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A Framework for Blockchain and Internet of Things Integration in Improving Food Security in the Food Supply Chain

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ABSTRACT

Food security, as defined by the United Nations' Committee on World Food Security, means that "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life". Food security is not just ensuring food sufficiency, but also ensuring the quality and the reliability of supply chains which have become more complex with diversified sources of farm productions. Some common issues in food supply chains are lacking efficient traceability of product origins and distributions. Blockchain is an emerging technology for the agricultural supply chain which could monitor food quality and safety by digitally tracking data and processes of material resources. Meanwhile, the Internet of Things (IoT) system is used for diagnosis and control in smart agriculture such as crop growth observation that can produce good quality and sustainable farm production. This work proposes a framework of the integration of blockchain with IoT to improve the reliability of food supply chain (FSC) by focusing on optimizing the consensus algorithm of blockchain. The expected outcome is to produce an efficient traceability and higher quality transactions which can integrate all procedures and dealings in real-time processes across the FSC.

1. Introduction

Food security, as defined by the United Nations Committee on World Food Security [1], means that "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life". Food security is more than just ensuring there is enough food to eat, but it is also about ensuring the quality of the food and the reliability of global supply lines. Frequent food security incidents are

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wearing down consumers' confidence. Food security, which aims to provide adequate, safe, and nutritious food for all through a reliable food supply chain (FSC), is the most important matter of human life and health. According to the World Health Organization (WHO) in its food safety fact sheet, approximately 600 million people worldwide suffer from foodborne diseases each year, and 420000 die from foodborne diseases [2]. In the investigation of potential food safety issues, it was found that chemical hazards, fungal toxins, and microbial hazards account for 90% of all food safety threat categories. In addition, temperature control issues for refrigerated and frozen products in the food chain account for 67% of all hygiene issues [3]. These food security issues arising from FSC are gradually eroding consumer confidence. Monitoring and tracing the physical environment of food production, packaging, transportation, and sales, as well as the growth and movement of animals and plants, are key measures to ensure food quality and reshape consumer’s confidence.

In this work, we focus on food security target goal on ensuring the reliability of FSC which have become longer and more complex with diversified sources of productions especially from farms or agriculture sectors that monitoring and authenticating the product quality is difficult. The scenarios results in inefficiency on aspects such as food traceability, safety, quality, and supply chain, that bring additional risks to the economy and human health. Hence, there is a need to create a digital transformation of the supply chain whereby blockchain technology and IoT system can help in achieving this. Blockchain and IoT technologies are being innovatively applied in FSC, with the potential to regain consumer trust in the food industry. The product sources of FSC are diverse, with numerous participants and complex environments whereby the traditional FSC feedback chain is slow and difficult to manage. With the development of IoT technology, the problem of automatic and continuous collection of FSC environment and production data have been solved, such as managing livestock on farms through intelligent foot loops or ear tags and tracking processed food transportation through RFID tags. However, due to the lack of trust between participants, some data from centralized systems may be tampered with and distorted.

This study aims to: (1) to design a framework of IoT integration with blockchain (B-IoT) for food supply chains that consists of detailed operations from end-to-end entities or stakeholders that may be adopted as a standard reference across multi-organizations to reduce scalability and interoperability issue; (2) design an optimized consensus algorithm of blockchain that is lightweight and dynamic that may promote widespread adoption among involved stakeholders along the supply chain that can improve efficiency of the whole FSC process.

The remainder of this paper is organized as follows. Section 2 discusses the background information on supply chain management (SCM) and food supply chain (FSC). Discussion on related works on blockchain and IoT implementation for FSC is presented in Section 3. The design of our proposed framework is presented in Section 4, whereby Section 5 concludes this paper.

2. Background

As aforementioned, one of the main targeted goals of food security is to ensure the reliability of food supply chain. Hence, it is important to study on the food supply chain’s overall framework and identify its operational issues and weaknesses such that blockchain and IoT can play vital roles in enhancing its efficiency.

2.1 Supply Chain Management (SCM)

Supply chain management (SCM) is a process of managing the entire integrative flow of materials, from the raw material supplier to production warehousing and transportation to the end consumers

[4]. It involves the coordination of various activities such as production, processing, transportation, warehousing, distribution, and retailing. There are variety of methodology involved in SCM, and it is crucial to identify its limits [5,6]. The significance of technologies for supply chain management is widely recognized. Recent developments as part of Fourth Industrial Revolution promises radical transformation in various industries, including manufacturing and logistics. The primary objective of SCM is to optimize the delivery of products or services to customers, ensuring efficiency and cost-effectiveness, while simultaneously meeting customer expectations. It encompasses the optimization of processes, cost reduction, and the improvement of customer satisfaction through the seamless coordination of goods, information, and services, from end-to-end supply chain line.

Advanced technology in SCM has allowed manufacturers to embrace new trends in improving the SCM efficiency. Recent developments as part of Fourth Industrial Revolution promises radical transformation in various industries, including manufacturing and logistics. Amid these development, blockchain and IoT technologies and their deployment for SCM are receiving a growing amount of attention.

2.2 Food Supply Chain (FSC)

Food industry is one example of manufacturing line that relies on SCM. The efficiency of the food supply chain (FSC) is very challenging to be maintained as it involves with many stakeholders along the chain to maintain end-to-end quality control to achieve the ultimate goal, food safety for consumption. If one link in the FSC, such as a farmer or distributor is not operating well, every other link in the chain may be affected. The food industry has a lot of work to do to earn the trust and safety of consumers. The lack of information transparency and the need to enhance the security of data are two major challenges that require continuous attention. The ability of consumers to make informed decisions is limited by a lack of information, and trust is undermined by insufficient data security that exposes sensitive data [7].

Lack of data for consumers is one of the major issues faced by the food sector. Consumers frequently find themselves at a disadvantage because they lack access to accurate and reliable information on the things they want to purchase. Without transparency, consumers have to choose their foods based on limited or potentially inaccurate information as sometimes the labeling is either not sufficient or not accurate in giving actual information. Concerns about dietary choices, allergies and ethical sourcing are brought up by this knowledge gap. Consumers have a right to know what they are eating and where their food is from, and a lack of trustworthy information prevents them from making educated choices, which creates an increasing mistrust between consumers and the food business.

In addition to the information transparency challenge, the food industry also faces inherent issues concerning data security [8]. Most of the food chain applications use and rely on traditional methods of data management and storage which are proven to be inadequate. Centralized systems are vulnerable to security breaches, data manipulation, and unauthorized access [9]. From operational view, FSC involves several steps as depicted in Figure 1 that can briefly described as follows:

1) **Production**: The stage of planting crops and breeding livestock that becomes the first chain in an FSC. Activities done by farmers are like soil preparation, irrigation, fertilizing, planting, pest control, and animal husbandry.

2) **Processing:** The phase of processing raw resources into marketable products via activities like cleaning, drying, fermenting, cooking, and preserving. Food processing facilities such as factories, canneries, and slaughterhouses are involved in this stage.

3) **Packaging and labeling:** After processing, food products are packaged and labeled before distributed to the next chains. Foods are packed according to their freshness lifespan period and labelled according to information like ingredients, nutritional value, halal status, and expiry dates.
4) **Distribution and transportation:** The stage where packed products are distributed and transported to various locations including exporting to remote areas. Proper handling and storage conditions are crucial to maintain the quality and safety of the food during the traveling journey.
5) **Storage and warehousing:** Food products would require storage and warehousing areas for the purpose of safe keeping before reaching any retailer. Depending on the type of products, the storage area should provide for example appropriate temperature, humidity, and other conditions to prevent any food contamination incidence.
6) **Retail:** Food products can be purchased through various retailers such as supermarkets, food stores or even online platforms. This stage involves activities like inventory management, on the shelf display, price tagging, and quality checking.
7) **Purchasing & Consumption:** The final stage of FSC involves consumers purchasing and consuming the food products. This is when the effectiveness of quality monitoring and control can be truly evaluated because more than often, any incident of product retraction happen when the retailers receive complaint from customers.

Fig. 1. Food supply chain (FCS)

Ideally, as a recommended ethical practice throughout the entire FSC, there should be regulatory bodies, quality control surveyor, and food safety standards enforced for the purpose of guaranteeing food safety for consumption. However, the efficiency of quality control and monitoring process along the supply chains may be dampened by several factors that are discussed in the next sub-section.

2.3 Issues in Conventional FSC

The flow processes of FSC as shown in Figure 1 involve with many stakeholders who conduct different specialized tasks along the chain. Despite having possibly stringent quality control monitoring for each chain, maximum efficiency cannot be assumed in conventional FSC system. This is especially true when dealing with short period expiration date food, long distance traveling food (import-export industry), and highly sensitive food like raw meat. If one of the chains malfunctions or mishandled for any reason, it will affect the remaining chains from working in the right order [8,10]. Common issues in conventional food supply chains can be summarized as follows:

- **inefficient monitoring of product quality and safety:** the results of long and complex supply chains making the monitoring process become slow and inaccurate if not facilitated by any automation system
- **inefficient traceability and transparency of product origins and distributions:** mainly because documentation is still recorded on paper or on local system that is not shared with others
- **slow feedback response and intervention on any faulty occurrence along the chains:** the results of inadequate communication among involved stakeholders along the supply chain and inability to make cross-checking of transaction/processing history
- **food shortage and insufficiency:** the results of food distribution unfairness issue especially in remote or rural areas
- **long-distance traveling and reliance on multiple intermediaries:** may results in delay to reach destination, thus, affect food's freshness that may cause contamination and wastage. This also causes supply chain to become highly costly, making food unaffordable

These issues require multi-faceted efforts to improve FSC's transparency and traceability, reduce food wastage, increase response and intervention promptness, and improve fairness in food distribution, etc. The most promising solution by far is to create a digital transformation by transforming the traditional food supply chain into a more sustainable and resilient system [11-13]. Such transformation can be realized by the following efforts (but not limited to):

- monitoring food production quality using automation and smart system using IoT system
- enhancing efficiency, visibility, and collaboration across the entire supply chain using transparent tracing system using blockchain technology
- improve data accessibility using cloud system
- forecasting demands and environmental changes using Artificial Intelligence (AI)

Our work is focusing on creating digital transformation for FSC system by using IoT and blockchain which will be discussed in the next section.

3. Related Works

The current state of the arts on blockchain and IoT implementation for FSC can be discussed in three major angles: blockchain only, IoT only and blockchain-IoT integration.

3.1 Blockchain Implementation for FSC

Blockchain is an emerging technology for the agricultural supply chain which could monitor food quality and safety by digitally tracking data and processes of material resources with the help of IoT system. The salient features of blockchain such as immutable, transparent, decentralized, and traceable are very useful and relevant to improve the transparency of every transaction record and mobility within the supply chain. This also enables greater traceability, allowing consumers to make informed choices and verify the sustainability and ethical standards of the products they purchase. Entities in the supply chain such as product producers (i.e. farmers) and suppliers be able to identify any possible faulty in their supply chains in real-time and take actions immediately. To support quality control, blockchain also allows retailers and customers to trace the origin and the route as the products travel from the point of origin to the store. There is a strong trend toward using blockchain technology in food and agricultural supply chains to improve information security, transparency, and verification of different criteria [14-17].

There have been several real use-cases of blockchain implementation for FSC and one of the is the VeChain company, founded by Sunny Lu, the former information officer of Louis Vuitton China. VeChain [18] is a blockchain platform that specialized in supply chain management such as logistics, agriculture, pharmaceuticals, and luxury goods. They utilize the use of smart contract to track their inventory. The initiative of smart contract that they implemented to their system is they tokenize the product as it navigates through the supply chain and using RFID labels to track each step. These labels disclose the entire production history of the product. Therefore, VeChain users can access a product's entire chain history at any time. The system developed by VeChain facilitates real-time product tracking and verification throughout the supply chain. It accumulates data on factors such as temperature, humidity, location and authenticity by integrating IoT devices. This information is recorded on blockchain, guaranteeing its traceability and transparency. They improve their system by preventing counterfeiting, enhance quality control, decreasing product defects and struct confidence among supplier, manufacturer, distributors, and end consumer.

CargoCoin (CRGO) [19] is a cryptocurrency project that develop cryptocurrency and smart contract platform that designed to decentralize global trade and transport which is part of the entities in FSC. This company employs smart contract to establish a safe method for the storage and transfer of goods including food. The purpose of CargoCoin is to facilitate global communication between cargo merchants and transporter. This enables the participation of all parties engaged in the supply chain process by providing a means of transmitting, sending, receiving, approving or signing the required documentation. The international trade is made more efficient and transparent by CargoCoin's system. It digitizes and verifies shipping documentation on the blockchain, such as bills of lading and letters of credit. This eliminates the need for manual processes, minimize errors, reduces documentation, and accelerate transaction. By automating smart contract, the system enhance confidence, decrease disputes, and reduce administrative cost in the supply chain.

Since 2016, Walmart has collaborated with IBM Food Trust to digitize its food supply chain. It announces that all supplier of green vegetables will be required to transmit their data to the blockchain by September 2019 [20]. In 2018, there was a large E. coli outbreak in lettuce that affected over 200 individuals in 36 states [21]. It took 37 days to trace the origin of the food (contact the supplier, obtain paper records, and use those record to contact the company that dispatched the product to Walmart's distribution center). Blockchain has reduce the time to 2.2 seconds. Thus, this drastically reduces the likelihood of contaminated food reaching the consumer. Walmart has effectively completed two blockchain pilots using IBM's blockchain solution based on Hyperledger Fabric: pork in China and mangoes in America [22]. It is using blockchain to monitor product across 25 product lines, including dairy, processed, and meat product. By August 2018, Walmart had monitored over 4 million food packages.

In January 2018, the World Widlife Foundation (WWF) announced the project of Blockchain Supply Chain Traceability to eliminate illegal tuna fishing by tracking fish from vessel to supermarket in the fresh and frozen tuna sector of the Western and Central Pacific Region in order to improve supply chain management [23]. A Straightforward scan of tuna packaging with a smartphone app will reveal the fish's history, including where and when it was caught, and by what vessel and method. Customer will have assurance that they are purchasing legally caught tuna, and not involving slave labour and oppressive condition. As part of innovative initiative, WWF-New Zealand, WWF-Australia and WWF-Fiji have partnered with global tech innovator ConsenSys, information and communication technology (ICT) coordinator TraSeable, and tuna fishery and processing company Sea Quest Fiji Ltd. to implement a project in Fiji.

Table 1
Comparison of blockchain-based FSC use-cases

Name/Year Started	**Industries**	**System Description**	**Impact**
VeChain (VET) 2015 [18]	Logistic	- Smart Contract to track inventory - Tokenize the product as it navigates through the supply chain and using RFID labels to track each step - These labels disclose the entire production history of the product.	- VeChain users can access a product's entire chain history at any time. - Guaranteeing its traceability and transparency. - Improve their system by preventing counterfeiting, enhance quality control.
CargoCoin (CRGO) 2018 [19]	Logistic	- Smart contract to establish a safe method for the storage and transfer of goods - Facilitate global communication between cargo merchants and transporter - Digitize and verifies shipping documentation on the blockchain, such as bills of lading and letters of credit.	- Enable the participation of all parties engaged in the supply chain process - The international trade is made more efficient and transparent - Eliminates the need for manual processes, minimize errors, reduces documentation, and accelerate transaction.
Walmart 2016 [22]	Agriculture/ Food	- Digitize its food supply chain - IBM's blockchain solution based on Hyperledger Fabric - Monitor across 25 product lines, including dairy, processed, and meat product.	- Reduce the time to track product origin in 2.2 seconds. - Drastically reduces the likelihood of contaminated food reaching the consumer.
World Wildlife Foundation (WWF) [23] 2018	Agriculture/ Food	- A smartphone app that scans tuna packaging will disclose the fish's history, including where and when it was caught, as well as by what vessel and method.	- Gain consumer's assurance - Eliminate illegal tuna fishing, oppressive condition, and slave labour.

3.2 The Internet of Things (IoT) System for FSC

The Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors, actuators, and connectivity to enable objects to exchange data with the manufacturer, operator, and/or other connected devices (IETF, 2022) [24]. IoT has been playing an important role in revolutionizing agriculture field that coin the term smart agriculture or smart farming to increase profits, improve sustainability, and preserving nature., etc. With respect to its roles in FSC, IoT system is utilized as an automated system in several chains whereby smart agriculture, smart animal husbandry, smart food factories, and distributors benefit from digital monitoring of IoT in all aspects of food production, processing and transportation with the help of RFID technology and other sensing devices for automated quality inspection and abnormality alerts.

IoT devices have the potential to be utilized for the purpose of monitoring the state of agricultural commodities. For example, monitoring and control of planting water and animal feed, an inspection of vegetable sunlight hours and livestock movement steps, temperature and humidity monitoring of food processing and transportation environments, etc., not only provide quality inspection for consumers but also automate scientific planting, feeding, and food processing. Sensors have the capability to gather information pertaining to various environmental factors such as temperature, humidity, light exposure, acidity level, among others. The timely detection of any form of contamination or abnormality is crucial for the implementation of appropriate intervention measures such as in the works done by (Yang *et al.*, [25]; Kim *et al.*, [26]; Ramli *et al.*, [27]).

IoT system also provides tracking ability to monitor movement. RFID tags can be attached to packages or containers to track the location of the farm products along the supply chain or attached to animals for livestock tracking to assess animal health and anticipate overall production capability. Many current implementations have been integrating IoT with Artificial Intelligence (AI) technologies for precision agriculture using robots, drones, sensors, and computer imaging. Integrated with analytical tools and supported with cloud system, the data is analyzed to obtain accurate insights of the real-time conditions [28,29].

3.3 Integration of Blockchain and IoT (B-IoT) for FSC

After the emergence of blockchain technology, many researchers have focused on the integration of IoT and blockchain technology. Many innovative applications and research have been invested in the fields of food security and FSC, which is expected to provide automated and trustworthy solutions for FSC visualization and traceability, improving the security and efficiency of FSC. These innovative applications have cases in fields such as planting, animal husbandry, and fisheries.

Tian *et al.,* [30] proposed an FSC traceability system based on blockchain, IoT, Hazard Analysis and Critical Control Points (HACCP) for farming sector named as BigChainDB. This system focuses on plant agricultural products and utilizes IoT technologies such as RFID, WSN, and GPS for data collection and transmission. These data include crop growth such as water, fertilizer, pesticide application, sunlight, processing, and additives, as well as transportation and quality assurance of the cold chain. These data can serve various aspects of FSC based on predetermined hazard control key points, reduce food security risks, and help track defective products in the event of food security incidents. Considering the scalability and efficiency of the system, BigChainDB is used to store and manage data, achieving data sharing across untrusted participants. Unfortunately, the article only described the implementation of the model and did not provide an in-depth analysis of performance details. Caro *et al.,* [31] proposed a fully decentralized AgriBlockIoT solution based on IoT and blockchain for the traceability management of agricultural FSC. It consists of 10 modules capable of collecting data and tracking food quality based on an extracted list of requirements along the FSC from farm to fork using IoT devices. AgriBlockIoT was deployed and performance compared on Ethereum and Hyperledger Sawtooth, respectively, but failed to extend deployment and performance analysis to resource-constrained IoT devices and there is little description of deployment size and other parameters.

Other than agriculture sector, there has been B-IoT efforts carried out for animal husbandry. Cao *et al.,* [32] established a traceability system for cross-border beef supply chains between Australia and China by integrating multiple signature rules, proof of authority protocols, and human-machine coordination mechanisms based on the original BeefLedger to connect beef supply chain stakeholders. The system has been technically designed on Ethereum and can provide text, image, and one-minute short video traceability services. However, the current testing of the system has not fully covered all participants and stakeholders in the cross-border supply chain, and the test sample is relatively small, which is prone to biased reactions. Bytable Inc. worked with chicken farms and egg packers in the Midwest of the United States to establish an egg supply chain traceability system. Where eggs are collected at the farm, then packaged and transported, and the entire process uses sensors for automatic data collection, generating transactions, and storing them in an immutable blockchain system to enhance consumers' trust in egg traceability information. The system is proof-of-concept research.

The integration of B-IoT has also been implemented for sustainable fisheries development. A pilot project in Indonesia by Kshetri [33] has successfully tracked fish in Indonesia using cell phones, IoT smart tags, and blockchain technology. This project explores solutions to issues such as overfishing, corruption in the up-market fish industry, and inaccurate reporting data. It is expected to help consumers track fish sources and provide transparency in the fish and seafood supply chain. In addition, the Sustainable Shrimp Harvesting Partnership (SSP) has a joint project with the IBM Food Trust, which includes the participation of five shrimp farms in Ecuador. The project is enhancing the monitoring of fish and shrimp product quality and promoting a sustainable and healthy fishing environment by recording all data from the shrimp production process through IoT and blockchain technology and opening up farm-to-table information for all retailers [34].

4. The Proposed B-IoT Integration Framework

Although B-IoT offers many benefits to the food supply chain management, its effective implementation seems challenging for the numerous involved organizations. Several frameworks on integrating IoT with Blockchain for food supply have been proposed in existing works, however, the tradeoff of the integration, such as scalability, privacy and interoperability issues are not looked into and ideal implementation of consensus mechanism is assumed [8,15,16,35]. The architecture and planning of a B-IoT network for the food supply chain of diverse applications are very challenging which is why until recently, there have not been many works that have been able to demonstrate a fully functioning B-IoT integration in food supply chain. Current active research that has been conducted focusing more on conceptual model before the real implementation takes place [12,36].

The integration of B-IoT in food supply chain requires the establishment of governance frameworks or models, standards, and protocols to ensure compliance, accountability, and trust. To date, there is a lack of framework that shows how IoT and Blockchain could be integrated for supply chain management system in an efficient functional way. Defining industry-wide standards for the B-IoT integration is a challenging task, which has become the goal of this work by proposing a framework on B-IoT integration for FSC that could be adopted as a standard reference.

4.1 Common Framework

IoT and blockchain are widely used in the food industry to provide automated and trusted solutions for food safety visualization and traceability. Figure 2 shows a common framework of B-IoT integration for FSC. The IoT system acts as a physical flow that contributes analyzed data from different entities in the supply chains to digital flow and blockchain network. Through a combination of cameras, various sensors, poultry-specific smart anklets, and ear tags, data such as site video, geographical location information, environmental information, and movement steps are collected from raw material providers and production factories at any time and uploaded to the blockchain for storage. The data is aggregated to the cloud, analyzed, and calculated to provide consumers with easy access and end-to-end visualization of food traceability through the application layer. As a results, all participants in the food traceability process, such as raw material providers, producers, distributors, retailers, and consumers, are mutually authenticated and may act as participating nodes in the blockchain. All operations are recorded on the blockchain in the form of transactions and blocks that are inaccessible to illegal users, the original data is immutable, and the operations are auditable, providing the food industry with decentralized food safety traceability services and data security assurance, thereby increasing commodity transparency and consumer confidence.

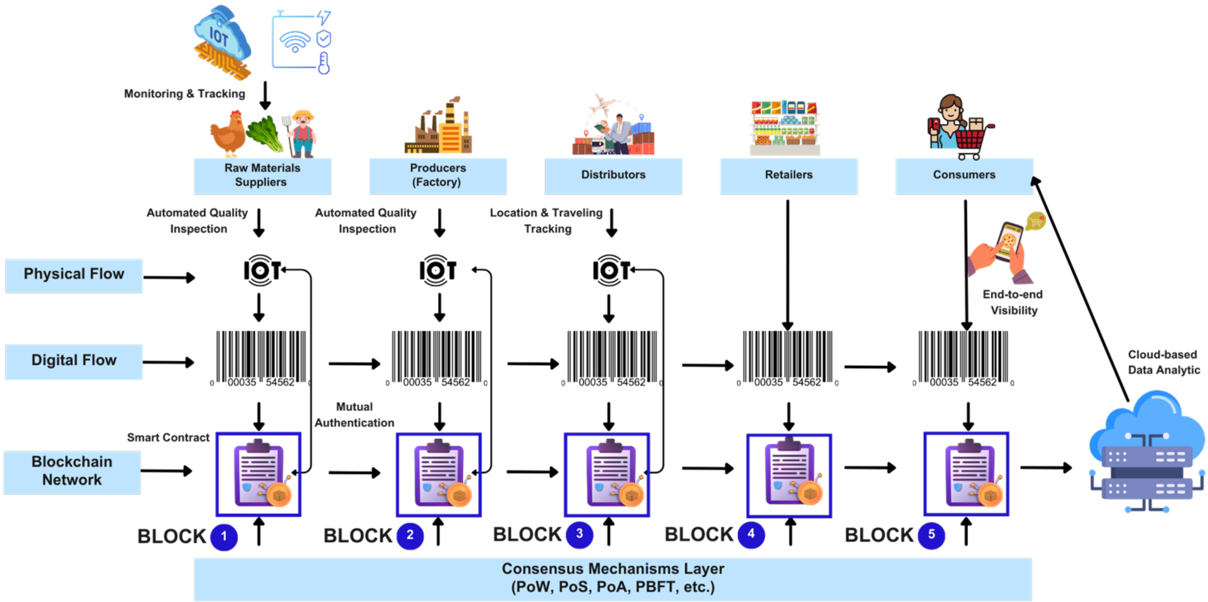

Fig. 2. Common framework of B-IoT integration for FSC (modified from [37])

4.2 Lightweight and Dynamic B-IoT Integration Framework

Blockchain networks rely on a consensus mechanism to validate and verify transactions. Classical consensus algorithms, such as proof-of-work (PoW) or proof-of-stake (PoS), have been used by organizations that involved in the food supply chains. Each organization may adopt different consensus mechanism that is well-suited with the nature of their productions, but this may result in interoperability issue along the supply chain. Implementing sole consensus among the different stakeholders is very challenging because the need for flexibility for different kind of applications is high. There is a need to propose a lightweight and dynamic model that is likely to solve the issue of interoperability.

This work proposes a model to create a lightweight and dynamic consensus mechanism layer that allows multiple different consensus algorithms to run on the same platform as depicted in Figure 3. The meta consensus algorithm component acts as a dispatcher for all transactions and group them into blocks of shards that have been aggregated according to similar consensus algorithm used which offers the lightweight element. The level of dynamic consensus can be observed from multiple heterogeneous groups that are processing transactions with different consensus algorithms able to be regrouped into 1 shard block of 1 consensus algorithm type. A dynamic approach would be more well-suited for application like food supply chain that involves with different stakeholders that rely on different consensus mechanisms. This dynamic algorithm combines the decisions or outputs of multiple underlying consensus algorithms to reach a unanimous agreement.

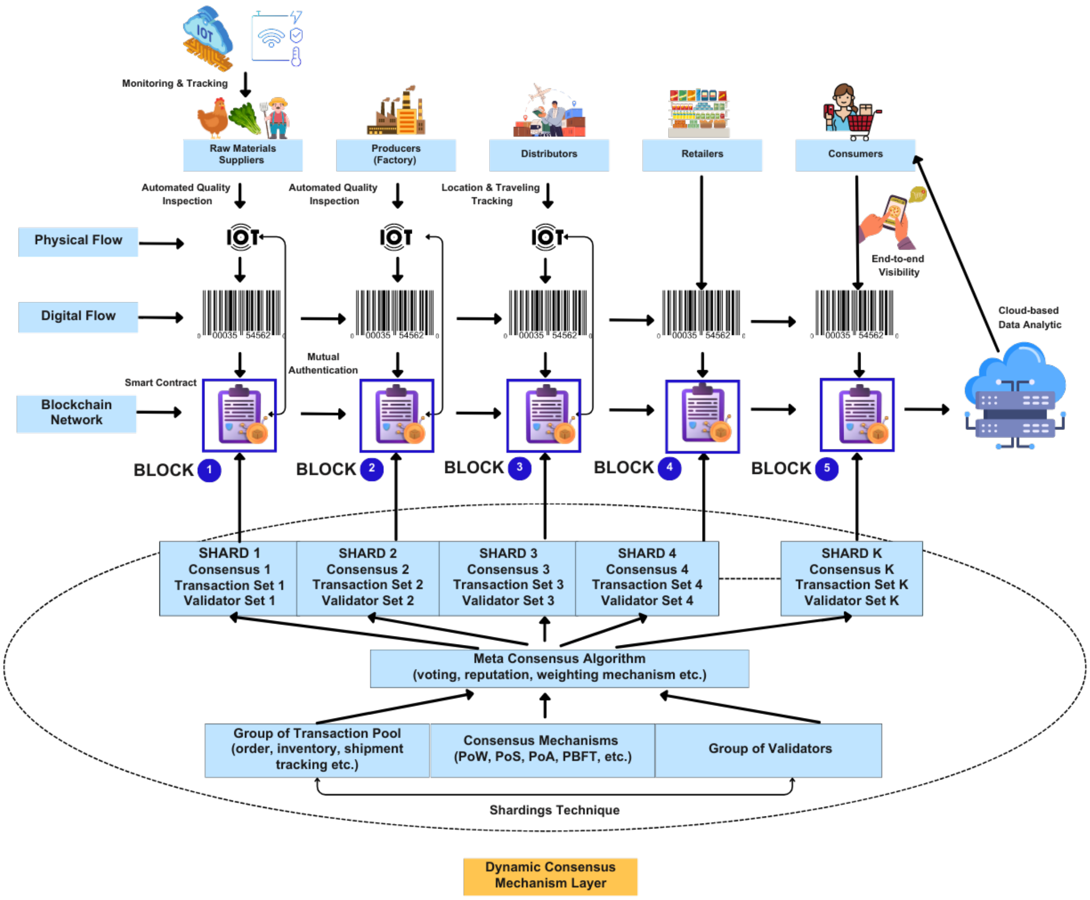

Fig. 3. Lighweight and dynamic B-IoT integration framework using meta consensus algorithm

The sharding technique used for this framework is based on our design that provides the lightweight and dynamic elements in the consensus mechanism. In the proposed sharding technique, not only the reputation mechanism is introduced to reduce the probability of aggregation of bad nodes in network sharding, but also some measures are taken to perform balanced transaction allocating and cross-shard transactions reducing, these measures include: account grouping, account moving, cross-shard transaction splitting, and transaction group allocation. First, all the transactions will be collected to the transaction pool, and a subset of transactions, Tx-Set, is taken from the pool in order of priority to prepare for transaction sharding. Then, a transaction association graph is drawn based on Tx-Sets and accounts, and accounts and transactions are grouped using graph partitioning or clustering algorithms. Meanwhile, the grouped accounts are assigned to shards ensuring that each accounts group is mapped to one shard. Moreover, the cross-shard transactions are split into multiple source and destination transactions, and all destination transactions need to wait for a confirmation message as a succeed of the source transaction before proceeding. Finally, according to the result of transaction grouping and cross-shard transaction splitting, transaction allocation is performed, and intra-shard consensus is initiated. For each epoch, after completing network sharding, transaction sharding and consensus, the committee will be reorganized and move on to the next epoch.

It is necessary to fully consider the resource-constrained and heterogeneity of IoT devices in the network sharding process, and all devices are divided into light nodes (sensor devices with extreme resource constraints, which only generate data and cannot participate in the blockchain) and blockchain participating nodes (mainly are devices of different stakeholders in the FSC). The sharding technique enables parallel work of blockchain, thus is expected to improve the efficiency of the FSC traceability system.

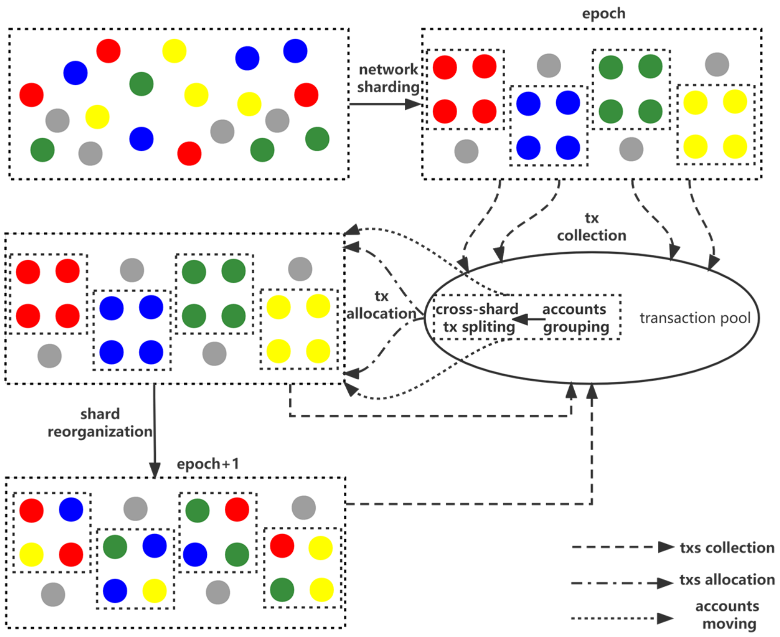

Fig. 4. Sharding technique

5. Conclusion and Future Direction

This work proposes a framework of the integration of blockchain with IoT (B-IoT) to improve the reliability of food supply chains by focusing on optimizing the consensus algorithm of blockchain. The expected outcome is to produce an efficient traceability and higher quality transactions which can integrate all different procedures and transactions, and dealings in real-time across the food supply chain. The work presented here is on the phase of designing the conceptual framework where it is hoped that it could become a general guideline that may be adopted as a standard reference across multi-organizations. As part of our next direction, we plan on simulating the proposed framework to assess its efficiency in increasing the scalability and interoperability of processes in food supply chain. The performance metrics that will be measured: latency, transaction rate, throughput, and number of joining nodes (scalability and interoperability). We will also be extending this work by developing a mobile application where a consumer can scan the QR code of a particular product and view the product information such as its origin, production methods, halal status and certifications which are provided by the blockchain network. This provides transparent traceability of the product information and fosters consumer trust in the food product's authenticity and quality.

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