Blockchain in Agriculture and Food Supply Management

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Abstract-Blockchain is an immutable chain that is used to keep track of food in agriculture and supply management to get information about the different stages of crop, commodities in chain. This reduces all the irregularities, frauds in agriculture and food industry. Smart Contracts are software programs that are executed in the systems that are part of the blockchain network. Triggering the smart contract sends the transaction, that triggers another contract in the network. The blockchain implementations using the Hyperledger fabric, Hyperledger Sawtooth and Ethereum platforms are discussed.The Agri-food supply chain implements from-farm-to-fork(F2F) model, represents the transformation of seeds right from the stage it's planted in farm till it takes the form of finished product. The systems use certificates to provide guarantee of food purity, authenticity and quality. It brings transparency to the food supply and agriculture management system increasing the security, reliability and trust.

I. INTRODUCTION

Blockchain was first used as the public ledger for the transactions made in bitcoin. In 2014, the blockchain technology was isolated from currency and people started to exploring it as a separate entity. The concept of blockchain originated from Bitcoin. Blockchain is the chain of records that grows continuously, linked to each other. Blockchain stores various information right from the stage of planting like the fertilizers used, the nutrients that support, the growth details of crops. The quality of the food is determined with the help of stored data. The purchases are made based on this quality analysis. The list of records of food continuously grows as the food passes from one phase to another. All these records are linked to each other. The block data is encrypted and its hash is kept in next block. The hashes are compared to check the data integrity. The centralization of data results in many challenges in the supply chain management system like wastage of food between different stages of food, lack of trust between parties involved in trade, lack of transparency in the system. All these issues can be resolved using Blockchain Technology (BCT). Blockchain is an immutable data structure, the blocks are arranged in chronological order of transactions. It is a decentralized network of participants. The people involved in the supply chain sign smart contracts that helps in the better management of supply chain. These contracts help in reducing the complexity and automating the activities involved in supply chain. These contracts are the computer programs that runs across the blockchain networks, it enables the transactions involved in agriculture by expressing triggers.

To improve trading among different organizations the activities should not rely on centralized server. So, all the peers enter into an agreement by deciding on the terms and conditions that are made by considering the views of all the actors involved in the network.

II.RELATED WORK

We have to know the basics of blockchain, smart contract to understand its importance in agriculture and food supply management. This study [1] outlines the architecture, challenges, few application scenarios and future trends of smart contracts.It summarizes the life cycle of smart contract into different stages based on its operational mechanism and provides the basic research framework of smart contracts. This study [2] gives the detailed information of the project "Blockchain for Agrifood". They developed proof of concept for the use-caseon table grapes from South Africa. BCT is applied on the demonstrator built for this use-case. The findings of pilot study explain the technological perspective, scalability and privacy of BCT. This paper [3] presents the AgriBlockIoT system that integrates both IoT and Blockchain. It defines the use-case popularly known as from-farm-to-fork(F2F), deploys it using two different blockchain platforms Ethereum and Hyperledger Sawtooth. The performance of the two implementations are compared and the results are given.

This study [4] proposes a food chain traceability system that implements F2F model, used in European Union.The Hyperledger Sawtooth is used for Blockchain implementation. The customer can access the product history using QR code. The Agile method of software development is used. This paper [5] introduces the distribution consensus algorithm used in blockchain network. Its an agriculture provenance system based on decentralization, collective maintenance, trust. A data structure is applied on the management operations and the that is data collected. It supports the formation of community among different stakeholders involved in the supply chain.This paper [6] gives blockchain based solution using token-based mechanism to indicate farmer's reputation. Farmers place certification request regarding their products and the certificates are issued by evaluating different parameters.The instances of smart contracts are created and deployed. The virtual product is referenced using quick response code. This paper [7] discusses the tracking and traceability of soybean across the supply chain. It presents and implements smart contract algorithms that ensures proper interactions among different stakeholders involved in the supply chain. It uses Ethereum smart contract, the different transactions involved in the supply chain are given. The decentralized file system to store all the details is created and linked with blockchain. It gives the relationship between different entities involved and the sequence of events that occur in the supply chain.

III. THE AGRICULTURASUPPLY CHAIN

Many entities, firms, actors are involved in the agriculture and food supply chain. Every entity adds value to the whole process of making the commodity available for the customer. The actors make entries in the ledger of the supply chain.The chain includes:

Supplier - The one who provides raw materials like seeds, chemicals, fertilizers for the growth of crop. She enters all the details like quantity of seeds sold to farmer, the details of chemicals and fertilizers and the selling dates.

Production – It involves the one who actually growsthe crop. She nurtures the crop plant by keeping it free from diseases and pests. She enters the details of soil, Temperature, Humidity and the details related to the conditions in which crop is grown, images of crops are also uploaded along with time and date.

Post-Harvest – It involves grinding, cleaning, washing, packaging and processing of commodity to produce end product. She enters the details of moisture content, quality of commodities and the details of foreign particles found.

Storage – It includes both transportation and cold storage of commodities. She enters the duration of storage and all the changes of commodity during the storage.

Marketing – It involves Distributor who distributes the product to retailors, the retailor is responsible for delivering it to end users. She enters thepurchased price, the sold price.

Customer – The one who buys the end product. She can trace the history of product at different stages of supply chain by scanning the bar code of commodity.

The layering helps in analysing the system, understanding the entities, dividing the tasks. The multilevel system gives the better picture of whole system. This system is divided into three layers. They are - Physical Layer: All the products, crops, fruits, vegetables, pulses that are involved in the supply chain comes under this layer.

Data Layer – This layer includes all the data that is associated with the products, crops of the physical layer of supply chain. The data that is captured by sensors on the farm land, storage warehouse and the data that is given by

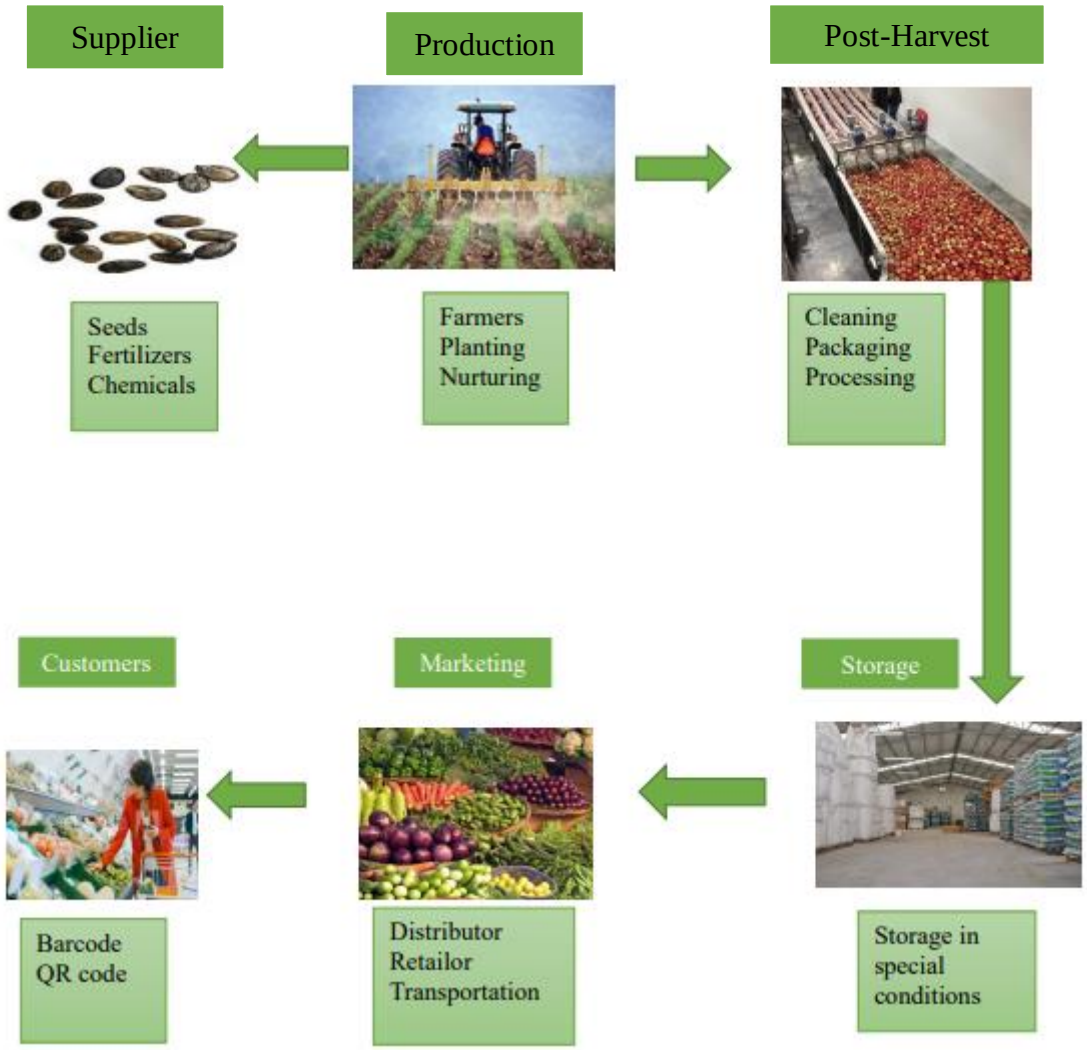

Figure 1: Detailed agriculture supply chain management

farmers, warehouse workers, logistics workers(drivers) Everything is collected, validated and stored in blockchain.

Blockchain Layer – This layer is about the blockchain framework we use to store the traceable data.

III. THE OPPORTUNITIES AND CHALLENGES OF BCT

The table 1 provides a view of the impact of BCT on various fields. It lists the advantages, Challenges and the knowledge they need to use BCT in agriculture and supply chain. Blockchain technology is not widely adopted in India. The people involved in farming, logistics management are not so aware of this technology. There is a need to make them understand and help them use this technology in their businesses.

IV. BREIF DISCUSSION OF METHODS OF USING BCT

There are different methodologies that can be used to ensure transparency, trust, authenticity in agriculture. We discuss few methods that makes the best use of blockchain in agriculture and supply chain.

Fig 2: Multilevel System

The clear division among different layers is shown in figure 2 .

Table 1: Opportunities and Challenges of BCT

Stakeholders	Advantages	Challenges	Knowledge needed
Producers	• Increase in food value • Fair price • Lower costs since there is no intermediary • Access to global market	• Accessing Blockchain • Framing correct rules for smart contracts	• Basic use of Blockchain
Trader	• Traceability of product • Associating with a brand	• Scalability with BCT • Privacy concerns	• Knowing various use-cases of BCT
Certifying Authority	• Added value to certificates	• New tools needed • Ensuring Compatibility with existing systems	• How BCT can improve certifying process
Blockchain companies	• Innovation • New business opportunities	• Funding • Making BCT apps user friendly • Scaling of nodes	• Different technologies needed for the implementation of BCT • How to minimise cost, resources

- Considering many factors like soil, humidity, water resources, skill, previous yield the farmers are given certificates. The farmers can certify other's crops if the former has the certificates. The certification details of farmer and crops are stored in blockchain. Every crop is given an unique ID. This ID is used to get the details of crop, the farmer who has certified the crop, the information about his certificate, his yields till date. The certificates are checked and updated regularly. These certificates increase farmer's reputation.
- The various organizations involved in farming and supply chain are certified by an authorized entity with a certificate to carry out certain agricultural work or any task related to supply chain. The smart contract contains the conditions that should be fulfilled. After fulfilling it, the nodes are certified to carry out the respective task like certifying the products, giving grades to the products, assessing the quality of products. The final product of supply chain has a barcode or an identity associated with it. All the details of product of every stage of chain can be obtained by scanning the barcode.

- We can integrate the IoT devices and blockchain technologies and develop a system that keeps track of products with the help of sensors attached to it. We can use various sensors like temperature and humidity sensors, location

sensors, optical sensors, Dielectric soil moisture sensors, Airflow sensors, electrochemical sensors, mechanical sensors for livestock tracking, soil moisture monitoring, water tank level monitoring, logistics tracking. The sensors transmit data to the fog devices, cloud from where it can be accessed. We can use affordable LPWA networks such as SigFox, Lora WAN or cellular networks for connectivity. The Radio Frequency Identification (RFID) technology is used to track the objects with the help of RFID tags. It uses radio frequency for transmitting the data. All the data can be analysed using machine learning models and the important data is validated and stored in blockchain.

V. THE BLOCKCHAIN PLATFORMS

A. **Ethereum Based Blockchain for Agriculture And Food Supply Chain**

Ethereum is the public blockchain that is open source, distributed. It also acts as an operating system where the decentralized Apps(dApps), games are developed. It's going to change the way internet works. An internet where everything is open, people own their data, earn from their data. Everyone can see other's data. The transactions in Ethereum platform is controlled by smart contract. ETH is the cryptocurrency of Ethereum. This platform can be used in financial transactions as a digital wallet, a digital asset. Ethereum is not controlled by any government or company. The transactions are cryptographically signed. Ethereum provides a decentralized virtual machine, the Ethereum Virtual Machine (EVM) that execute scripts in a public network of nodes. The Ethereum smart contract runs on the public network of large number of nodes as shown in figure 3. These nodes share blockchain database that contains the crop and product details. All these nodes can communicate each other. The details that are entered is stored across the entire network of nodes. The information is verified by consensusbefore storing in blockchain. According to the consensus, more than half of the nodesmust agree about the information before saving in blockchain. It's impossible to hack this kind of system since it's difficult to take control of more than half of system. Ether is the currency used in Ethereum Blockchain. The mining process generates the new block using proof of work (PoW) competing with fellow miners by running a hash script. The miner has the code and stored data, both in smart contract. The miners are rewarded with Ether for performing the computation. Every participant has an account associated with his name, identity. It has Ethereum Address (EA). Every account has a certain amount of gas(fuel) associated with it. After verification, these transactions are committed. The smart contracts are executed on Ethereum platform. All contracts are run by everyone running on the mining node, the decisions are taken collectively. A mining node can be any computing machine. These nodes are distributed all over the network, they store data related to the transaction in a ledger. This platform has its own language called Solidity. The drawbacks of this framework are high Latency and it's not suitable for confidential transactions, since its permissionless blockchain. Now we aregoing toillustrate how Ethereum smart contract can be used in different stages of supply chain as shown in figure 4:

1. The Seed company creates the contract and sell seeds to farmers. The conditions are set like if 10 Ether is transferred from buyer's account(farmer) to seller's account only then the farmers are given the seeds, then the transaction is stored in blockchain. Otherwise it's dropped.

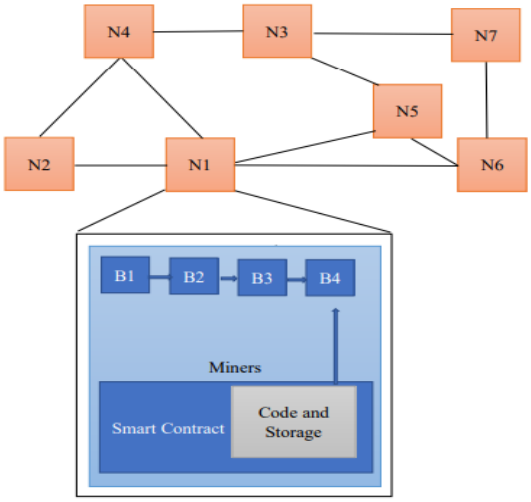

Fig 3. Ethereum architecture

2. The Farmer plants the crop, updates the crop, growth details in his account. Once the details are found genuine, the miner adds the block to chain.
3. The Elevator buys the grown crop from farmer and stores it for a certain period of time. Then updates temperature, storage duration, moisture details through his account. These details a
4. re added to the chain in the form of block after verification.
5. The Processor purchases the stored product from Elevator to convert it into finished product. She adds the cleaning, processing, packaging details.
6. The Distributor purchases the products from Processor and sells it to Retailor. The transactions between Distributor and Processor are said to be valid only if the smart contract conditions are met. These conditions are pre-decided by the parties involved.
7. The customer is the end user of the product who buys it, the transaction between her and retailor is also recorded and stored in the blockchain. After

verification, these transactions are committed. The Figure shows the agricultural and supply chain transactions executed on Ethereum smart contract.

B. **Hyperledger Based Blockchain For Agriculture And Food Supply Chain**

Hyperledger has open source projects, tools under it that are handled by Linux. It was originally created by IBM and Digital asset under the name Open BlockChain(OBC). Later it was handed over to Linux foundation. Hyperledger Fabric provides a permissioned blockchain framework for enterprises. It mostly uses Kafka algorithm. Its available in Go language and JavaScript. It enables us to provide different degree of permissions. The application is deployed on server and smart contract is deployed on peers. The participants have to register to get permission to issue transactions. It offers high scalability, privacy. It supports only Crash Fault Tolerance. The transactions can be executed serially and parallelly.

- **Hyperledger Fabric architecture:**

It's a distributed ledger framework used to build permissioned applications and solutions. The applications have modular architecture. This framework supports plug and play operation. The nodes are distributed across different organizations making it private. The validation methods depend on the organizations involved in the transaction. For example, it can be solely based on trust. Each participant is given certificates and has an unique identity. The assets are defined as a key/value pair. The organizations can have their own rules and regulations. These conditions are in the form of code in chain code. The transaction is committed only if the conditions are met. The membership modulemanages the addition, removal, updating the membership status of different nodes in the organization.Some of the important features of Hyperledger Fabric are - The organizations are grouped into channels. The members are given unique ID's by membership service when they are added to network.Using these unique ID's, two or more organizations forms a private channel to execute transactions with each other. These transactions are validated by validators. The Practical Byzantine Fault Tolerance algorithm is implemented to reach consensus. The Practical Byzantine Fault Tolerance algorithmis implemented to reach consensus. The people involved in farming and food supply chain can query and retrieve data from database.It offers privacy by hiding the transaction from other nodes. It's a permissioned ledger only the nodes that has access permission can join the network. This helps in solving scalability issues.

- **Hyperledger Sawtooth architecture:**

It was initially developed by Intel and later it became one of the distributed ledger projects under Hyperledger umbrella. It's mainly for enterprises to build modular distributed ledger and applications. It has a simplified architecture with the separation of core system from application domain. The consensus algorithms, transaction processor conditions, permissioningcan be ofdeveloper choice. It mostly uses Proof of Elapsed Time algorithm. Any required information can also be broadcasted all over the network. The Seth or Sawtooth-Ethereum Integration project creates link between two platforms. A transaction family is a group of transaction operations that are used to perform the tasks on ledgers. The Sawtooth Validator, RESTful API provides easy interactions. A group of sawtooth nodes can be made private with separate permissions. The transaction processes are written in Rust, Python, JavaScript, Go. It supports Byzantine Fault Tolerance.When the transactions are created and applied, it results in the change of the state. The clients create the transactions, but they are committed only if its approved by validators. The atomicity is ensured by committing the transactions in batch. These blocks enter validator through interconnect – with the help of gossip protocol or REST API.They are added to blockchain after its validated by Journal. Sawtooth transactions can be scheduled both serially and parallelly.The executor sends the transactions to transaction processors for execution. The transaction processors arethe programs that has conditions related to the governing data. It has business and validation logic. The sawtooth nodes are connected in the blockchain network. This network can be permission less or permissioned depending on the business application. For the agriculture and supply chain applications we need a permissioned network for the security of crops and product data. In public blockchains the malicious node can try to access, tamper data stored in blockchain database.

VI. THE USE-CASES OF BLOCKCHAIN IN AGRICULTURE

1. We can prevent the crop losses, fungal growth, insect infestations in the post-harvest stage by monitoring the inventory using sensors to collect data and store it in blockchain. . This data helps us in devising a suitable crop storage technique. Ambrosus provides IoT integrated blockchain solution.

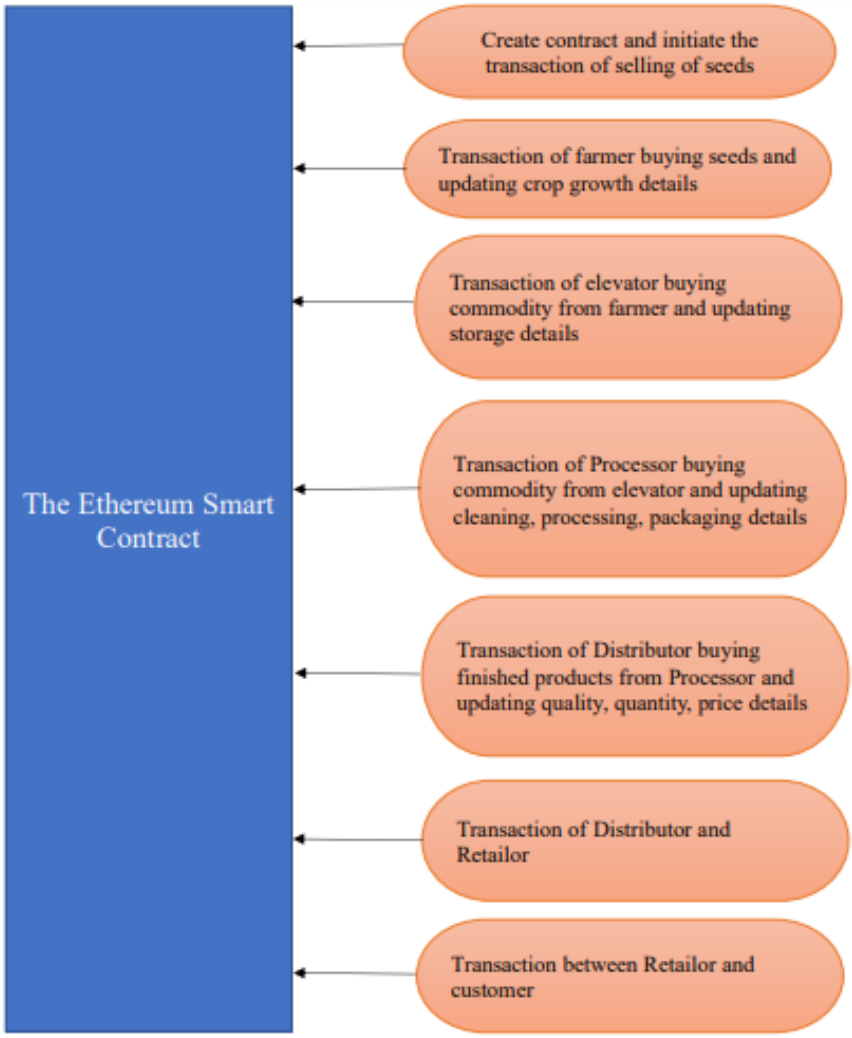

Fig 4. Ethereum Smart contract transaction

2. The studies show that using proper agricultural technologies helps in increasing 70% of yields. So, we need supply chain management specific technologies. The Ripe, Origin Trail companies are helping in implementing these technologies with their products. For example, IBM Food Trust has helped increase trust across seafood supply chain.
3. We know the situation of farmers in our country India and other developing countries. We need innovations in blockchain based farm management softwares that helps farmers manage their crops at low cost. AgriDigital is one such platform that helps in management of grains.
4. The communities of people who wish to support farmers financially can be formed using the blockchain networks. It helps farmers to get loans easily. EthicHub and Lokaal are trying to provide microloans for farmers. It encourages people to invest in farming. The transactions are recorded and it helps in better profit distribution.
5. The blockchain platform plays key role in certifying crops, commodities and processing import and export certificates.

VII. CONCLUSION

Blockchain being decentralized, immutable, traceable the contract terms can be executed between untrusted parties without a centralized server. The blockchain platform is selected based on our needs. We can help farmers get fair prices, subsidies using BCT.The end users can get the product history, enhancing the food safety and authenticity. The Future work includes the study of scalability of blockchain network - different ways to scale up and down easily, formal verification, the automation of entering the qualities of products, automated payments and proof of delivery.

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