, the demand for drugs by different pharmaceutical companies is a complex combination of the necessity of drugs, shelf life, regulations and the cost associated with drugs.

The consumption method [46] of forecasting of drugs is the usage of historical data of past consumption of drugs.

As the data is recorded in the blockchain in a well-ordered manner, it can be used to predict future requirements of drugs easily.

We used this use case scenario to experiment the block analytics application designed. With the help of hospital prescribing dispensed in the community dataset [47], batches of drugs were created. The data about hospital prescribing data related to the Manchester University NHS Foundation [47] were used for the study. The batches were added in a manner where batches would be transferring through the supply chain at different stages. A block contains details about RFID tag, drug name, dosage, quantity, cost, organization (production, supplier…), temperature sensor readings, transaction time, manufactured and expired dates. During a transaction the organization, temperature sensor readings change while the other details remain the same. The block index was updated with the addition of batches to the platform.

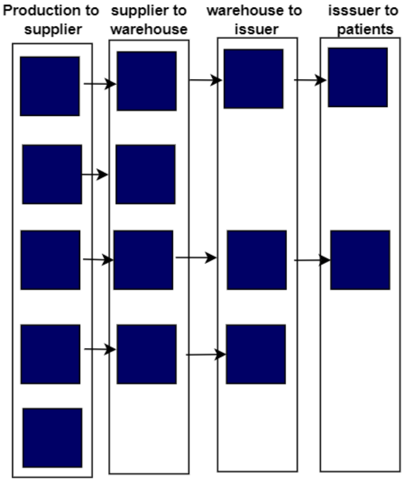

FIGURE 8. Block index for the use case scenario.

Figure 8 shows part of the block index which shows the state of transfer of batches through the supply chain. The transaction ID is used to map the block index to the blockchain. Table 1 shows the comparison of querying time using block index and using block index. In the table, the batches issued to the users means retrieving data of the 4th column. Selecting quantity for the batch X is getting data about a batch, which is querying through the first column and getting the data without going through all the blocks. Get the details about the batches of drug type z result in the search pointer moving only through the first column and checking the block types where drug type = z. When getting the transaction history for a batch, the pointer would not have a special use in using the block index as it would have to go through all the columns to get the transaction history.

TABLE 1. Performance analysis of the block index

Query	With block index (ms)	Without block index(ms)
Select blocks which are issued to users	1235	2786
Select quantity for batch x	312	561
Get batches of drug type z	376	542
Get transaction history for batch x	527	533

For the demand forecasting analysis, the details about Drug name, quantity, cost and issued date of batches had to be extracted. According to the block index designed, the details about issued batches to the patients are available in the 4th column. Using the block index, the specific batches could be extracted easily without querying the full blockchain. If the block index was not used for this purpose, the querying would be more complicated with more functions and algorithms.

The retrieved blocks are stored in the BDC. For the study, non-relational database MongoDB [48] was used as the candidate on-premise database for the Blockchain Data Cache. Data were preprocessed using the BAT tool and machine learning model was built on Tensorflow. The demand analysis of supply chain data is a time series analysis as the previous storage, seasonal weather patterns, average salary is affected by the time. Pharmaceutical drugs show correlations between each other as many drugs are prescribed as a set for a specific disease. While preserving these correlations, the time series analysis model was built using xgboost regressor [49] with SVR machine [50] as the base estimator. The model was built with the accuracy of RMSE value of 0.5213. The demand of drugs for the next month can be predicted using this model.

Figure 9 shows the demand prediction and actual values of total quantity of certain types of drugs for the month October of 2019 for the hospitals in Manchester University NHS Foundation [47].

The BDC can be pulled down after the analysis. The BAT saves the state of the model, BDC, and query terms are saved and when the model is required again, the BAT will invoke the state and the BDC will be updated with the newly added blocks of batches to the blockchain.

VII. CONCLUSIONS

The rapidly growing autonomous systems which integrate IoT devices, network and storage systems have many vulnerabilities. In this paper we design and implement a blockchain based IoT platform which address scalability, data security

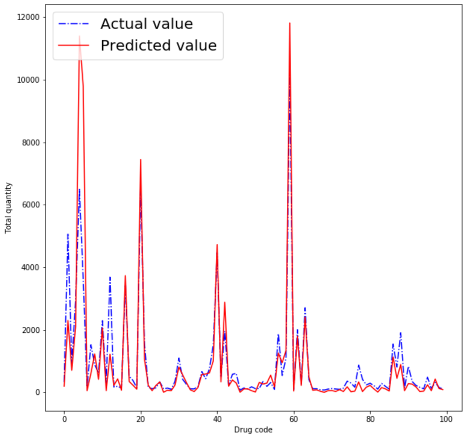

FIGURE 9. Predicted and actual value comparison for the demand forecasting.

and access control problems found in these autonomous systems with the use of blockchain technology. The devices can be connected to the blockchain and monitored through the end user applications. Furthermore, we introduce a novel approach to converge machine learning and Artificial Intelligence (AI) technology to perform secure learning and prediction methods using data analysis. The Block Analytics Tool (BAT) uses a new method to query the blockchain with a block index. This index is ideal to be used in systems where blockchain is used to record and manage transactions. The queried data is stored in a Blockchain Data Cache (BDC) which act as a temporary data storage to be utilized by data analytics platforms and frameworks. After the data has been analyzed the created resources could be pulled down using the BAT. The implementation of the case study depicts how the proposed system meets the defined design principals and requirements. This novel approach of BAT with BDC saves resources such as storage facilities compared to the traditional approach of creating mirror storage which duplicate resources. The usage of block index reduces the cost associated with queries saving processing time which increase the efficiency of the proposed system. Furthermore, the architecture can effectively be utilized as the state of the created forecast models can be saved to be reused with the addition of new blocks. Moreover, the usage of smart contracts to invoke the BAT make sure that unauthorized parties will not have the access to use or modify the data.

In the future we mainly focus to bring the platform towards edge computing. The BAT tool has to be optimized further for real time processing. In the current implementation the created BDC do not communicate with each other. In future versions, the inter communication between BDCs will be implemented.

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