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Scalable and Socially Inspired Blockchain Architecture for the Organic Food Supply Chain

Thanushya Thanujan[1], *Chathura Rajapakse* [2], *D.N. Wickramarachchi* [3]

[1,2,3] *Department of Industrial Management, Faculty of Science, University of Kelaniya*

email :[1] *thanushyal@esn.ac.lk* , [2] *chathura@kln.ac.lk* ,[3] *dilani@kln.ac.lk*

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ABSTRACT

Organic food supply chains are faced with heavy pressure to increase their output to meet global demand. This confronts various challenges including scandals, adulteration, contamination, and growing regulations. As an alternative to third-party certification, Participatory Guarantee Systems (PGS) are popular community-based quality assurance system that integrates the social verification context into the organic certification process. As PGS is a local community-driven system, it has inherent limitations in the scalability of reaching consensus as the size of participants increases. The organic food industry has the potential to grow globally therefore, an appropriate scalable consensus mechanism is needed to deal with community-level consensus as an alternative to the existing PGS system. Blockchain architecture with hybrid consensus mechanisms seems to be the potential solution to address the trust and scalability issues in the organic food supply chain. This paper proposes a socially inspired hybrid blockchain architecture for the organic food supply chain to address the scalability issues via hybridizing two consensuses' mechanisms with the combined advantages of Proof of Authority (PoA) and Federated Byzantine Agreement (FBA). In the proposed architecture, many eminent aspects of community-level trust are integrated into the consensus process. Furthermore, this paper presents a concept-level validation as a qualitative analysis of the proposed architecture based on experts' opinions. Concept-level validation of the proposed model acknowledged that, in the context of social verification, the credibility of the organic products would be enhanced, and hybridization of the consensuses would mitigate the scalability issues.

1. INTRODUCTION

Organic farming refers to a farming method that involves growing and nurturing crops without the use of synthetic fertilizers and pesticides[1]. Organic farming practices are promoted globally to reduce the impacts on agriculture and the environment [2]. Specifically, organic farming practices reduce the greenhouse effect and global warming through their ability to segregate the carbon in the soil[2]. Organically grown foods are higher in nutrients, reducing public health risks, as they avoid artificial manures and pesticides [2], [3]Due to growing health concerns among people, the demand for organic food has risen over time[4]. In addition to the environmental benefits, revenue from organic food exports plays a significant role in the economies of developing countries such as Sri Lanka, India, and the Philippines [5]. Accelerating the demand for organic food has significantly increased supply chain challenges such as scandals, adulteration, and contamination [6].

Consumer trust is a key element for establishing a market for organic products as it influences the purchase intention among consumers[6]. Organic certification is a credential to ensure that organic foods were grown through organic regulations - without synthetic fertilizers and pesticides[7]. Certification and

**) Corresponding Author : thanushyal@esn.ac.lk*

labeling have been the niche approaches to building consumer trust in organic products. In recent years, illicit behaviors such as scams and scandals in the certification process have hindered the market growth for organic products[8]–[10]. Therefore, certification and labeling were not very trustworthy mechanisms to ensure the credibility of organic products.

As yet, the third-party certification has played a vital role in fostering consumer trust in organic products. Due to the high costs of certification and documentation requirements, small-scale farmers face difficulties in obtaining third-party certification and accessing local markets[11]. As an alternative approach, Participatory Guarantee Systems (PGS) became popular among local markets with the continued growth of organic farming [11], [12]. PGS is a volunteer-driven quality assurance system that focuses on the domestic level. It relies on a foundation of trust, social networks, and knowledge building and exchange[12]. PGS has shifted knowledge about sustainability away from being centralized in the certification governance mechanism[13]. In PGS, the certification is provided based on a peer review conducted by the stakeholders and vested authorities through an annual visit to the farm. PGS is typically driven by a small group of people or sometimes by an individual who takes the initiative to establish a system at the local level[14]. Lack of time in inspection, visiting in-person, continuous monitoring process, experience perceived expertise to be present in the committees, and political influences are the hinder factors of the PGS advancement beyond the local market.

Due to the rising health-conscious among people, the demand for organic food has increased. As a consequence, the global trade in organic products has shown immense growth in recent years[15]. Organic certifications are essential for export products. Despite PGS being widely accepted by the rural community, it faces difficulty in convincing the export market as it is governed by the local community[10]. That is, if the supply chain expands as the export market, it becomes more complex with the extended number of participants. Moreover, how to ensure the credibility of organic products in such a system remains largely unresolved. Thus, the organic food supply chain faces scalability issues while reaching a consensus with the increasing size of participants. As the organic food industry has the potential to grow beyond local markets, a proper system is needed to confront the scalability issues while incorporating social verification context in the certification process.

The agricultural food supply chain braids all the processes from the farm to the fork together. Transparency in the food supply chain is essential to guarantee food quality, origin and provenance to all consumers. Blockchain is a promising technology to enhance the transparency and traceability of the food supply chain [16]–[18]. It provides a platform for conducting transactions without the need for an intermediary, validating records publicly, and distributing transactions in immutable encrypted ledgers between the infinite and anonymous parties in the decentralized network [16]. The consensus mechanism is considered the backbone of blockchain technology as it enables trust and security by reaching a common agreement in the network. Furthermore, the consensus mechanism plays a critical role in implementing a blockchain-based system to resolve scalability issues[19]. Choosing a precise consensus mechanism is imperative for the sustainability of a scalable blockchain-based system [20].

Several research has been done on the adoption of blockchain technology in food supply chains. To the best of our knowledge, they have yet to be focused on solving scalability issues posed by the integration of social verification context in the consensus process. Therefore, this paper focuses on incorporating community-level trust in the consensus process. Consequently, in the proposed blockchain architecture, two consensus mechanisms, namely, Proof of Authority (PoA)[21]and Federated Byzantine Agreement (FBA)[22], were hybridized to incorporate community-level trust into a consensus process to achieve better consumer trust and mitigate the scalability issues.

By incorporating the community into the certification process, the credibility of a blockchain-based supply chain becomes unpredictable, as the credibility of the certification might be influenced by dynamic human activities such as scandals, adulteration, and growing regulations. To retain the trustworthiness of the organic supply chain, a reputation-based feedback mechanism is proposed as an incentive mechanism since reputation is vital for establishing trust in a community-based certification system[23] and driving it in the long run. Hence, the proposed incentive mechanism is expected to align participants' behavior, to maintain the sustainability and scalability of the system.

This paper pays attention to proposing a solution to the scalability issues found in PGS via blockchain technology. The rest of this paper is organized as follows. Section 2 reviews the prevailing approaches for the traceable food supply chain, existing blockchain-based systems for food supply chains, analysis of consensus mechanisms and hybrid approaches, and at last, incentive mechanisms. Section 3 depicts the methodology. Section 4 presents an architectural design of a proposed socially sustainable blockchain-enabled organic supply chain and the incentive mechanism for the proposed sustainable architecture model. Section 5 elaborates on the discussion of concept-level validation, and Section 6 concludes the research work and illustrates future work.

2. LITERATURE REVIEW

Traceability and transparency are mandatory requirements for the food supply chain, as it brings many benefits, such as increasing the quality of the product, preventing scandals, reducing wastage, and minimizing the impact of safety hazards in the food supply chain. In recent years, several research has been conducted on the traceability, transparency, and safety enhancement of the food supply chain. In[24], the application of Radio Frequency Identification (RFID) technology for the traceability of agri-food products at different stages of the supply chain has been explored. They analyzed the current developments in RFID technology and its future directions in the agri-food industry. Some researchers have studied the integration of technological innovations such as real-time sensors, Wireless Sensor Networks (WSN), Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), and Time Temperature Tolerance (TTT) with food supply chain[25]–[27]. Furthermore, some researchers proposed frameworks and models to deal with the increasing complexity of the food chain[25], [28]. Reaching reliable information in the food supply chain was the biggest challenge with the exchange of traceability data and transparency of the data. Furthermore, [26] proposed Physical Markup Language (PML) based framework to exchange and manage the traceability data in fresh, non-processed food products supply chains. In[29], a model using web-based systems for a flexible way of information access in data processing, data storage, and transfer, and usability to achieve traceability has been proposed.

Although researchers have tried to solve the problem of the supply chain through various technologies, among them blockchain seems to be a promising technology as it produces immutable, traceable, and transparent data. Moreover, none of them focuses on mitigating the scalability issues while integrating community-level trust into a consensus process. Therefore, hybridizing pertinent consensus mechanisms was selected as the candidate approach to resolving this issue. As consequence, the literature was reviewed into three categories: understanding existing blockchain-based systems for food supply chains, analysis of consensus mechanisms and the hybrid approaches aimed at enhancing scalability, and the incentive mechanism for a sustainable blockchain-based system.

2.1. Blockchain-based food supply chain

In recent times, many researchers were attempted to solve the emerging problem of food supply chains through blockchain technology, as blockchain enables the creation of decentralized information systems with immutable and trustworthy records of transactions. In [30], a blockchain-based model of RSCM (Rice Supply Chain Management) has been proposed to increase rice productivity, trace the productivity and enhance the operational efficiency of the supply chain. In [31], a solution to trace the soybean supply chain via the Ethereum blockchain and smart contracts has been proposed. In the proposed solution, smart contracts were used to govern and control all the transactions within the supply chain system. To maintain an immutable transaction, a decentralized file system (IPFS) was selected. In [32], a traceability system of the agri-food supply chain based on blockchain technology was conceptualized and tested in the Proof of Concept (PoC) pilot to trace the berries supply chain. In 2017 Walmart successfully tested IBM's blockchain pilot for food provenance: pork in China and mangoes in America. Throughout this case study, the challenges of implementing blockchain technology in the food supply chain and the opportunities for deploying blockchain solutions were highlighted [33].

Despite the undeniable benefits of blockchain-based supply chains, the technical challenges and barriers to their adoption still need to be fully resolved. Some studies have reviewed the challenges of blockchain adoption in food supply chains and the future direction of integrating blockchain with IoT[34], [35]. Although the integration of IoT with a blockchain-based supply chain helps to obtain real-time data, some scholars have argued that the integration of IoT with blockchain is not feasible due to the computational efforts and costs involved in performing real-time processing[36], [37]. Organic foods are perishable, and most of them are seasonal. Therefore, building trust at the community level is appropriate to enhance thrust over the product. Most of the existing research on blockchain-based supply chains proposed a framework to address challenges such as security, transparency, and traceability. However, none of them focused on integrating community-level trust in the consensus process.

2.2. Consensus mechanisms and hybrid approaches

The consensus mechanism is the backbone of blockchain architecture. In literature, numerous consensus mechanisms have been proposed to address different problem specifications. Several studies have been conducted to analyze the consensus mechanism based on their security and performance characteristics[38]–[40]. In[41], knowledge of blockchain consensus mechanisms and their unique security and performance characteristics was provided. A notable study on the evolution of consensus mechanisms has been presented in [42]. This research classified the existing mainstream consensus mechanisms under the evaluation type as described in Figure 1. The evolution of the consensus mechanism was classified into three categories based on the miner selection strategy. Compute-Intensive-based consensus protocols consume more energy and insist on exorbitant costs for resources and contamination of the environment. To overcome this, Capability-Based Consensus Protocols came into play. However, it has the ability of wealth dominance, which is biased toward the rich, and the attackers may take advantage of this grievance. Furthermore, voting-based consensus mechanisms were introduced to address the issues of high computing power and wealth dominance. In [43], the mainstream consensus mechanisms were reorganized as a guideline to choose the most appropriate consensus mechanism for the application being developed considering multiple performances. There is no consensus mechanism yet to satisfy all the performance and security characteristics. As a solution to the increasing complexity of the applications, in literature few studies have proposed hybrid consensus mechanisms based on their problem specification. In [44], an improved hybrid consensus algorithm has been presented with the combining advantages of the Practical Byzantine Fault Tolerance (PBFT) algorithm and the PoS algorithm. The proposed hybrid consensus reduces the number of consensus nodes to a constant value by verifiable pseudorandom sortition and performs transaction witness between nodes. And the comparison experiment of the hybrid consensus mechanism results shows better performance compared to traditional PBFT and PoS in terms of throughput, scalability, and latency.

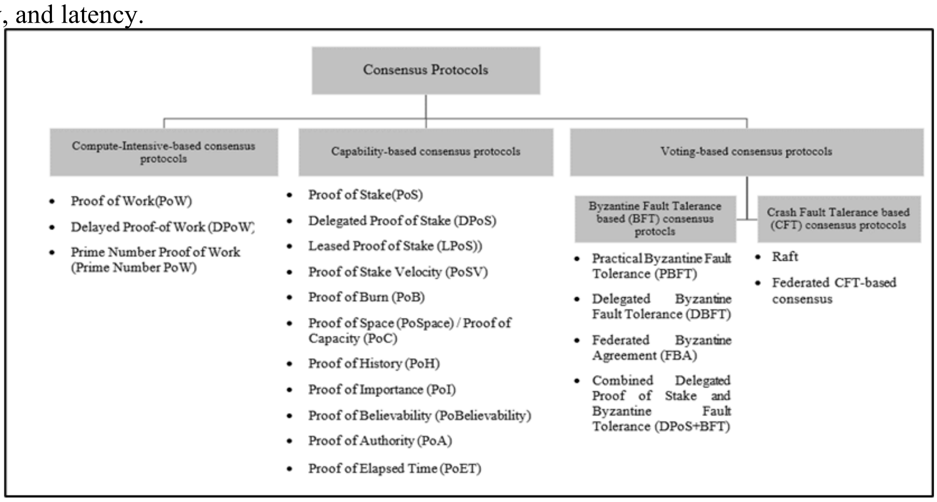

Figure 1. Evolution of mainstream consensus mechanisms

A hybrid consensus algorithm based on hierarchical authority has been proposed by [45]. Based on the pros and cons of the PBFT algorithm and Raft algorithm, the Raft algorithm is adopted at the lower level to improve the Byzantine fault tolerance, and the PBFT algorithm is adopted at the higher level to control the malicious attack behavior. Through the stratification mechanism, the communication volume is reduced, and the consensus efficiency is effectively improved. Another hybrid consensus mechanism for a public and private blockchain has been proposed for incognito payments like tips. The public blockchain is based on the Federated Byzantine Agreement (FBA) consensus. In contrast, BRAVO's private, incognito blockchain is based on an anonymizing Proof-of-Stake algorithm, which gives the end-users control over transaction speed, privacy, and cost [46]. FBA is used to establish trust through the concept of quorum slice. And compared to other Byzantine Fault Tolerant consensus FBA is preferable due to the high throughput, network scalability, and low transaction cost. A hybrid consensus model with a sharding mechanism (PSC-B chain) has been proposed to emphasize security and improve the scalability and efficiency of a blockchain-based e-voting system. This model is formulated by combining PoS and PoC(Proof of Credibility) consensus mechanisms. The PoS consensus is proposed as a means of saving energy. PoC is used to address the problem of coin collapse found in the PoS consensus method and for credibility verification with the function of attack deterrence. Furthermore, their experimental results confirmed that the proposed PSC-Bchain with sharding is secure and highly scalable [47].

2.3. Incentive mechanisms for blockchain-based systems

Most of the existing blockchain-based research focused on tackling sustainability challenges via incentive mechanisms. Incentive mechanisms were defined to control the participants' behavior, and they reward the participant for their honest engagement and penalize them for any fraudulent actions. This section depicts how blockchain-based applications provide control over the system to lead the system sustainability. In [48], they designed the algorithm to calculate the incentives, and they analyzed the algorithm concerning the average transaction fee. Their proposed incentive mechanism uses a cooperative game theory approach in which all parts of the supply chain demonstrate cooperative behavior to follow blockchain-based distribution chain protocols, and also this mechanism makes a fair attempt to reward the supply chain parties with incentives. In [49], they proposed a Blockchain-based incentive mechanism to meet the diverse requirements in a dynamic and distributed P2P environment. They employed the idea of credit-based incentives to motivate intermediate nodes to cooperate. Thus the intermediate nodes who contribute to a successful delivery obtain the rewards from Blockchain transactions once the next-hop node sends a signed acknowledgment. The transactions are securely verified by the miners by using commutative encryptions. A pricing strategy is proposed to guarantee the security of their incentive mechanism. Further, a game-theoretical analysis and simulation study was conducted to demonstrate the security and efficiency of the proposed incentive mechanism.

In [50], the analysis of the evolutionary game process of data sharing was conducted. Based on the analytical results, four constraints were obtained to design an adaptive smart contract mechanism that can be used to motivate more users to participate in data sharing. Accordingly, a smart contract-based incentive method is proposed to maintain the level of user participation by dynamically adjusting incentives and participation costs. In [51], they proposed a RepChain -a reputation-based secure, fast, and high-incentive blockchain system via a sharding mechanism. In this architecture, they incentive their participants based on the defined reputation scheme. They provide a significant standard amount of reputation score for newly joined participants. In each successful transaction verification, the leader node will gain half of the transaction fee, and the rest will be distributed among the validators for their honest engagement. In this distribution process, to prevent monopoly, malicious nodes get fewer reputation scores than the honest majority, thus it has barely any chance of being a leader and threatening the system.

3. METHODOLOGY

Design Science Research (DSR) methodology is followed to propose a scalable blockchain-based architecture for the organic food supply chain described in Figure 2. DSR is an iterative-creative and solution-based approach that deals with problems via artifacts and design theories[52]. Accordingly, as a preliminary of this research, to understand the existing organic supply chain practices, a series of open-ended interviews were conducted. Spontaneous questions were asked based on the interviewer's previous answers which led to the identification of gaps, current status, and challenges in existing organic supply chain practices. Furthermore, the proposed model was verified to address the identified gaps and challenges via questions. Popular certification bodies and community-driven organizations like PGS were analyzed in terms of the organic certification process. As a consequence of the investigations, blockchain technology was selected as a viable technology. To integrate the social verification context in the certification process and enhance the scalability in reaching consensus, prevailing consensus mechanisms were reviewed. As a result, highly scalable consensus mechanisms were filtered. Attempts have been made to consolidate social verification with authentication into the certification process to enhance consumer trust [53]. With the advantages of Proof of Authority (PoA) and Federated Byzantine Agreement (FBA) consensus mechanisms, a hybrid consensus is proposed to mitigate the scalability issues while consolidating social verification.

According to the analysis of literature and the open-ended interview with various levels of stakeholders and industrialists, to drive the blockchain-based social system, a reputation-based consensus mechanism is proposed which aids the sustainability of the socially inspired blockchain-enabled organic supply chain system. Further concept-level validation was carried out as a qualitative analysis of the proposed model.

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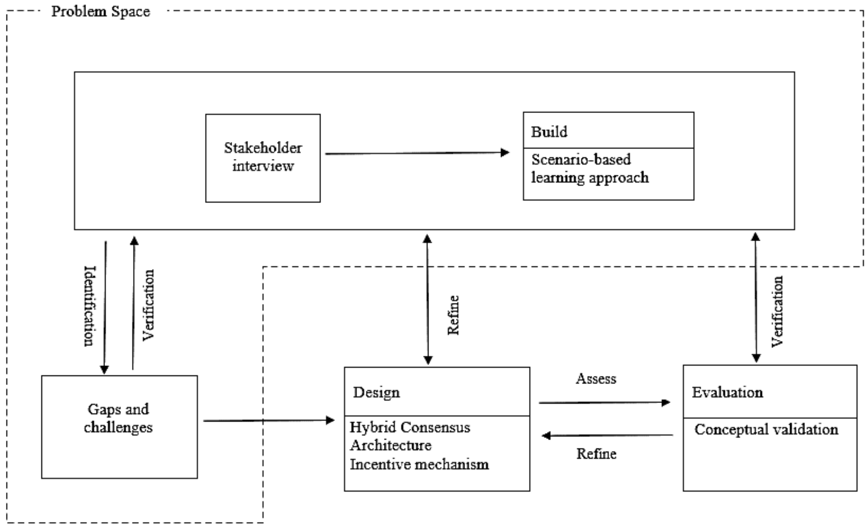

Figure 2. Design Science Research (DSR) approach

4. PROPOSED ARCHITECTURE

Community-level trust is an important aspect of the organic agriculture industry[54]. To attain consumer trust over products, safety regulation and product labeling were not enough. Therefore, this study aims to enhance the trust in the organic food supply chain from the ground level of the community. Thus, primary attention was paid to incorporating community-level trust into consensus protocols.

4.1. Role of community in the consensus process

Community is a predominant component in the process of ensuring the sustainability of the organic food supply chain[54]. In the traditional organic supply chain, the credential of the product was certified by the PGS of the specific area or appointed certification agent. Despite this, to enhance trust in the product, a collaborative certification process is to be defined in the consensus process of the proposed architecture. That is 1. Without bypassing government regulatory procedures, the authorized person (who was vested by governing bodies) be empowered in the certification process, 2. Despite the occasional monitoring process by the authorized person, the neighbor of the farm or any reputed person of the particular area (e.g., a priest) gives meticulous observations that are obvious, thus everyday people's voices should be integrated into the validation process. Accordingly, in the proposed architecture block creation was envisaged from the accredited vested bodies, and the validation process was designed to be strongly influenced by the voice of community members.

4.2. Consensus Mechanisms

Prevailing mainstream consensus mechanisms were analyzed[43]. Among them, Proof of Authority (PoA) [21]and Federated Byzantine Agreement (FBA) [22]was identified as the underlying consensus mechanisms to address the scalability issue with the increasing size of participants.

4.2.1. Proof of Authority (PoA)

PoA consensus is considered a variant of Proof of Stake (PoS) as it leverages the identity as a form of stake instead of any form of monetary (Ex. crypto tokens) and further, it avoids the need for spending huge computational power to validate a block, hence it is considered as an alternative to Proof of Work(PoW) consensus[55]. PoA relies on a group of pre-approved validators, who are empowered to create new blocks. Each validator will receive an equal chance to reach the privilege of creating a block[56]. To become validators in PoA, nodes have to comply set of strict rules such as they have to voluntarily disclosing their identity[56]. Due to the nature of having a limited number of validators, PoA compromises decentralization to achieve high throughput. The ability to meet the immediate finality of PoA[57] was expanded its use cases in various platforms such as Microsoft Azure, Ethereum Express, POA Network, and VeChain further Global giants, Walmart and GE Aviation are using PoA to track their supply chains[58]. PoA consensus was the ideal approach for providing a controlled environment for community-integrated systems. Hence, it was chosen to incorporate the authorized group in the certification process by adhering to the formal regulatory procedures imposed by the governing bodies.

4.2.2. Federated Byzantine Agreement (FBA)

Federated Byzantine Agreement (FBA) is a consensus protocol that emerged from the famous Byzantine Generals Problem[59]. In the FBA network, each node forms its quorum slices to determine the system-wise quorum based on their individual trust[22]. Based on the inherent infrastructure of the quorum intersection of FBA, the network reaches a consensus by convincing quorum slices by each other [60]. Thus through the collective decision-making process, it will control the impact of the malicious node's action[61]. Notable cryptocurrencies such as Stellar and Ripple have adopted FBA consensus due to their high scalability and throughput[62]. The infrastructure of FBA prevents malicious actions - Although most nodes in the network were malicious nodes, the consensus will not reach until convincing a significant number of nodes comprise their quorum[61]. Moreover, the social connection in-between the individuals resembles quorum slices. Based on this, FBA was chosen as appropriate to enhance the scalability of a community-level certification in a community-integrated complex system with a diverse population.

4.2.3. Hybridization

The outcome of the analysis of consensus mechanisms led to a hybrid approach to mitigate scalability and trust issues in the organic food supply chain. Accordingly, vested officers by the regulatory bodies who are inevitably socially responsible persons were empowered to propose a block as it is based on PoA consensus. The social connection in-between the community members was transformed as the FBA quorum structure [63]. Hence the block creation is envisaged from the accredited vested bodies, and the voice of the community members strictly influences the validation process. Accordingly, the traditional PoA consensus is proposed to empower the authorized persons to propose blocks [58], and the Federated Byzantine Agreement (FBA) protocols resolve the issues of scalability and latency in the validation process[22]. Thus according to PoA consensus, the power to create a new block is designated to the authorized node that satisfies the preliminary authentication. FBA consensus is reaching its high throughput and network scalability through its quorum structure. To obtain high scalability, PoA sacrifices its decentralization as the pre-authorized members were limited in the network[21]. This drawback will be mitigated by hybridizing PoA with FBA. Hence, hybridizing both consensuses aims to mitigate the scalability issues and enhance the trustworthiness of the proposed architecture.

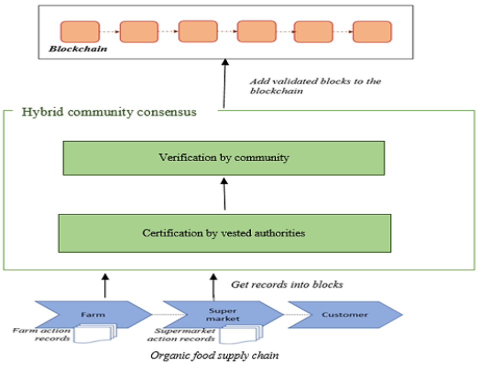

Figure 3. Overview of the proposed blockchain-based organic food supply chain

4.3. System Overview

The actors involved with the socially inspired organic food supply chain are classified into two major categories namely consortium members and community members. Consortium members are the formally authorized officers vested by the regulatory bodies who are empowered to propose a block. Community members are willing participants of the community of interest, incorporated in the validation and verification process. Hence, their contribution is prominent in preventing fraudulent activities such as corrupt practices and alterations of records about past actions.

The actors involved with the organic food supply chain do actions and transactions. When an action or a transaction is initiated, a member who has a formal authority to oversee, authorize and regulate actions and transactions of supply chain actors from the particular phase (farm/supermarket) aggregates transactions and proposes a block within a particular time slot. Thus, this part comes from the PoA component of the architecture. Once a block is initialized, broadcasted within the own quorum where the block proposer resides. If a consensus is reached within that quorum slice, the members of that quorum slice communicate it to the other quorum slices which are involved through the quorum intersection structure. If a substantial percentage of the network reaches consensus, the block is said to be validated and then appended to the existing blockchain. Thus the FBA consensus component takes part in the architecture.

The community-based blockchain architecture for the organic food supply chain depends on various human-behavioral dynamics, so the scalability and sustainability of this architecture have become immensely unpredictable when integrating community members into a blockchain-based supply chain. Such a system needs to have control mechanisms put in place to encourage transparent and legitimate actions while strictly eliminating fraudulent actions from the network. An incentive mechanism is proposed to align and steer human activities for the sustainability of a blockchain-enabled social system. Moreover, social attention is eminent for sustainability therefore, the cost reduction mechanism is also proposed to encourage everyday people to participate frequently.

4.4. Incentive Mechanism

Reputation relates to good social status, which reflects the legitimate behavior of past actions of socially embedded individuals[64]. Reputation is vital to establish trust in a community-based system which will pave the way for a sustainable and secure future[65]. Therefore, a reputation-based incentive mechanism is considered well-suitable for blockchain-enabled social systems as it aligns with the dynamic human-behavioral. Therefore, retaining the reputation is crucial hence it employs as an incentive for the participants to engage in honesty. Therefore, in this paper, a reputation-based control mechanism is proposed to improve the reliability of the community-level trust in the blockchain-enabled organic food supply chain.

Hence the reputation is infused in the proposed architecture to influence the selection process very much. Furthermore, a star rating scheme is introduced to represent the reputation value in the community. Moreover, a review mechanism is developed to pertain to the credibility and sustainability of the system[66]. As a consequence of the review getting by the feedback mechanism, the rewards and penalization scheme is designed. Also, the cost reduction scheme is designed to encourage participants to purchase organic products; thereby inherently the demand for organic products will increase.

4.4.1. Community Reputation Index

Reputation is a subjective quality belief scale and aggregated opinion of a community which refers to social value based on criteria such as the behavior or performance of a person, place, or organization[64]. Therefore, respective suitable equations for calculating individual's and supply chain phase's (such as farm, supermarket) community-level reputation scores were defined. Based on [67]–[69], the Community Reputation Index (CR) of a person in the community was determined by the combination of the past action of the respective individual and the current social-relational connection within the community. The following formula is used to compute the Community Reputation Index (CR) of an individual(i) at time t,

$$CR_i = PA_i + SC_i \quad \text{(A)}$$

where,

PA_i : Past Action of an individual*(i)*

SC_i : Social connection index of an individual*(i)* at time t

In accordance with the classification of the actors involved with the blockchain-integrated organic food supply chain, an unbiased formula was obtained to calculate their past actions. Only when a new block is successfully added to an existing blockchain will the successful block creation*(sB)* and successful block validation*(sV)* process associated with that particular blockchain be considered as a successful attempt. There may be chances that a new block will not be able to connect to the existing blockchain due to illegitimate activities of participants and corrupted or altered transactions. In such situations, the attempts will be calculated as a failed block creation*(fB)* and failed block validation*(fV)*. Thus past legitimate action of an individual *(PA)* is obtained by subtracting the failed attempts from the legitimate successful attempts.

If individual*(i)* is a Consortium member, then

$$PA_i = \left[\frac{P(sB)+P(sV)}{2}\right] - \left[\frac{P(fB)+P(fV)}{2}\right] \quad \text{(a)}$$

If individual*(i)* is a not a Consortium member, then

$$PA_i = [P(sV) - P(fV)]$$

Here, *P(sB)* is the probability of successful bock creation. It is obtained by dividing the total number of blocks added by the particular individual (i) by the total number of blocks in the chain. *P(sV)* is the probability of successful attempts in block validation, it is obtained by the division of the total number of blocks validated by the respective individual(i) by the total number of blocks in the chain. Similarly, *P(fB)* is the probability of failed bock creation. It is obtained by dividing the number of blocks attempted and failed to be added by the individual (i) by the total number of blocks in the chain. And *P(fV)* is the probability of failed bock validation. It is obtained by dividing the number of blocks attempted to validate and failed to be added by the individual (i) by the total number of blocks in the chain.

$$SC_i = \frac{\deg(i)}{n} \quad \text{(b)}$$

SC_i is an individual's Social Connection index, representing the social-relational connection ratio of the individual with other community members based on trust with them. Here, the deg(i) is the total social connection of an individual (i) at time t divided by n which is the total number of participants in the network at time t.

The production method and its path in the supply chain will influence the product selection process when choosing a product. Therefore, a Community Reputation Index for phases (such as farms, and supermarkets) in the supply chain was introduced to ensure the trustworthiness of the organic product. The Community-Reputation Index of the phase is obtained by the authorization-based trust index and the community-based trust index. The Community Reputation Index (CR) of a phase (j) at time t is computed by the following formula.

$$CR_j = A_j + CT_j$$

(B)

Here, the authorization-based trust index leads the vested parties associated with the particular phase in the legitimate actions. The community-based trust index is obtained from the feedback mechanism representing the respective phase's legitimate past actions. The following formula calculates the authorization-based trust index of phase j,

$$A_j = \frac{\sum_{i=0}^{n} (A_i . CR_i)}{n} \quad \text{(c)}$$

A_i is the hierarchical authorization level of an individual (i), CR_i is the reputation index of the respective individual (i), and n is the number of authorized persons employed at phase j.

Consumer feedback is a very powerful tool that assesses the credibility of the product and drives the reputation in a community [70], [71]. In the proposed architecture. the feedback mechanism is included in order to account for reputation score for incentive the honesty and repetitive engagement of the participants [72].

CT_j: is the *Community trust index* of phase j is calculated based on the customer feedback mechan

$$CT_j = R_j - P_j \quad \text{(d)}$$

where,

R_j: reward by marked customers (positive feedback)

$$R_j = \frac{\sum_{i=0}^{n} CS_j}{m} \quad \text{(e)}$$

P_j: penalty by marked customers (negative feedback)

$$P_j = \frac{\sum_{i=0}^{n} CS_j}{m} \quad \text{(f)}$$

where m is the number of customers who attempt review and customers can have leftover the stars if they can't decide or don't want to rate. And CS_j is the feedback count.

4.4.2. Rewards and Penalties

Actively collecting feedback can encourage reviews from a broader range of people, including those who had a positive experience and may not have. Therefore, the feedbacks have to be collected to review the credibility of the particular product. Based on the feedback mechanism, the stakeholders in the supply chain are rewarded with a reputation increase, on the other hand, if any fraudulent activity is encountered, then the respective stakeholders in the supply chain are punished in the form of a decrement of their reputation score in the society. The feedback mechanism comprised for every honesty engagement (positive feedback) will receive rewards and penalization for fraudulent activities (negative feedback), and both these will be adjusted with the prevailing current reputation rating score. According to the feedback mechanism, the community reputation index is visualized into star rating points aimed at easy identification in the selection process. Based on using standard mathematical rounding rules, the star rating will be rounded up or down to equal valued full star. Moreover, depending on the quality and reliability of the product passing through the supply chain, in each phase, the rewards and penalties will be given as a dynamic community reputation index for honesty and fraudulent activities respectively.

5. CONCEPT-LEVEL VALIDATION AND DISCUSSION

Concept-level validation of the proposed architecture was carried out as a qualitative analysis. A series of open-ended interviews were conducted with active organic food supply chain participants. As the preliminary of this concept-level validation, specific supply chain stakeholders from different disciplines were interviewed to verify the identified gaps and challenges in the prevailing organic food supply chain. Spontaneous questions were asked based on the interviewer's previous answers. Accordingly, the key concerns regarding the current supply chain by the farmers, supermarket managers, and consumers are,

“Poor quality products with organic labels are selling in abundance in the market. Labeling is not enough to be capable of ensuring the quality of the product. This undermines trust in the quality and thus leads the revenue downward even if what we produce is purely organic”.

"Each record was maintained in manual form. Which is not capable enough to satisfy the purchaser's trust in the organic practices".

“Most of the farmers from the Vahara district have practiced this organic farming for more than five years and they have some experience in grading. So mostly they come up with superior quality vegetables and grading will be taken as an empirical process.”

“To gain the consumer trust over the grading mechanism, the classification process should be illustrated to consumers or any digital testing process should be established”.

Moreover, two notable feedbacks were received from the consumer side.

“Compared to conventional food, organic foods are not affordable”.

“Even though the price of the organic food is comparatively higher than conventional food, we are ready to buy if it is truly organic certified”.

According to stakeholder feedback, the gaps and challenges of the current organic food supply chain were verified. Based on the specific problem domain, a blockchain-based supply chain was accepted as an ideal solution to enhance the credibility of the organic food supply chain.

The majority of organic farming happens in rural areas, and the way they follow farming practices is not portrayed in the label. Further organic food supply chains are faced with heavy pressure to increase their output to meet global demand which may lead to malpractices such as scandals and contamination. Hence community involvement in quality assurance is prominent in enhancing consumer trust. Traditional traceability mechanisms have repeatedly proven to be incapable of ensuring trust in supply chains. So far, the certification system has been in practice to ensure the credibility of the organic product. PGS is a popular locally-focused assurance system that verifies producers’ compliance to certain organic standards. Even though it adopts social verification into its quality assurance process, it fails in terms of scalability in reaching consensus. Pursuant to this, there is a great need to enhance the scalability with the increasing size of the participants when reaching a consensus. Therefore, while adhering to the formal regulatory process, consolidating everyday people such as neighbors of the farm, village officers, or any reputed person from the community into the verification process is a novel concept, and building trust from the base level is the desired idea.

The insight of the proposed architecture was conceptually validated by the leading blockchain practitioners, industrialists, and educationists in Sri Lanka. The expert's opinions are,

“Incorporation of community-level trust into the consensus protocol is a novel and desired idea.”

“Hybridizing the consensus protocol will mitigate the lapse of each and enhance the security and scalability of the system.”

“A proper mechanism is needed to establish trust over the certification of the product.”

"Exploring a consortium blockchain model based on quorum is beneficial."

“The proposed architecture seems to resolve the scalability issue in reaching consensus, and reputation is designed to highly influences the selection process so, it should address the business risk associated with that.”

"Blockchain enables the significant cost reduction and scalability by far-reaching automating of insurance and payment processes and reducing the complexity in the chain."

"Reputation is the key identity in the community, therefore converting the reputation into a measurable form can help to easily identify the status of the individual/phase in the society."

"The proposed model enables consumers to be provided with flexible financing options."

An incentive mechanism is proposed to control the dynamic behavior of the participants by rewarding and penalizing them. It is not targeted at punishment despite the drive for the participants' loyalty. Furthermore, a price reduction scheme is introduced to engage the participants with the system more enthusiastically. The potential validity of the concept of the proposed incentive mechanism and the equations defined within it were validated by two expert mathematicians.

"The reputation of a person is accounted for through continuous and collective action. A person's past actions also influence his current reputation. when defining reputation at the time, considering the past reputation value of the person is optimum."

"The way the defined equations seem to fit some situations but not always."

"The defined equations were linear, and they will show an increasing pattern always. But when we implement it in real-world scenarios, the reputation value is dynamic."

Furthermore, arbitrarily selected individuals from the community and the stakeholders of the organic supply chain were interviewed to analyze the adoption of the proposed architecture.

"Since the reputation of a shop is influenced by the feedback mechanism, motivating the participants to be active is eminent to reduce the reputational risk and to keep the business on track."

"Business risks will arise when the organic product does not meet the expectations of the standards as it is negatively perceived. Hence in this situation, the chance of a reduction in reputation is high."

"The cost of organic food is higher than conventional food, so the price reduction scheme is an impressive intensive scheme for the consumption of organic products."

Blockchain is a viable technology to enable traceability, transparency, and record immutable data. Integration of blockchain technology into the organic supply chain addresses the challenges by detecting the lapse. The proposed blockchain-based organic supply chain empowers the authorized persons in the certification process and involves the community in quality assurance as well as mitigates the scalability issues in the consensus process. To address the identified shortcoming, choosing an appropriate consensus mechanism is one of the potential solutions in blockchain-based systems. The hybridization of consensus is a feasible way to achieve credibility and scalability. According to the feedback of the expert, the hybridization of the two existing consensus protocols, namely the Proof of Authority (PoA) and the Federated Byzantine Agreement (FBA), is the novel concept of obtaining better consumer trust due to the incorporation of community-level trust into consensus protocol. PoA is proposed to empower the authorized persons to propose blocks as adhere to the formal regulatory compliances. Thus, the consortium model enables the control of a particular group of authentic participants, instead of a sole entity. This control helps to set rules which encourage the honest engagement of the participants and comply with the formal regulatory procedures. FBA resolves scalability and latency issues by reaching a consensus via a quorum structure. FBA consensus determines a decentralized quorum by allowing each participant to select their own quorum slices based on individual trust as it facilitates reaching the system-level quorum, hence it resolves the scalability issues with the increasing size of participants. Since it is a community-driven system, the opportunistic behavior of the participants may influence the certification process. Therefore, a precise system with human behavioral control was needed to enhance the trustworthiness of the organic certification. Consequently, a suitable incentive mechanism was proposed to control fraudulent activities as it is not targeted at punishment despite the drive for the participants' loyalty.

In the proposed model, reputation is a qualitative measure of public information that summarizes how an individual is loyal to the system. Reputation does not hold a constant measure always, as it might be influenced by many factors such as corporate behavior, deception, and corruption. Hence the proposed equation seems to fits certain situations. Therefore, a proper equation should be defined to fits all situations. the proposed equation was defined by the combination of past action and current social relational status. Past action influences the current reputational value. The past action of an individual at a time was calculated based on the legitimate and illegitimate actions performed by a particular node. Furthermore, the social-relational connection ratio of a person is calculated by calculating the connections of the individual with other community members based on trust with them. Furthermore, the Community Reputation Index of phase was defined by the combination of the authorization-based trust index and the community-based trust index. Instead of calculating authorization-based trust, the probability of the action of an individual has considered was ideal as it is similar to the occurrence of the actions carried out by the particular phase. Consumer feedback is a powerful component in defining the reputation of a product and its origin. The community trust index of the particular phase is calculated based on the customer feedback mechanism. Thus, the introduced reputation-based incentive mechanism retains people and stimulates them to be active. If the people will not actively engage with the system, there is a high risk that sustainability will collapse. To actively engage everyday people in the validation process, a transformation mechanism such as the conversion of reward as revenue was introduced as a price reduction scheme. Concisely, the proposed incentive mechanism encourages the participant to gain more rewards by engaging in legitimate activities to protect their reputation and motivate them to participate actively by creating price reduction schemes. In the proposed architecture, reputation highly influences the selection process. Therefore, actively collecting feedback from the customer will reduce the business risk. Further business risks will arise when the organic product does not meet the expectations of the standards as it is negatively perceived hence in this situation the chance of a reduction of reputation is high. Therefore, smart contracts defined at each level of the supply chain will assure the quality of the product and reduce the business risk in investing, and ensure the participants' legitimate actions.

The involvement of communities of interest in the block validation process significantly impacts the sustainability of the community-based blockchain system. Hence the dynamic property such as the sustainability of the community-based blockchain architecture is not very much predictable by qualitative review. This further reinforces the need to conduct experiments on the dynamic properties of the proposed blockchain architecture. Testing the system with the real community in the aspect of scalability may have adverse negative consequences. Hence the testing of this system is thought to be best done in a simulation environment with the control parameters.

6. CONCLUSION AND FUTURE WORK

The architecture presented in this paper is novel mainly due to the integration of social verification context in the consensus process. Hybridizing two existing protocols namely, Proof of Authority (PoA) and Federated Byzantine Agreement (FBA) aims to mitigate the trust and scalability issues. The PoA is proposed to empower the authorized persons to propose blocks, and FBA addresses the issues of scalability while the size of the network increases. Thus, the trustworthiness of organic products can be enhanced by empowering the vested authority to propose a block and integrating community-level trust in the verification process. The intention of involving the local community is to contribute to the third-party certification which is also manipulated by the influence factors. Moreover, in the case of PGS, scalability is not predictable with the increasing size of participants. Therefore, a hybrid architecture is proposed which incorporates the stakeholder communities in the certification process while addressing the issues of trust and scalability when the market is growing beyond local boundaries. Which will provide better credibility in the organic food supply chain. To enrich this architecture, a reputation-based incentive mechanism is proposed to control the dynamic properties of the community-based blockchain system. The credibility and sustainability of a system rely on the legitimate behavior of the participants. Therefore, a solid reward and meticulous penalty mechanism are driven by a feedback mechanism that influences the measurable community reputation index. A price reduction scheme is proposed to motivate the participants, even more, to actively engage with the system.

Furthermore, a concept-level validation was carried out as a qualitative analysis of the proposed model. As a result, a proposed model was ideologically accepted by the various level of stakeholders, prospective consumers, vested authorities, and community members. Furthermore, some suggestions were proposed to adapt the incentive mechanism to suit all situations in real scenarios. Hence the proposed architecture is yet to be implemented and tested in terms of dynamic properties such as scalability and sustainability. The involvement of the social component in the validation process is vital to this architecture. Actual human behavior might influence the scalability and sustainability of this system hence it becomes very much unpredictable. Concept-level testing is not enough to test the scalability and sustainability of this system. In the future, it is planned to test a computational model in a simulation environment that is a real environment. The agent-based social simulation (ABSS) is a scientific discipline for simulating the actions and interactions of autonomous agents to understand the system's behavior and consequences[73]. Moreover, it has the ability to study emergent properties of the complex social system. Hence, the agent-based social simulation (ABSS), seems to be well suited to the testing of a complex system like this. Thus, the future work of this research would be conducting experiments on the dynamic properties of the proposed blockchain architecture using the ABSS approach.

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