FARM-TO-FORK TRACEABILITY: BLOCKCHAIN MEETS AGRI-FOOD SUPPLY CHAIN

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ABSTRACT

The transfer of goods along the agri-food supply chain currently lacks sufficient visibility. Starting from providers of raw materials to farmers, to food processors, to distributors, to retail outlets and finally to the consumer the ability to trace the history, application or location of any food substance and entity has become an important priority. Consumer food decisions are not only affected by taste and price. Consumers are also concerned about transparency, traceability and social impact. They also expect all participants in the agri-food supply chain to have effective practices in place that allow for the rapid identification, location, and withdrawal of food lots when problems are suspected or confirmed. On top of consumer expectations, there are new regulations and standards that require an improved evaluation of foreign suppliers, fully documented processes and an assessment of all vulnerabilities in the supply chain. These social, economic and legislative demands as well as the fact that most existing traceability solutions are usually proprietary IT systems, make it difficult to develop a scalable, universal and cost-effective traceability system. Emerging technologies, such as blockchain could transform supply chain traceability as we know it and bring more transparency through the value chain, creating value to stakeholders. From a technology perspective, the proposed solution leverages blockchain to keep track of the flow of physical goods. This paper introduces FoodBlock, a theoretical, 'farm-to-fork' traceability solution, which integrates Hyperledger blockchain, mobile apps and GS1 identification standards. We have created a framework for building a minimal viable prototype by using existing technologies.

Keywords: Blockchain, Hyperledger, Food Traceability, Smart Contracts, Smart Agriculture

1. INTRODUCTION

Due to the opaque nature of the agri-food supply chain, regulators, as well as customers have been unable to determine with accuracy the food quality and safety. The endpoints of the food supply-chain - farmer and consumer are pressured to trust a system without having visibility into the processes of the intermediaries. Consumers, despite their growing concerns, are still in the dark on which products are sustainable and have verified high quality. Today, the vast majority of traditional logistic information systems in Agriculture and Food (Agri-Food) supply chains merely track and store orders and deliveries, without providing effects such as transparency, traceability and auditability (Stefanova, 2019).

Traceability is a general term referring to the completeness of information about every step in a process chain (Jansen-Vullers et al., 2003). From a food supply chain perspective, a more rigorous definition defines traceability 'as the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed through all stages of production, processing and distribution' (European Community Regulation, 187/2002). In the food industry traceability has been a focal point for several years (Bechini, et al., 2005). The needs for food traceability can be summarized as food safety, quality verifications, and legal and market requirements (Wang & Li, 2006). A traceability system can be useful in the cases of recalls of affected products, improved quality controls, increased consumer confidence in food products and production optimization (Salampasis, et al., 2012).

Currently, there is a large variety of traceability mechanisms used in food supply chains. Some older traceability schemes are paper based while more recent are obviously IT based. Solutions based on IT are usually proprietary systems which are developed ad-hoc from food businesses to respond to particular demands on food traceability originating from EU legislation or demands from large retailers. These systems typically respond to needs within a single operator in the supply chain. The diversity of the systems used among different operators makes their integration difficult. Also, current traceability systems address traceability of food products in such a way which usually does not allow an integrated and transparent retrieval of traceability information along the whole supply chain (Cao et al, 2010). Each link in the supply chain requires keeping information about preceding and succeeding links in local databases, without making it possible to get a complete view of traceability recorded information.

Without a doubt there is a significant technology development which call towards the development of new generation traceability systems. This new technology push is Blockchain (Underwood, 2016). Blockchain can transform supply chain traceability as we know it and could bring more transparency through the value chain, creating value to stakeholders both upstream and downstream. In this paper we discuss a theoretical framework and we provide practical insights on how Blockchain could be used for traceability solutions in a farm-to-fork setting.

2. PROPOSED SOLUTION

The food supply chain is one of the most complex and fragmented of all supply chains. The production is found all over the world, both on land and in water, making many producers and intermediaries difficult to identify and track. This brings uncertainty to all stakeholders in the production chain. Examples of problems that have been difficult to solve with current technologies include preventing fraud and counterfeiting. These issues can have serious domino-effects on public health and the environment and increase financial costs of unnecessary recalls of food products.

Using blockchain to keep track of the entire food supply chain, we have a technology and an infrastructure for secure and trustworthy data storage for all traceability data involved that can also be presented to the end consumer. Tracing and controlling food are possible without the blockchain, however, the implementation of Blockchain technology brings three major inherit benefits to the table:

- The data cannot be manipulated.
- The supply chain can keep traceability and control secure without all participants disclosing all their customers and suppliers' data to a central party. The level of privacy to enforce can be decided by the participants in the system/network.
- The blockchain creates trust in low cost IT solutions. You can use email, Word, mobile phones, and still be sure data is accurate. This allows for example rural farmers and independent truck drivers to seemingly integrate with a larger traceability system.

2.1. Key criteria for food-traceability blockchain

Blockchain networks can come in many variations. The first step before implementing a specific solution is to map the needs and key criteria that a blockchain should meet in order to serve the food-traceability domain. Below we summarize the key requirements of a traceability application. The design and development of our framework is mainly inspired and driven from these requirements.

SPEED AND LATENCY. The food-traceability blockchain is tasked with mapping the digital world to the physical one, which means transactions should be reflected in the chain with the same speed, which is usually required to exchange the food physically. Consequently, the time interval needs to be short enough for convenience and relevance. An interval between 30 seconds and 1 minute is optimal.

REPUTATION AND GOVERNANCE. Considering the latest scandals in the crypto space (The Chain Media, 2018) and the relative conservatism of food chain participants to technology crazes (Tamirat, et al., 2017), a network with clear reputation and preferably already successfully realized industry prototypes should be selected. Businesses need sufficient governance to run blockchain effectively over the long-term.

SCALABILITY. It should be anticipated that the number of participants in a food-traceability blockchain could grow from a handful of enthusiasts to millions of daily users. Still, the blockchain could be limited to a certain agricultural sector, even bounded to a given country, but the capacity of the system to grow and manage increased demand should be there, because its value is directly proportional to its size, also known as network effect.

TYPE OF BLOCKCHAIN. There are three core types of blockchains: public, permissioned and private. Firstly, public networks are large and decentralized, anyone can participate within them at any level. They tend to be more secure and immutable then private or permissioned networks. However, they are often slower, more expensive to use and have limited storage capacity. Within the food-traceability use case, the participants' roles and relative number, except for that of end consumers, are known in advance. To some extent, the participants can be regarded as trusted parties, who demand fast and easy-to-use blockchain network. As a result, the inherent properties of public blockchains are not suitable for the food transparency scenario. Secondly, private networks are shared between trusted parties and may not be viewable to the public. They're very fast and may have no latency. However, the food-traceability ledger must be readable for the general public so that transparency is guaranteed. Finally, permissioned networks are viewable to the public, but participation is controlled (Investopedia, 2018). Their properties such as scalability, low latency and lower cost to build applications on top of them, make them a more optimal choice for the food-traceability scenario.

2.2 Why hyperledger?

There are possibly many suitable blockchain networks for food-traceability, but the investment by many top-players in Hyperledger as well as the resulting quality and robustness, make it a preferable choice compared to volatile networks. Hyperledger (Hyperledger, 2018) is under the guardianship of the Linux Foundation. Hyperledger has more than 230 organizations as members—from Airbus to VMware. The platform offers the benefits of high reputation as well as flexibility and robustness thanks to the successful open-source model. Its projects Hyperledger Fabric or Sawtooth meet all the requirements for food- traceability blockchain listed above and add additional advantages, such as no vendor lock-in, lower total cost of ownership, access to source code, out-of-the box templates, etc.

2.3 Technology

The proposed solution leverages blockchain to enable the traceability of agri-food products. Given the task of providing supply chain system that would connect many small farms and the performance challenges of public blockchains, the need for expensive infrastructure is minimized by employing a permissioned blockchain such as the one provided by the Hyperledger effort. Since the roles of the participants in the agri-food supply chain are known and can be mapped, a permissioned blockchain model is chosen for increased security. This means a person needs to meet certain requirements to perform certain actions on the blockchain. For example, a retailer can verify food status only of lots, which are already known to be purchased by him, so that he will not interfere with the food status of his competitor's inventory. Alternatively, a registered vegetable producer is not allowed to produce data about milk products, etc.

PROTOTYPE: SMART CONTRACTS ON HYPERLEDGER COMPOSER

Hyperledger Composer is a set of tools that can be used to build a blockchain business network on top of Hyperledger Fabric. Hyperledger Composer is best used for the creation of development versions and proof-of-concepts. It makes it simple and fast to create smart contracts, since it is built with the widespread JavaScipt language and supports lots of modern tools such as node.js and popular editors. An example smart contract, which is called chaincode in the Hyperledger world, is a check for expiry date of eggs –egg batches, which were recorded by farmers 27 days ago or more, are automatically rejected for processing on the blockchain. Hyperledger Composer enables easy alignment between business requirements and technical development. However, after the PoC phase, going for Hyperledger Fabric native development is advised.

FOOD TRACEABILITY ON HYPERLEDGER FABRIC

Hyperledger Fabric serves as a decentralized ledger or more simply -distributed database. Hyperledger Fabric is a permissioned blockchain network that can be set up and owned by the organizations forming a consortium. In the agrifood case that could be the farming associations, big producers and retailers, interested in providing transparency and traceability to the end customers. These organizations are called members. Each member is responsible to setup their network of peers. Peers would include raw material providers, farmers, distributors and processors. All peers should be configured with appropriate cryptographic material including certificates ensuring their identity. Peers can use different clients to create transaction invocation requests. A client can be any specific mobile app, web application or organization portal. Client applications use either Hyperledger Fabric SDK or REST web service to interact with the Hyperledger Fabric network. All the peers maintain the ledger they are subscribed to; hence we have Distributed Ledger Technology (DLT). But unlike most other blockchain networks, in Hyperledger Fabric peers have different roles – Endorser peer, Anchor peer, Orderer peer and General peer (Figure 1).

ENDORSER PEER

If a peer is marked as Endorser Peer, it is responsible for receiving the transaction invocation requests. Upon receiving such a request, the Endorser peer:

- Validates the transaction by checking certificate details and the roles of the requester
- Executes the Chaincode and simulates the outcome of the transaction

The Endorser peer does not update the ledger. It can only approve or disapprove a transaction. It is the only type of node that executes the Chaincode, which is why it is not necessary to install the Chaincode in every node of the network which greatly helps scalability.

In the agri-food case, each actor should have at least one Endorser peer so it can guarantee to the end customers a certain set of rules (Chaincode) has been followed during the process.

ANCHOR PEER

The Anchor peer or a cluster of Anchor peers is configured at the time of channel/ledger configuration. It receives updates from the Orderer peer and broadcasts to all other peers in the network. Anchor peers should be discoverable at any time by all other peers. It should reside in a cloud or data center that guarantees high availability and fast response rates with enough bandwidth.

ORDERER PEER

It is the central communication channel for the whole Hyperledger Fabric network. It is responsible for the consistent state across the network. The Orderer peer creates the new blocks, adds them to the blockchain and delivers them to all peers through the Anchor peers. Orderer peer is built on top of a message- oriented architecture. During development a solo instance is possible, creating a single point of failure for the whole system. A production-ready Hyperledger Fabric network should use a more reliable solution such as Kafka or any other high availability messaging service.

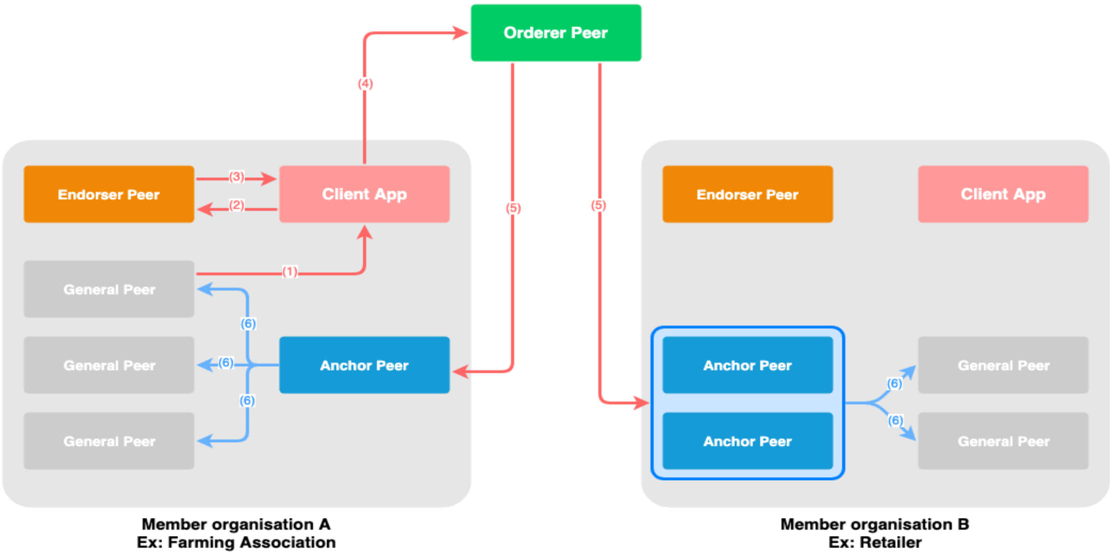

Figure 1. Architectural diagram of peers

BUSINESS LOGIC FLOW (FIGURE 1)

- Some general peer initiates a transaction e.g. a farm delivers goods to a processor, or a distributor arrives at the retailer's warehouse. The transaction is initiated using the Client App (Web App, Mobile App etc.)
- The Client App sends the transaction to the Endorser Peer of the corresponding Member Organization. The Endorser Peer applies the Chaincode/Smart Contracts business logic and either approves or disapproves the transaction. Chaincode logic can be organization specific e.g. different retailers can enforce different rules for freshness.
- After that the result is sent back to the Client App
- In case the transaction is approved, the Client App sends it to the Orderer Peer, and it gets added to the blockchain.
- The Orderer Peer sends the new version of the blockchain to all Anchor Peers, including the ones owned by all other Member Organizations (each Member Organization has at least one).
- All General Peers get access to the new version of the blockchain, containing the latest transactions via the Anchor Peer of the Member Organization that added them to the Hyperledger Fabric Network.

3. CONCLUSIONS

As showcased thanks to the described sample solution, implementing blockchain network for agri-food traceability is feasible. Leveraging an established platform such as Hyperledger, which is advancing through constant contributions by the blockchain community and trusted industry players, solves the inherent challenges for public blockchains and proves the initiative viable. Consumers have clearly articulated how highly they value proven food quality and transparency, which makes food traceability endeavors desirable for the end consumers. Existing technological solutions didn't manage to deliver on the promise for food transparency and even though blockchain is still perceived as complex, farmers and consumers can be presented with simple blockchain-based tools, which they can easily adopt.

We believe that we have already demonstrated the feasibility of building such a system since most of key characteristics of the proposed traceability application framework have already been applied in developing blockchain applications in other domains and environments.

We wish to further develop the FoodBlock framework in order to improve it with a large set of core and other services that will make the development of traceability applications easier and in adherence to the paradigm of Blockchain computing. In conclusion then we feel that in this paper we illustrated an architecture, a business model and basic processes which will enable members of the food supply chain to design and develop the traceability systems that meet many of the requirements identified and without being put under excessive economic costs.

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