An Open and Fully Decentralised Platform for Safe Food Traceability

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***Abstract*—Concerns about food safety have grown across society in recent years. Building a trustworthy traceability system is essential for effectively identifying and preventing food safety issues as well as tracing the responsible parties. The entire food supply chain, which includes the stages of production, processing, warehousing, transportation, and sale, must be precisely recorded, shared, and traced. Traditional traceability systems suffer from problems like data invisibility, tampering, and the leakage of sensitive information. This paper proposes an open platform for a food safety traceability system that indefinitely and incessantly stores and records all transactions, events, and activities on the blockchain's immutable ledger linked with IPFS - a peer-to-peer decentralised file system - for storing and providing maximum transparency and traceability. The platform leverages the blockchain's characteristics such as immutability, transparency, smart contracts, and consensus algorithms to make it ideal for food safety traceability systems. But more importantly, it mirrors the food supply chain making it a pluggable toolbox for all stakeholders across the food chain to adapt to their system irrespective of the food products they deal with since it is a multi-asset system as well. It could be even adapted for non-food products that have a supply chain similar to the typical food supply chain. Simulation results show that there is the complete success of all the blockchain transactions on our platform with real-time responsiveness.**

***Index Terms*—food safety, traceability, open platform, blockchain, smart contract.**

I. Introduction

Governments have always been concerned about the societal issue of food quality. At the same time, people are becoming more concerned about the quality of food products. This is due to a number of newsworthy events that have occurred recently, some of which have even resulted in consumer deaths, such as fipronil contamination of chicken across Europe [1], consumers infected by a variant of the mad cow disease called Variant Creutzfeldt–Jakob disease (vCJD) [2] [3], horsemeat scandal [4] [5], bacteria-infected spinach [4], gutter oil [6], and mercury-laced rice [6], [7]. As a result, people are increasingly more aware of food safety. Nowadays, consumers place a lot of importance on food traceability. Additionally, these incidents have prompted the Global Food Safety Initiative (GFSI) to harmonise food safety regulations globally. The grocery and agri-food industries are under more pressure to make sure that their suppliers abide by the various GFSI-recognized food standards. Nonetheless, it is difficult to trace the provenance of food data as well as keep it traceable all through the supply chain.

Conventional food traceability systems rely on an arbiter for commerce and are centralised. These centralised systems lack accountability, transparency, and auditability. They have a lengthy cycle, several participants, and links across regions. Poor information exchange and problems with data trust exist among participants, particularly in nonadjacent supply chain links. The very first use of blockchains was in the world of cyber currencies to guarantee transactions [8]. Since then, a variety of industries have become interested in blockchain. Blockchain technology enables the secure exchange of information across organisational borders. Blockchains are a type of Distributed Ledger Technology (DLT). The types of DLTs are classified by, and in fact derive their names from, the underlying data structure used in implementation. Blockchains are a type of DLT implemented with blocks - which are linked to one another sequentially via cryptographic hashes - as their data structure. Blockchains are characterised by decentralisation, all-inclusive record-keeping, authenticity, and security. In particular, they enable the deployment of immutability, where each party is directly connected to the blockchain via a computer. Secure transactions with many parties who pursue various economic interests are made possible by the integrated validation process. Peer-to-peer communication, or direct communication between the participants, is an option.No central authority or middleman is needed to aggregate and control data, in contrast to the present dominant platform business models. This enables companies to handle business processes digitally that were previously too costly or where it was not possible to agree on the location or platform to store and process the data. Therefore, implementing blockchain in the

Funding Statement: This research received funding from the Future Africa Research Leadership Fellowship (FAR-LeaF) programme. This paper was written as part of the Development of an Open Toolbox for Safe Food Monitoring project, which is financed by the FAR-Leaf Progamme with technical and Implementation support from the Responsible Artificial Intelligence Lab Project which is being co-finance by IDRC (Grant Number 109832-001) and GIZ (Agreement Number 81280702)

979-8-3503-2028-2/22/$31.00 ©2022 IEEE
DOI 10.1109/CSCI58124.2022.00185

management of information for the food supply chain has the potential to do away with data asymmetry as well as attain synchronous updating of data across all nodes and resolve issues with goods quality brought on by stakeholders [9] to increase data credibility. Blockchain can be seen as a means to solve the drawbacks of conventional food traceability systems due to its decentralised nature and capacity to prevent data manipulation. For the reasons listed above, this paper suggests a blockchain-based safe food traceability system to monitor the entire process from the raw materials (animals or a field) to the final customer. This can considerably increase consumer confidence in food and improve the effectiveness of trademark protection.

An open platform in computing is a system platform built on open standards. For instance, external application programming interfaces (API) that are publicly available and completely documented permit utilising the system to work differently than the original programmer intended, without needing source code modification. A third party could integrate with the platform using these APIs to provide added functionality. Our proposed platform's architecture closely mirrors the food supply chain making it a pluggable toolbox for all stakeholders across the food chain to adopt irrespective of the food products they deal with. This is possible because it is a multi-asset(product) system as well. The platform could be even adapted for non-food products that have a supply chain similar to the typical food supply chain. The platform is dubbed DOTbox as we seek to contribute to the Development of an Open Toolbox(DOTbox) for safe food monitoring. This is very essential as current implementations even those that are built with Distributed Ledger Technologies are proprietary and not available to the general public but only to their customers(in the case of ones implemented by companies). Further, we use user interaction diagrams to explain in full detail how a generic use case platform could be implemented with the DOTbox architecture to give insights into how the open-source community could build on our platform. We then provide an open prototype for oil palm traceability in Ghana.

The following is the structure of the rest of this paper. Related works are discussed in Section II. In Section III, we describe our proposed platform for food traceability systems. Performance evaluation is included in Section IV. The paper's conclusion, limits, and suggestions for further research are presented in Section V.

II. Related Works

The problem of safe food monitoring and management has caught the eyes of many researchers and industrial partners. Numerous solutions have been proposed in the literature [10] and some industrial partners have as well implemented food traceability systems.

Agricultural and Processed Food Products Export Development Authority (APEDA) provides stakeholders in India with a closed, centralized food traceability system called TraceNet to facilitate process approval for the sale of organic goods from India that meet the National Organic Program (NOP) requirements [11]. Inside the Indian agricultural supply chain, this system allows business owners and certification authorities to submit forward and backward traces, as well as quality control data, which TraceNet then collects, saves, and reports. APEDA also provides a similar but decentralised food traceability system to track and authenticate fresh grape shipments from India to Europe [12]. By fusing supply chain elements with the fundamentals of blockchain technology, IBM Food Trust adds economic benefit to the food industry through standards, technology, and interoperability [13]. However, it is also a closed, proprietary platform. Their system architecture and source code both remain closed from the developers and thus making everything inaccessible. An open blockchain-based system has as well been proposed in the literature by the Roundtable on Sustainable Palm Oil (RSPO) to ensure the sustainability of palm oil [14]. However, the open framework they recommend has not yet been implemented.

It can be seen that food traceability has moved from centralised systems to being decentralized. K. Demestichas et al observed that this has been the general trend since 2016 till date [15]. However, all of the solutions which have been implemented are proprietary, not open-source, and usually for a specific product. Thus, there is a need to build an open and multi-asset (product) food traceability system that is fully decentralised.

III. Model Design

A. System Architecture

The DOTbox architecture, as shown in figure 1, models all stakeholder groups of a typical food supply chain as organisations to ensure end-to-end traceability. The management organisation is made up of an independent developer group as well as administrator nodes of each stakeholder organisation and they collectively manage the blockchain using the Raft consensus algorithm [16]. Most blockchains employ the Raft Mechanism, a leader election algorithm, for consensus. For leader elections, it offers the use of randomised timers, which helps settle election disputes fast. It has numerous open-source implementations, making it significant for our platform. The developer group which is not part of the supply chain has the sole purpose of setting up the blockchain network with HyperLedger Fabric [17] as well as creating the technological tools for managing the network such as end-user applications and shell scripts. Hyperledger Fabric is a fork of the open-source Hyperledger project hosted by the Linux Foundation intended for enterprise use. It provides a platform for the building of enterprise blockchain networks and performing all network configurations via a deployed chaincode(smart contract). Hyperledger Fabric is a permissioned platform that provides excellent security measures that validate and authenticate incoming players before they can join the network, in contrast to other platforms, like the public permissionless Ethereum blockchain. HyperLedger project allows the Developer group to set up an enterprise standard blockchain based on the DOTbox architecture specifically for the food supply chain

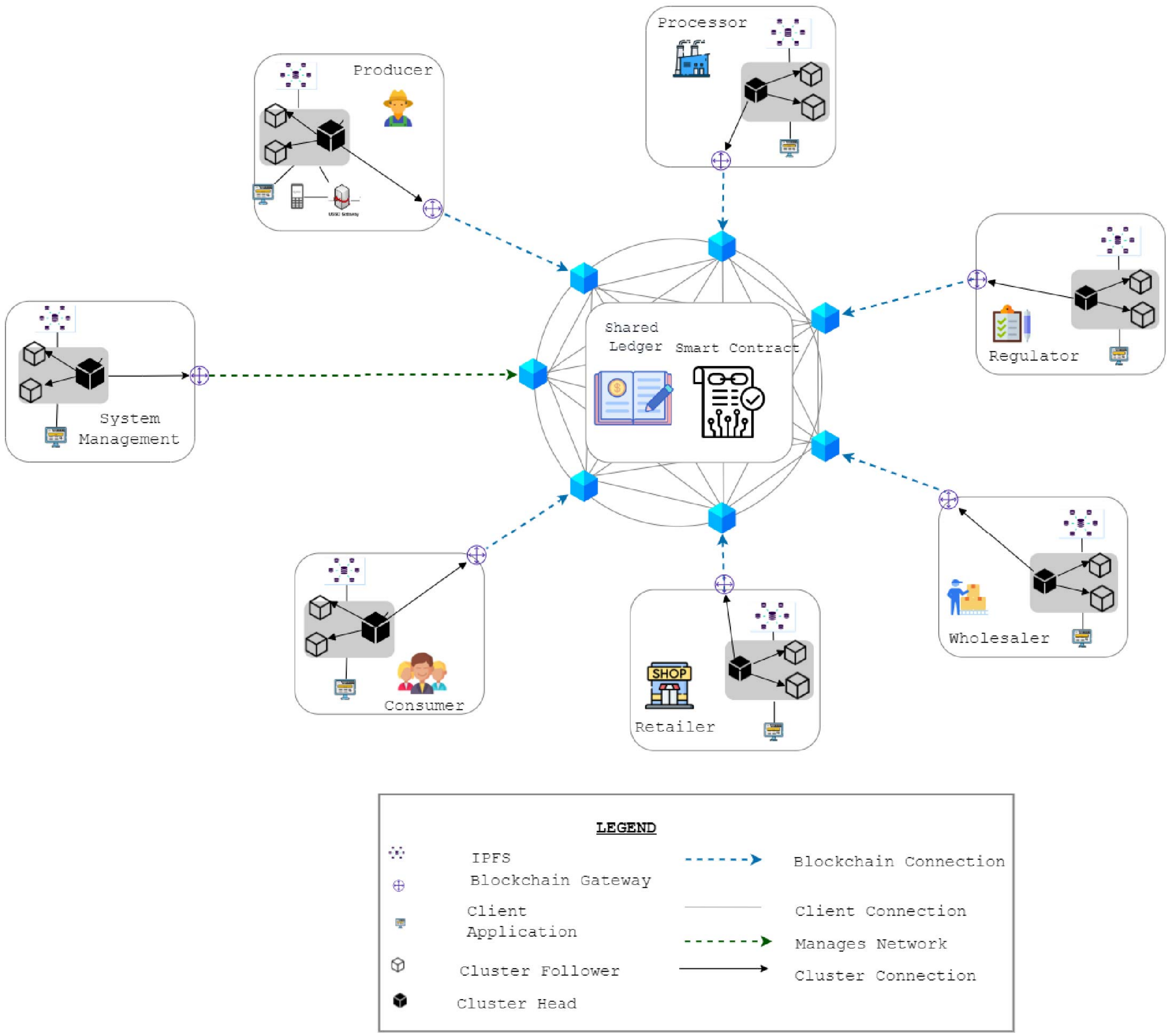

Fig. 1: Overall System Architecture for DOTbox platform

as compared to other platforms which are essentially already existing public blockchain networks.

Each stakeholder organisation in the DOTbox architecture has a fixed number of peer nodes directly connected to the blockchain to make transactions and as such have the chaincode and the ledger installed on them (figure 1). These blockchain nodes use Raft to elect their leader as well. The number of these blockchain nodes per stakeholder organisation - which should be a default minimum of three - is decided by the management organisation and is defined within the network configuration file. Additionally, each stakeholder organisation also has several nodes that form a cluster of nodes for that stakeholder organisation (figure 1). These cluster nodes also elect a cluster head using the Raft algorithm. The cluster heads serve as anchor nodes to the organisation only to send data to the leader of the static nodes dedicated to that organisation. The network configuration gives administrative rights to the management organisation and so the developer group - which forms part of the management organisation - initiates the network by setting up and starting the ordering service (figure 1). The ordering service is configured according to the network configuration file. At the blockchain network level, the Certificate Authority(CA) for management organisation dispenses identities to the nodes of the developer group. The identities

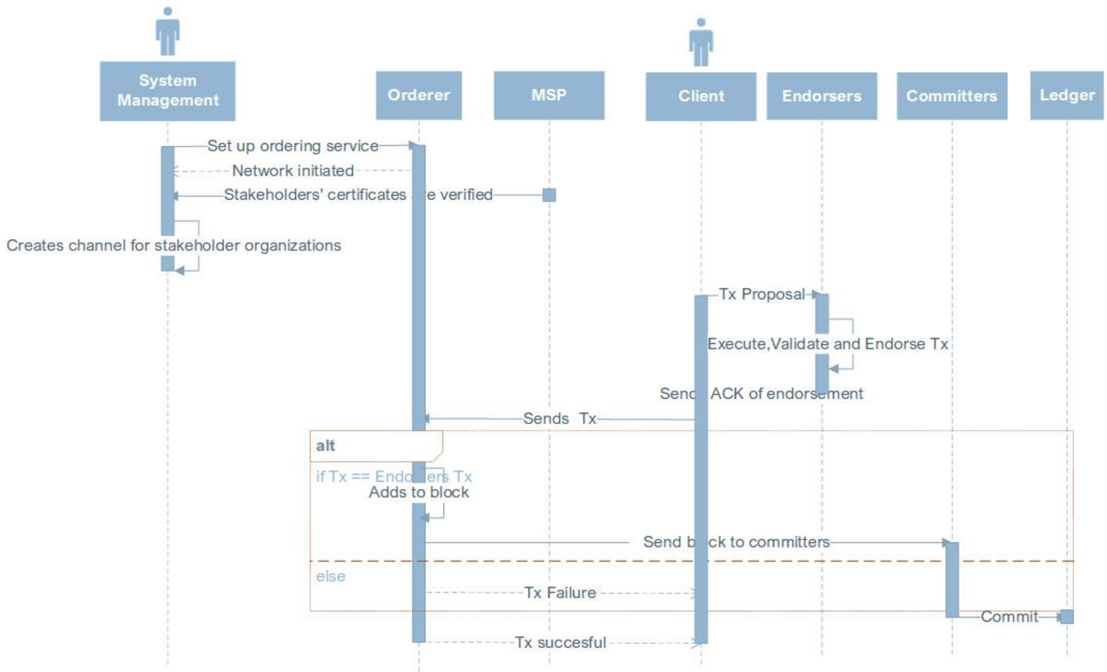

Fig. 2: Sequence Diagram for a Blockchain Typical Transaction Flow

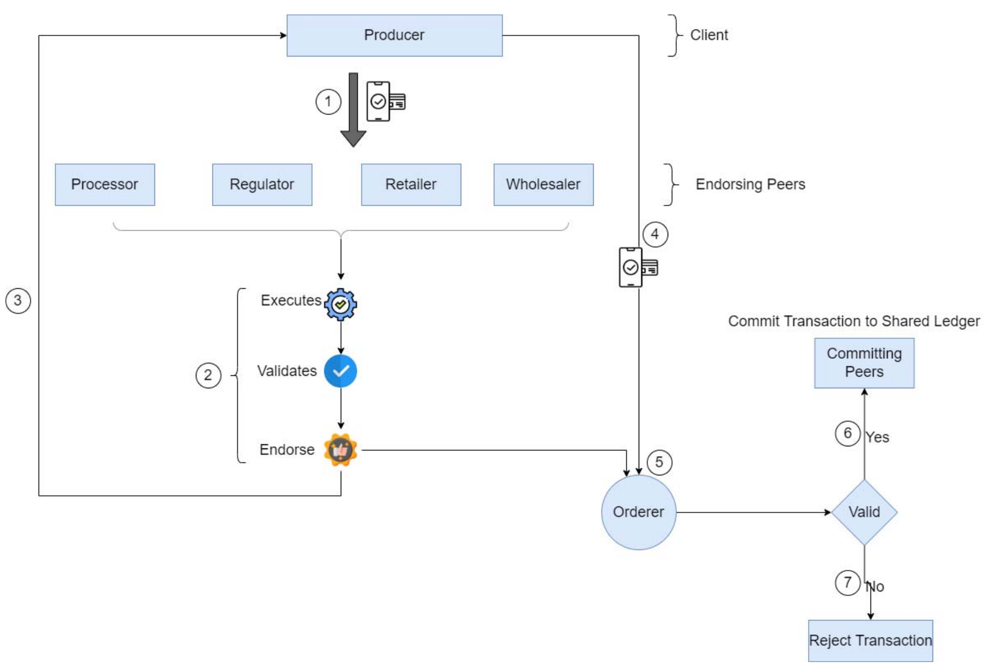

Fig. 3: A Producer Node Initiating a Transaction

are verified by the Membership Service Provider(MSP). CAs of the various stakeholder organisations issue identities to nodes of the various organisations. The supply chain stakeholders' identities are then verified by the MSP as well. The developer organisation now creates a consortium for supply chain stakeholders of the food product being integrated into the system. The consortium definition is used to set up a channel for the supply chain stakeholders where each stakeholder has nodes with administrative rights in the consortium definition. This channel serves as the communication platform for all the supply chain stakeholders of that particular product. The communication in the channel is governed by the smart contracts (chaincodes) of that supply chain and transactions that occur are tracked by the shared ledger. In the blockchain network, smart contracts are the sole way for stakeholders to carry out supply chain transactions. The platform users and the blockchain network are connected through smart contracts. Thus, a large number of the smart contracts known as "chaincode" may be bundled using Hyperledger Fabric. Following the deployment of the chaincode on the network, the next steps involve calling functions on smart contacts. Private data collections are used within each stakeholder organization and can as well be used between some specific stakeholder organisations when necessary (as dictated by the demands of the supply chain). As an aside, it is noteworthy to know that multiple consortia, as well as channels, can be created for different food products with their respective supply chain stakeholders since the architecture supports multiple assets/ products.

Transactions initiated by any of the stakeholders will be verified using the RAFT consensus algorithm. Existing smart contracts allow for the creation of food assets (either raw or processed food assets), their updating, and even the reading of historical data. As shown in figure 2 typical transaction begins when it is initiated by one of the blockchain nodes. Then the endorsing peer nodes of all the other stakeholders - excluding the initiator - evaluate, validate and endorse the transaction. An acknowledgment of endorsement is sent to the initiating node which then forwards the transaction to the ordering service. The ordering service compares the results of the endorsers to the proposed transaction from the initiator. This evaluation results in either adding the transaction to a block and forwarding to the committing peers or a failure message. Figure 3 shows a case where the initiating stakeholder node was a producer node.

As shown in the overall DOTbox architecture (figure 1), all movements and changes of food - throughout the supply chain - interacting with the blockchain undergo the typical transactions process (figure 2) described above. Stakeholder organisations contribute to the blockchain through a client application with its files connected to the interplanetary file system to make the whole system fully decentralised. Special consideration is made for the producer organisation to be able to use a USSD gateway to connect to their cluster node since most food producers in developing countries do not have access to smart computers (phones) and the world wide web in real-time. This special consideration can be made for any stakeholder organisation in the system depending on the supply chain circumstances of any product that is being integrated into a traceability system using our DOTbox architecture. This special consideration also shows the potential to connect the cluster of each stakeholder organisation of a food supply chain to IoT devices for data capture and entry - depending on local circumstances - and as such allow the interfacing of IoTs with less difficulty.

B. Use Case

Not all requests necessitate the activation of smart contracts. We keep client files on the IPFS to make the platform completely decentralised. Smart contract invocation requests, on the other hand, will necessitate access to the blockchain platform to retrieve or save on-chain data. A request is initially sent to the cluster nodes in order to perform such core functionality. Requests that have nothing to do with blockchain access will go to the InterPlanetary File System (IPFS) nodes for processing (figure 4. The request is forwarded to the blockchain network server provided chaincode has to be invoked. Finally, the results are communicated to the client. The top layer of figure 5 represents the stakeholders (actors) and essential items with whom they interact (objects) in the food traceability system. The pre-processing screen is only used by the producer actor. Users who register as producers use the pre-processing screen to create raw assets that will then be processed by the processor. When creating fresh raw asset data, information about the asset will be included that is relevant to both the farmer and the next actor in the supply chain - the processor. There is the option for the producer to update the entered raw asset data as long as he owns the asset. When the data is complete, it is transmitted to the processor. A certified processor engages with the processing screen in the DOTbox food traceability system to create new products. Many processing industries commonly incorporate test results into the completed product. When it comes to traceability, testing is very core and hence needed to guarantee the deliverable safe product to the consumers. One might painstakingly attempt to test the asset for its correctness probably umpteen times. Implementation-wise, this won't be feasible thus causing a scintilla of fear in the consumers. Our platform is able to circumvent the latter by performing the testing right before it reaches the culinary stage of the supply chain hence, our testing happening at the processor stage. The packaged product is subsequently sent to regulators and traders. The regulator provides the findings of their tests on the sample food product provided by the processing organisation. If the product test results meet the criteria, it is deemed excellent and sellable. This feedback is given to the trader before the products can be sold to consumers in the open market. If it is deemed unsafe, a food recall is issued to collect the batches that have already been distributed to traders. The consumers are then able to trace the provenance of food products as well as make informed decisions about their safety.

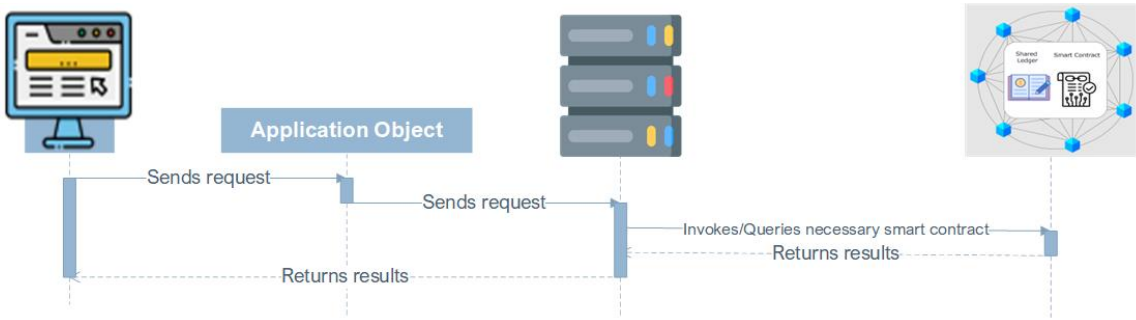

Fig. 4: Client Request Process

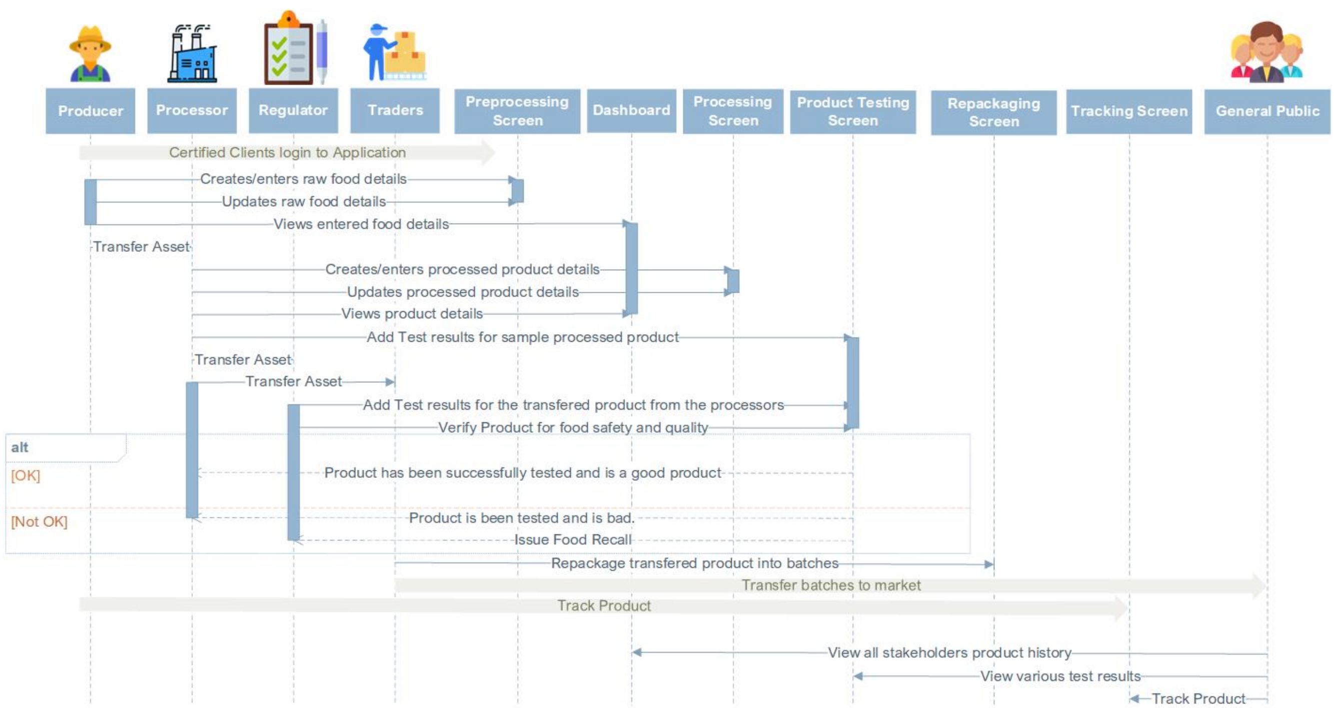

Fig. 5: Sequence Diagram for Many Possible Client Interactions

We use these interaction diagrams for insights into how the open-source community could build on our platform.

1) Oil Palm Traceability Prototype: We provide an open prototype for oil palm traceability in Ghana based on the DOTbox architecture [18].

IV. Performance Evaluation

We design a simulated blockchain environment for testing the DOTbox platform using hyperledger caliper [19] on an Intel Core i5-7260U 2-cores with 2.20 GHz and 8GB RAM for a duration of 30 seconds and with 10 assets. With the exception of read transactions, all the CRUD actions invoked by the chaincodes for the oil palm traceability prototype undergo plausibility queries (dependent on local conditions) before going through the validation and endorsing process of blockchain consensus. We therefore only measure the performance of createAsset and readAsset transactions on the DOTbox architecture for evaluation purposes. Figure 6 shows that the average latency of the createAsset transaction was higher than that of readAsset as expected due to the plausibility checks and the endorsing processes. In as much as the send rate afforded by the processor and RAM used for the testing was low, it could be seen that transaction throughput was equal to the send rate and even improved in the read transaction. This shows the real time responsiveness of our blockchain system and there was complete success of all transactions guaranteeing availability at all time.

V. Conclusion and Future Works

We investigated the challenges that food supply chain management systems encounter. It was seen that decentralized platforms for food traceability improve the efficiency and

HYPERLEDGER CALIPER

Basic information

DLT: fabric

Name: dotbox-contract-benchmark

Summary of performance metrics

Name	Succ	Fail	Send Rate (TPS)	Max Latency (s)	Min Latency (s)	Avg Latency (s)	Throughput (TPS)
createAsset	46	0	1.4	4.86	0.88	3.12	1.4
readAsset	1476	0	50.4	0.44	0.01	0.07	50.3

Fig. 6: Summary of DOTbox performance metrics

security of the food supply chain management system and so the development of an open food traceability architecture based on blockchain was our main focus. We developed a system architecture that enables management and tracking of the whole food supply chain. The DOTbox platform for food traceability outperforms conventional systems in terms of efficiency and security of the food supply chain management system. It can successfully satisfy food traceability requirements, increase customer confidence in food traceability, and increase customer satisfaction with food traceability. In Sub-Saharan Africa, DOTbox could help promote the participation of food supply chain stakeholders in adopting decentralized safe food management resulting in health benefits associated with safe food management. N. K. Akrasi-Mensah et al [20] and R. Antwi et al [21] provide an in depth overview on blockchain network and storage optimization schemes respectively which provides the foundations of improving scalability in blockchains. There are ongoing researches on adaptive storage and network optimization at DIPPER Lab which could be combined with interoperability blockchain architectures to improve scalability and interoperability of our platform. We are also researching on combining blockchains and Internet of Things technologies to produce reliable data collection and automated data entry.

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