Blockchain - Bringing Accountability in the Public Distribution System

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***Abstract*—The Central and State governments of India uses the Public Distribution System(PDS) to distribute food grains to the citizen of India at subsidized rates to ensure food security. The system is prone to losses of food grains because of prevalent corruption among the officials serving the system and also due to physical losses during storage and transport. Blockchains have become a commonly used audit trail verification utility because of its inherent nature, that it is a distributed ledger for recording transactions. This makes it a key candidate to replace the current centralized system that exists for the tracking of commodities being distributed by the PDS. Like any centralized system the current centralized system can be sabotaged by the people in administration, as it relies heavily on trust on the central authority.**

In this paper we propose an intelligent scheme for tracking the commodities in PDS using IoT based sensors that monitor the arrival and dispatch of commodities and generate corresponding transactions. These transactions should be stored permanently to keep track of the commodities for which a decentralized Blockchain based system is used that continuously logs every valid transaction. As the amount of transactions increase so does the data to be stored on the blockchain, hence we propose a hierarchical blockchain approach where in transaction summaries of a local blockchain are recorded as transactions in a higher level blockchain after which the local blockchains can start afresh recording newer transactions only. This approach results in reduction in the amount of data to be stored on the blockchain. At the same time one can find aggregate information at a higher level which can be used to determine the supply demand ratio. Anyone can verify the current availability of the food grains throughout the distribution network of the PDS and track the commodities right from the network of warehouses to the end point sales-the fair price shops where the food grains are delivered to the consumers. These transactions can be audited at any time as all transactions are recorded in the Blockchain which can prevent any misuse or corruption.

Keywords— Blockchain, Public Distribution System, Distributed ledger, IoT

I. INTRODUCTION

The Government of India and its state governments together manage and administer the PDS by using a network of warehouses, logistics and fair-price shops (ration outlets). The entire PDS is a complex system both because of its structure and scale. It has to identify the demand and supply requirements and make judicious decisions in planning and resource allocation. Since PDS is a very large system spread across the whole country the commodities should be continuously tracked to prevent mismanagement or theft. So the goods have to be tracked from the point of procurement (i.e. the warehouses)to the point of sales(fair-price shops). Any person should be able to verify the current status of the stock at any point. Currently this system is being administered in a centralized manner with the government digitizing the whole process. Even though digitization has brought in level of transparency, the current centralized structure places a high degree of control and power with officials administering the system. With rampant corruption in the bureaucratic system, it is more likely that the people in the administration can tamper with the commodities by fudging the transactions maintained in a central ledger or database. Once these transactions are tampered with there is no way by which such malicious changes can be identified later during an audit mechanism. Like any other centralized system this system is prone to lack of trust among its users. The proposed decentralized model using blockchain allows for any person to verify any transaction happening in the system. This in turn prevents hoarding or misuse of the commodities by the persons running the PDS fair-price shops and any common man can get to know the current quantity available at a fair-price shop in a transparent manner. This system when coupled with a sensor based IoT system gives a complete tracking system during transit of commodities and its storage at various levels thereby avoiding any scope of theft.

The objectives set out at the beginning of this work are as follows:

- To identify and verify commodity arrival and dispatch at warehouse and fair price shops using IoT based sensors.
- To record a valid transaction into a blockchain.
- To periodically summarize the transactions stored in a local blockchain and update it on a higher level blockchain.

Any transaction in the PDS system be it arrival and dispatch of commodities at a chain of warehouses or sales at the endpoint fair-price shops is considered a transaction and is recorded in a blockchain which is tamper-proof. This is trust less system as there is no central authority and a transaction once recorded cannot be tampered by the people involved. Usage of sensors for weighing and tracking will automate the system to a greater extent.

The organization of the paper is as follows. Section I describes the introduction, identifying the objectives of the system and their significance. The details of current research

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work in the domain of blockchain for supply chain management is provided in Section II. Section III discusses the design of the proposed system. Section IV delves on the implementation details and discussion of results. Section V brings about the conclusion of this work followed by the references.

II. Literature Survey

The following is a summary of existing works related to our work in the field of blockchain for food supply chain management.

Weigbin Hong, Yefan Cai and Ziru Yu[1] discussed the usage of Internet of Things(IoT) devices in monitoring the food products efficiently and the advantages of blockchain technology in recording the data compared to traditional database. They have also discussed the life cycle of a food product by considering detailed architecture of the system.

The blockchain is a distributed immutable ledger which is mainly introduced to store transactions of financial applications. But now a days, blockchain has its applications across multiple domains including supply chain. There are many research papers focused on technological part and business process in non financial applications. Guido Perboli, Stefano Musso and Mariangela Rosano[2] proposed a methodology to design multiple use cases in non financial applications like supply chain. They mainly concentrated on fresh food delivery by showcasing the critical aspects of implementing a solution using blockchain in the respective use case.

Youness Tribis, Abdelali El Bouchti and Houssine Bouayad[3] had performed a review on different use cases which are proposed using blockchain in the area of food supply chain management. In this review they had analyzed about 40 research papers in food traceability domain and concluded that usage of blockchain technology in food traceability system helps to improve the trust of consumers and to improve food products safety.

The stakeholders for the food products are more and they may be located at different places. So it is difficult to manage data across all stakeholders using central storage facility. The production procedure and manufacturing procedure is not known to the end users. So it is difficult to build trust in the consumers. Jing Hua, Xiujuan Wang, Mengzhen Kang, Haoyu Wang and Fei-Yue Wang[5] proposed a reliable, distributed system using blockchain to solve trust issues of consumers. The blockchain records information about irrigation, planting, manufacturing, packing etc. till the end point where it reaches the consumers.

Feng Tian[6] analyzed the requirement of food product traceability in china because the traditional food supply management system does not meets the demands of the market. To propose effective food traceability system, they make use of Radio-Frequency Identification(RFID) and blockchain technology. They had analyzed the advantages and disadvantages of RFID and blockchain technology in developing Agri-Food supply chain management system. Through the analysis, it is realized that the usage of these technologies in traceability system helps to improve food safety, production, warehousing, distribution and selling. Prabu Devan S, Ruthara Kumar V and Prasath N[7] describes the uses of IoT and blockchain technology in building transparent, fault tolerant, immutable and auditable records which will be used for food traceability systems. They had developed a web application where producer enters the data of goods in webapp. RFID will track the goods physically. The IoT sensors are used at every stage, where the data collected from sensors is stored on cloud directly. M. P. Caro, M. S. Ali, M. Vecchio and R. Giaffreda[8] presents AgriBlockIot, a blockchain based traceability system for agriculture food supply chain management. Here they had used various IoT devices which will produce voluminous amount of digital data to monitor and trace the food products efficiently. They have implemented the food supply chain use case using two well known blockchain implementations namely Ethereum and HyperLedger and also made a comparison study on the pros and cons of both the blockchain implementations.

Dr Maciel M. Queiroz and Dr Samuel Fosso Wamba[9] developed a model to remove the gap in adopting blockchain technology and networking theory in supply chain management. The model is evaluated using the Partial least squares structural equation modeling (PLS-SEM). In the current supply chain management system, there is a common problem exists. That is the customer does not have information about the product they are going to buy. Roberto Casado-VaraJ, avierPrieto, Fernando Dela and PrietaJuan M.Corchado[10] proposed a model for supply chain management using blockchain to make the consumers know about the product which they will buy. This model uses the concept of circular economy and eliminates some of the problems of current supply chain management. In order to give transparency to all transactions which will occur in supply chain management, a multi agent system is proposed.

Now a day's many government entities are actively participating in exploring upcoming technologies to achieve smart transportation, customer satisfaction, efficiency and less cost. The blockchain technology is a good example to achieve paperless work and can be incorporated in multiple use cases of government. Because blockchain is a decentralized data structure to store data in the form of blocks, which can easily build trust among users. It also able to solve security challenges in IoT like data integrity and data sharing. Ahmed Alketbi, Qassim Nasir and Manar Abu Talib[11] identified specific use cases in government services which suits the usage of blockchain technology.

IoT devices can be used to collect information about vehicles in cities especially in the areas where the traffic is more. EiichiTaniguchi, Russell G.Thompson and TadashiYamada[12] describes some of the applications of decision making system to provide efficiency in city logistics. David Allessie and Lorenzino Vaccari[13] discussed about economic effects and constraints about the implementation of blockchain technology in public sector. They also identifies the true drivers of costs and benefits of implementing blockchain technology in public sector.

In the existing systems, authors had discussed about the usage of blockchain and IoT in food supply chain management. They have proposed many mechanisms to improve food quality, safety, transparency in food supply chain management. In this paper we are proposing a scheme for tracking commodities in the PDS using Blockchain for recording valid transactions.

III. Proposed System and Design

In the proposed system we first present the view of the system using the architecture diagram. We then outline the methodology used in designing this system. Then we discuss the design part that shows the organization of subsystems identified. Later we propose the Hierarchical blockchain approach to build the blockchain infrastructure required for recording all valid transactions.

A. *Architecture*

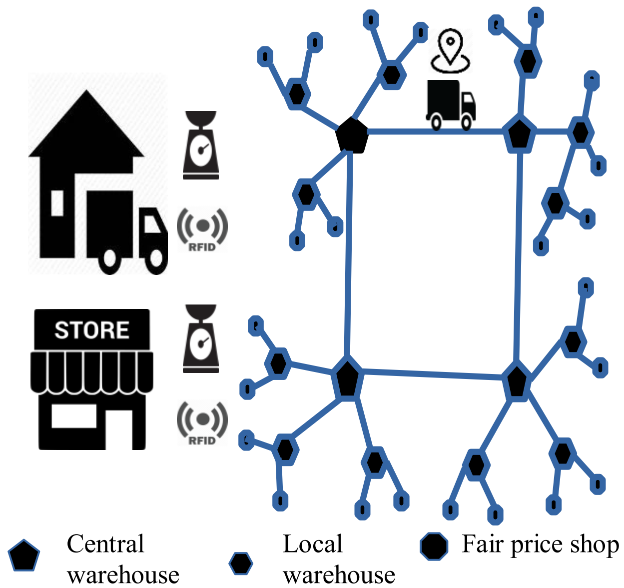

Fig 1: Public Distribution System using Blockchain

The architecture diagram as shown in figure 1 illustrates the overall structure of the PDS system augmented with the IoT based sensor module which store transactions on blockchain infrastructure. The movement of commodities in the PDS system result in sensors generating transactions which need to be stored in the blockchain. The PDS network is made up of central warehouses, local warehouses and the fair price shops which are arranged in a hierarchy. Commodities are dispatched from the central warehouse to fair price shops passing through intermediary local warehouses.

B. *Methodology*

The warehouses and fairprice shops are equipped with IoT sensors that monitor the commodities for arrival/dispatch, weight and destination. These sensors triggers transactions on the occurrance of events like arrival and dispatch. The generated transactions are validated after which they are written to a block in the blockchain. Over time these transactions pool up to form huge amount of data, hence to help alleviate this problem the transaction summaries of local blockchains are recorded in higher level blockchains in a hierarchical manner, after which old transactions can be removed from the local blockchains. The detailed structure of this system is espoused in the design part discussed in the next section.

C. *Proposed System*

The proposed system leverages the benefit of blockchains which are tamper-proof distributed ledgers to bring in accountability in the system, but at the same time is designed as decentralized system that records all transactions in the PDS. The system comprises the following sub systems:

- IoT based Sensor module
- Blockchain Infrastructure
- Administrative Console

a) IoT based Sensor module

The IoT based Sensor module is placed at each exit/entry points which continuously record incoming and outgoing commodities. The identification of the commodity is done with tamper-proof sacks fitted with a RFID tag and weights using appropriate sensors. RFID Scanners/readers are placed at entry/exit points of the warehouses and fair price shops. Whenever an RFID scanner reads a RFID tag it immediately triggers a Crop dispatch/arrival transaction which will measure the commodity weight automatically using IoT based weight sensors. The blockchain infrastructure will later record this transaction if this transaction is found to be valid by majority of its participating nodes. This reduces the scope for human intervention to a significant extent thereby eliminating the possibility of human error in recording the transaction details. Each transaction is recorded on a blockchain that is distributed and available for verification to anyone, here in this case it is the common man. We can also explore the possibility of a Hierarchical Blockchain approach.

Adding to these the commodities in transit are continuously monitored to verify whether the transport vehicles are indeed following the intended route. This is achieved by fitting the transport vehicles with a GPS module that relays its location coordinates frequently to the command centre. In case of any deviation is detected then the authorities will be notified immediately for further action.

b) Blockchain Infrastructure

Since the PDS network is huge both in terms of geography and scale of commodities it requires an efficient blockchain infrastructure to record all its transactions. To reduce the size of the blockchain it is feasible to use a hierarchical blockchain that is implemented at different levels. We maintain blockchains at a lower level of hierarchy that records all transactions at a particular place. At periodic intervals we summarize the transactions in these blockchains and record them in blockchains at the next higher level. This greatly reduces the amount of data stored on the blockchains at higher levels so that they are manageable. This also makes reporting tasks and analysis easier at the higher levels of administration as they have to contend with lesser data and which is already summarized.

The hierarchical structure is shown in the figure 2. Each Solid dot represents a blockchain structure. The smaller dots at the periphery represent a blockchain that records transactions at end points which are at the fair price shops. All these transaction summaries of each end point are aggregated and stored in the blockchain of the local warehouse that supply the commodities to the fair price shops. Similarly all the transaction summaries at several warehouses are aggregated and stored in a regional or a zonal blockchain. The number of levels in the hierarchy can be determined based on the convenience of administrative people. The number of levels should not be too much such that there is little information to be stored at the different levels but at the same time it should not be too little increasing the amount of information stored to unmanageable levels. Choosing a geographical approach based on the distribution of fair price shops seems to be a better approach. Considering the current system we can aggregate transactions and store them in the blockchain at the level of taluks, districts, state and the nation.

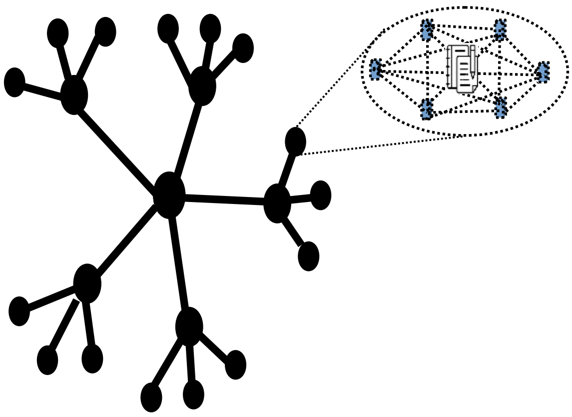

Fig 2: Hierarchical Blockchain

c) Administrative Console

The Administrative Console enables people in administration to track and verify the commodity levels at warehouses and fair-price shops at various levels and timelines. The administrative console has different level of user access control based on different stake holders in the PDS system. However this shall not be confused with a centralized system, since it is only used for reporting purposes which has view only access to the data. The console enables them to perform a secure audit of all transactions and generate suitable reports. All the transactions recorded generate a huge amount of transactional information, after prolonged usage of the system the data generated by it can be used for identifying trends and getting newer insights. Using this information the administration can identify reasons for crop loss due to pests and storage facilities. They can plan the logistics based on demand and supply for food commodities. A citizen obtaining the services of the PDS system can get information on what is the current amount of commodities available in the fair price shop to which he is registered.

D. *Mode of operation*

Each transaction is defined to be of a particular structure that is compatible for recording in the blockchain. The different transactions that can happen are:

- Commodity Arrival
- Commodity Dispatch
- Summarize operation

Each of these transactions when executed trigger a smart contract that validates the transaction. A transaction is considered valid subject to the following conditions. A Commodity arrival record at a warehouse/fair-price shop should match its Commodity dispatch record at its previous level. Similarly, the aggregation of summarize operation at lower level should match summarize operation at its immediate higher level. The query status operation for each commodity should show the updated status of any commodity. In case of any loss or mismatch between Crop dispatch and arrival records, then this event should be flagged for taking appropriate administrative actions. Further this loss in commodities should also be logged as a transaction with suitable reason mentioned. When an audit is performed all transactions should be able to trace back the history to the first transaction or initial stable level.

Every transaction has to be validated by at least 60 percent of the participating nodes before it can be approved as a valid transaction. Once this is achieved all the nodes mark this transaction as valid, otherwise all the nodes discard that transaction. A valid transaction now qualifies for being written into the block. Note here that after this validation all nodes make the update in their copies to reflect the change so that all nodes have a consistent view of the transactions. The nodes in the system can make use of either Proof of Work or Proof of Stake strategies to arrive at a consensus in deciding who has to write this valid transaction into the block.

Here using Proof of Stake consensus mechanism reduces the computation load on the blockchain system as compared to the blockchain system that uses the Proof of Work strategy, which results in significant savings on investment on costly hardware upgrades. To arrive at a consensus we can choose a mechanism where every node gets a chance to write a block to a blockchain in a circular fashion. Here every node is treated as equal. Another strategy could be to designate a particular node to write a block to the blockchain always which could be like the oldest node or the node that has written more blocks or even a random selection. The chosen node then writes the block to the blockchain.

IV. Implementation and Results

The current work is implemented as a decentralized application popularly known as a DApp on the Ethereum Platform. The DApp is an application that creates a user friendly interface usually through a web browser to smart contracts.

A. *Implementation*

At the heart of the blockchain is the smart contract which is used to negotiate and enforce rules of a business transaction on a blockchain platform automatically. The smart contract defines contractual obligations under which a business transaction for transferring assets among participating entities is considered valid. The figure 3 below shows the structure of a commodity represented in the smart contract.

```
contract CropRecord{
    address office
    struct Crop{
    uint cropId;
    bytes32 cropName;
    uint cropQuantity;
    uint cropPrice;
    }
    uint warehouseID;
}
```

Fig 3: Commodity Structure

Figure 4 shows a StockArrival method that gets executed whenever a commodity arrives at a warehouse. If the transaction satisfies the rules then it gets recorded in the blockchain.

```
wareHouseStockArrival(wId, cropId, cropQuantity){
    if cropId not in cropIdVector
        cropIdVector.append(cropId)
            cropIdVector[cropId].cropQuantity = cropQuantity
    else
            cropIdVector[cropId].cropQuantity += cropQuantity
}
```

Fig 4: StockArrival method

Similarly figure 5 shows the StockDispatch method which reduces the commodity quantity, if the necessary conditions are satisfied. Likewise figure 6 shows a getStatus method that returns the quantity of the commodity specified.

```
wareHouseStockDispatch(wId, cropId, cropQuantity){
    if cropId not in cropIdVector
        report error
    else
            cropIdVector[cropId].cropQuantity -= cropQuantity
}
```

Fig 5: StockDispatch method

```
getStatus(wId, cropId){
    if cropId is in cropIdVector
        return cropIdVector[cropId].cropQuantity
}
```

Fig 6: getStatus method

B. *Results*

A sample result is shown below for illustrating the mechanism of smart contract execution. Let's consider that several food commodities have arrived at a particular central warehouse. Each commodity arrival is being stored as a separate transaction. The transaction record state is shown below.

CropId	CropName	CropQty	CropPrice	WarehouseId
100	Rice	100	40	1
105	Ragi	150	25	1
103	Jowar	200	45	2
102	Wheat	50	30	3

Assume there has been a request for dispatching 125 metric tonnes of Jowar to a local warehouse and 150 metric tonnes of Rice have arrived at the warehouse. Now before we dispatch the said commodities from the central warehouse to the local warehouse, we have to verify whether there is sufficient Stock available to honour this request. The smart contract takes care of this request validation. In our example since sufficient stock is available the request is approved and the transaction is recorded in to the blockchain.

CropId	CropName	CropQty	CropPrice	WarehouseId
100	Rice	250	40	1
105	Ragi	150	25	1
103	Jowar	75	45	2
102	Wheat	50	30	3

When we invoke the get status method on a particular commodity we see the updated record state as follows.

CropId	CropName	CropQty	CropPrice	WarehouseId
103	Jowar	75	45	2

V. CONCLUSION

Using Blockchain brings in transparency to its stakeholders, which is a major goal of governance in the PDS system. Any stakeholder can easily verify the stock available at various warehouses and fair price shops and also the transaction history. The tracking of arrival or dispatch of a commodity at any point in the supply chain system is automated by the use of IoT based sensors. These sensors trigger transactions that are verified subject to business rules and then stored onto a blockchain. The usage of the IoT based sensors makes this process an automated one, eliminating the possibility of human error. As the volume of transactions increase, it results in a huge amount of data to be stored which can be mitigated by the usage of hierarchical blockchains that store transaction summaries of the lower level blockchains. This results in lesser data to be stored on blockchains as older data can be summarized and stored onto a higher level blockchain, after which this older data can be deleted once its utility is over. The savings due to prevention of corruption is significant for governments which implement this system. Since all the transactions are logged in the Blockchain, it can be used by administrative authorities to perform audit, understand trends and be able to make well-informed decisions in determining future supply and demand of commodities and resources can be allocated suitably.

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