Blockchain and IoT based Food Traceability for Smart Agriculture

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ABSTRACT

[1]Food safety is becoming more and more serious topic worldwide. To tackle the food safety issues from the technical aspect, people need a trusted food traceability system that can track and monitor the whole lifespan of food production, including the processes of food raw material cultivation/breeding, processing, transporting, warehousing, and selling etc. In this paper, we propose a trusted, self-organized, open and ecological food traceability system based on blockchain and Internet of Things (IoT) technologies, which involves all parties of a smart agriculture ecosystem, even if they may not trust each other. We use IoT devices to replace manual recording and verification as many as possible, which can reduce the human intervention to the system effectively. Furthermore, we plan to use the smart contract technology to help the law-executor to find problems and process them timely.

CCS CONCEPTS

• **Security and privacy → Security services**

• **Networks →** Network services

KEYWORDS

Blockchain, Internet of Things, LPWAN, Edge Computing, Food Traceability, Smart Agriculture

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1 INTRODUCTION

In recent two decades, with the rapid development of the economy and the continuous improvement of people's living standards, food safety has gradually become the focus of attention and has been developed into a worldwide problem. Examples include the outbreak of the Mad Cow Disease at United Kingdom in 1996, the Avian Influenza at Hong Kong in 1997, the Pig Encephalitis at South East Asia in 1998, the Foot-and-Mouth Disease at Europe in 2001, the SARS at Hong Kong in 2003, the Sanlu milk scandal at China in 2008 and the global pandemic H1N1 flu in 2009, etc. These food safety incidents made people feel worried. Some people even feared that all animal food may have hormone and all plant food may have toxins and colorant. This fear may be overdone, but it also reflected many problems in the current food production, supply chain and processing environment.

We summarize some causes of these problems as follows:

1) The common use of chemical fertilizers, pesticides and other substances in some of the vegetables, fruits. In agricultural production, some vegetable farmers and fruit growers often use toxic or even highly toxic pesticides to spray vegetables and fruits in order to increase their income. This directly leads to excessive

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pesticide residues in vegetables and fruits. Such vegetables and fruits will certainly be taken by consumers. It is a great health hazard.

2) Heavy metal contamination in food. Due to the illegal removal of waste water by some industrial and mining enterprises in the city or countryside, the drinking water source of human and livestock, as well as the irrigation water source of crops in some areas are polluted by excessive intrusion of heavy metal elements, such as lead, tin, mercury, and zinc etc., which is harmful to human health. When drinking water and agricultural foods contaminated with these heavy metal elements enter the human body, they will cause great harm to people's health. In addition, some packaging papers, packaging bags, and stainless steel utensils used to hold food are also important sources of heavy metal pollution such as lead, chromium, and nickel. Once these heavy metals are infiltrated into food, they will be accumulated and pose a great potential threat to human body.

3) The use of inferior raw materials in the manufacturing and processing of food poses a great risk to food safety. Examples include processing cooked meat products from sick poultry and livestock, processing fried foods with illegally recycled waste cooking oil, and "water-injected pork" (supplying water to pigs is equivalent to poisoning, and it is extremely harmful to the human body after eaten). If these inferior raw materials with safety hazards are not totally destroyed in time, they may evolve into food safety accidents that endanger the health of consumers.

4) Excessive use of food additives and other chemical products in food processing. Some black-hearted enterprises and commercial households are driven by money for business. In the process of food production, they often use food additives, antibiotics, and hormones in excess quantities, and even add toxic and hazardous chemicals. In order to pursue profits, some food producers ignore the protection of consumers' lives and right to health, illegally use and add chemical substances beyond the scope of food laws and regulations. Examples include adding an ultra-fine amount of brightener "benzoyl peroxide" in flour; using synthetic chemical sweeteners in beverages to exceed the limit; using steamed bread to make steamed buns; using mineral oil to brighten rice and biscuits; and soaking sea products with formaldehyde to make it tough, brightens, and to extend shelf life etc. Other chemical products such as malachite green, sudan red, melamine that are too hard to see, touch, smell, and taste by ordinary people, which can lead to food poisoning, chronic diseases and even death, are also used in some food. In addition, hormones and other drugs are abused in crop farming and aquaculture to increase production and to mature fruits, vegetables, poultry, livestock, and aquatic products in shorter term. For example, sharp-edged tomatoes, hard kiwifruit, hypertrophy sprouts, etc. may all be the result of using hormones to promote long maturation. This practice not only significantly reduces the nutritional value of the cultivated product, but also brings great harm to the health of consumers.

To tackle these problems from the technical aspect, people need a food traceability system that can track and monitor the whole lifespan of food production, including the processes of food raw material cultivation/breeding, processing, transporting, warehousing, and selling etc., which involve a large number of untrustworthy business parties. In this paper, we propose a blockchain and LoRa IoT technology based food traceability solution, which integrates trustworthy blockchain verification mechanism and tamper-proof advantage into the low-power wide-area network (LPWAN) IoT system, such as LoRa/NB-IoT based smart agriculture system. We believe that this integration will help people to improve the food safety status.

2 RELATED WORK

Smart agriculture is the application of technologies such as Internet of Things (IoT), Big Data, Global Positioning System (GPS), Cloud Computing, and Artificial Intelligence (AI) etc. into traditional agriculture. The use of intelligent agricultural IoT platform, through a large number of sensing nodes in the target areas, such as farmland, greenhouses, forest gardens, pastures, can collect the information of agricultural breeding or planting in real-time. Such information like temperature, humidity, light, gas concentration, soil moisture, electrical conductivity, and production images during production, processing, transportation, and sales process, are aggregated into the cloud based central control system for study or analysis using AI algorithms. Agricultural production personnel can analyze environmental big data through monitoring pests and diseases and various risk factors, so that targeted agricultural production materials can be put in place; various execution equipment can be mobilized as required to perform temperature control, dimming and ventilation, as well as other actions to achieve intelligent control for the growing environment of agriculture. Smart agriculture is an innovative way of carrying out farming activities by reducing human efforts and by making maximum utilization of the available resources. It can solve the problem of shortage of agricultural workers, improve the ability of agricultural production to resist risks and help small, weak farmers to produce large-scale network and intelligent transformation. The use of sensors, gateways, cloud servers, etc. to control agricultural production through mobile platforms or computer platforms will make traditional agriculture more "wisdom". In addition to precise perception, control and decision-making management, in a broad sense, smart agriculture includes agricultural e-commerce, food traceability and anti-counterfeiting, agricultural leisure tourism, and agricultural information services.

The rest of this section will review the related work on different methods, technologies and applications for smart agriculture and food safety.

2.1 IoT framework for Smart Agriculture

In paper [1], based on Material Conscious and Information Network (MCIN) model, authors proposed a method to design the MCIN-based architecture for smart agriculture, which is different from current vertical architecture and involves production, management and commerce. The architecture is composed of three participants which are enterprises, individuals and commodity. It uses enterprises and individuals personalized portals as the carriers which are linked precisely with each other through a peer-to-peer network called six-degrees-of-separation block-chain. The authors want to establish a self-organized, open and ecological operational system which includes active, personalized consumption, direct, centralized distribution, distributed production for smart agriculture. The authors think that new architecture improves current agriculture greatly and inspire a lot in production-marketing-combined electronic commerce.

In paper [2], authors studied the realization of IoT in the field of agriculture, including a comprehensive review of its framework, considerations and implications in implementation. The paper intends to brief the reader about the IoT technology and its operational requirements in agricultural practices. Some real-world examples about the working of agriculture IoT are discussed. The result shows that the use of IoT in the fields and orchards will help the farmers reap the benefits of its technology manifold.

In paper [3], authors surveyed some typical applications of Agriculture IoT Sensor Monitoring Network technologies using Cloud computing as the backbone. This survey is used to understand the different technologies and to build sustainable smart agriculture. Authors think that precision agriculture sensor monitoring network is used greatly to measure agro-related information like temperature, humidity, soil PH, soil nutrition levels, water level etc. so, with IoT farmers can remotely monitor their crop and equipment by phones and computers.

In paper [4], authors reviewed state-of-the-art communication architectures for the Internet of underground things (IOUT), which consists of sensors and communication devices, partly or completely buried underground for real-time soil sensing and monitoring. An underlying sensing technology and communication mechanisms for IOUT are presented. Recent advances in the theory and applications of wireless underground communication are also reported. Major challenges in IOUT design and implementation are identified.

2.2 IoT based Intelligent Irrigation

In paper [5], authors proposed a design of a smart IoT communication system used as a low cost irrigation controller. The proposed irrigation tool uses real time data such as the variable rate irrigation and some parameters taken from the field. The field parameters, the index vegetation (estimated using aerial images) and the irrigation events, such as flow level, pressure level or wind speed, are periodically sampled. Data is processed in a smart cloud service.

In paper [6], authors proposed a novel fuzzy computational algorithm for IoT smart irrigation systems. It describes all the possible sensors, actuators and microcontrollers that could be used in the irrigation systems. The irrigation system continuously monitors air temperature, humidity, and ground moisture. The ground humidity sensors are interspersed all over the field. The measurements are sent into a microcontroller that applies a fuzzy computational algorithm and decides whether to open a servo valve or not. All the data collected from the microcontroller are sent to a cloud database for statistical information and processing.

In paper [7], authors also proposed an IoT application, named "Smart Irrigation Analysis", which provides remote analysis of irrigation on the field to the end user that is better than traditional irrigation of crop on field. Smart irrigation application has an automated recurring watering schedule, sensing and analysis of water used for crop and the moisture level given real time data. They use ESP8266 Microcontroller with built-in Wi-Fi module. Soil Moisture sensor is set in the field, which keeps track of moisture level in field soil. The collected data are sent over cloud to make people's nurturing activity pleased and tranquil. Data from the cloud is analyzed and irrigation related graph report for future use for farmer is made to take decision about which crop is to be sown.

In paper [8], authors proposed a LoRa based smart irrigation system. The irrigation node is mainly composed of LoRa communication module, solenoid valve and hydroelectric generator. The irrigation node sends data to cloud through LoRa gateways via wireless transmission. The system can be controlled remotely by mobile applications. Their experimental results show that both transmission distance and energy consumption in the proposed system are reliable.

2.3 Blockchain for Internet of Things

In paper [9–10], authors proposed a blockchain built-in solution for LoRaWAN network servers to build an open, trusted, decentralized and tamper-proof system, which provides the indisputable mechanism to verify that the data of a transaction has existed at a specific time in the network. They think it is the first work that integrates blockchain technology and LoRaWAN IoT technology, and utilizes advantages of both.

In paper [11], authors purposed a proof of concept to enable low-power, resource-constrained IoT end-devices accessing a blockchain-based infrastructure. To achieve this aim, they designed an IoT gateway as a blockchain node and proposed an event-based messaging mechanism for low-power IoT end-devices. A demonstration of such a system was implemented using LoRa nodes and gateway in a private ethereum network.

In paper [12], authors discussed the integration of the blockchain with the IoT with highlighting the integration benefits and challenges. They think that moving the IoT system into the decentralized path may be the right decision. The blockchain is a powerful technology that is able to decentralize computation and management processes that can solve many of IoT issues, especially security.

2.4 Blockchain for Smart Agriculture

Blockchain technology has been applied in smart agriculture. Even UN FAO also recommended that ICT (Information and Communications Technology) e-agricultural infrastructure components are a confluence of ICT and blockchain technology requirements. They think that when ICT e-agricultural systems with blockchain infrastructure are immutable and distributed ledger systems for record management, baseline agricultural environmental data integrity is safeguarded for those who participate in transparent data management. In paper [13], authors reviewed blockchain-based concepts associated with ICT-based technology. Moreover, they proposed a model ICT e-agriculture system with a blockchain infrastructure for use at the local and regional scale.

In paper [14], authors proposed a lightweight blockchain based architecture for smart greenhouse farms to provide security and privacy. The IoT devices in greenhouses which act as a blockchain managed centrally to optimize energy consumption have the benefit of private immutable ledgers. In addition, they presented a security framework that blends the blockchain technology with IoT devices to provide a secure communication platform in Smart Greenhouse farming.

2.5 Smart Food Monitoring/Traceability System

Traceability is very important in the food supply chain to ensure the consumers' food safety. In recent years, many solutions with various emerging ICT technology have been proposed to improve the traceability of animals, plants, and food products.

In paper [15], authors proposed a RFID-enabled traceability system for live fish supply chain. The system architecture is designed according to the specific requirement gathered in the life fish processing. Likewise, it is adaptive for the small and medium enterprises. The RFID tag is put on each live fish and is regarded as the mediator which links the live fish logistic center, retail restaurants and consumers for identification. The sensors controlled by the PLC are used to collect the information in farming as well as the automatic transporting processes. The traceability information is designed to be exchanged and used on a web-based system for farmers and consumers. The system was implemented and deployed in the live fish logistic center for trial, and the results are valuable for practical reference.

In paper [16], the author proposed an agro-food supply chain traceability system that utilizes the RFID (Radio-Frequency IDentification) and blockchain technology. He analyzed the advantages and disadvantages of using RFID and blockchain technology in building the agro-food supply chain traceability system and demonstrated the building process of this system. He thinks it can bring the traceability with trusted information into the entire agro-food supply chain, which would effectively guarantee the food safety, by gathering, transferring and sharing the authentic data of agro-food in production, processing, warehousing, distribution and selling links.

In paper [17], authors presented their experimentation and implementation journey to open source IoT for cows tracking. They proposed a LoRaWAN architecture for long range communications and analyzed the high level system architecture for cattle tracking. Furthermore, they also developed and presented the design of software application and protocol.

In paper [18], authors proposed a new approach that lead to trusted cooperative applications and services within the agro-food chains. They used blockchain to enhance the transparency, information flow and management capacity allowing better interactions of farmers with other part of supply chain, especially the consumer. They think the research will provide better performing value chains by proposing new food-on-demand business model, based on new Quality of Experience (QoE) food metrics, bridging the gap between subjective experience and objective metrics based on quality standards.

In paper [19], authors proposed a decentralized, blockchain-based traceability solution, named AgriBlockIoT, for Agri-Food supply chain management, which is able to seamlessly integrate IoT devices producing and consuming digital data along the chain. They defined a classical use-case within the given vertical domain, namely from-farm-to-fork, and developed and deployed such use-case, achieving traceability using two different blockchain implementations, namely Ethereum and Hyperledger Sawtooth. Finally, they evaluated and compared the performance of both the deployments, in terms of latency, CPU, and network usage, by highlighting their main pros and cons.

3 PROPOSED METHOD

3.1 Blockchain and IoT based Smart Agriculture Ecosystem

The above research work show that the applications of IoT and blockchain technologies can bring smart agriculture and food traceability system many benefits, but most of them are ad hoc solutions for one function or some specific aspects. In this paper, we propose and design a general blockchain and IoT based smart agriculture ecosystem as shown in Fig. 1.

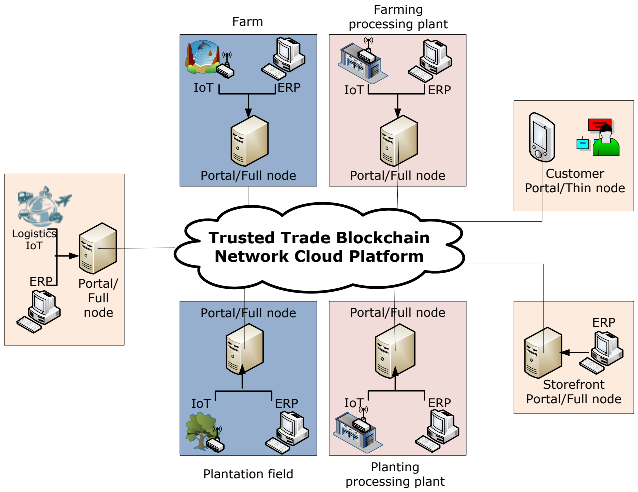

Figure 1: Blockchain and IoT based Smart Agriculture Ecosystem.

Our ecosystem involves the traditional ERP (Enterprise Resource Planning) legacy system and a new IoT system. Farm companies, farming processing plants, plantation companies, planting processing plants, logistics companies and food retail storefronts as well as the customers can use their smart mobile phone as a portal or blockchain thin node to access the data stored in the chain. The core of the whole architecture is a virtual Trusted Trade Blockchain Network Cloud Platform (TTBNCP), which can help us to establish a trusted, self-organized, open and ecological smart agriculture application system.

3.2 Blockchain System Architecture

The virtual TTBNCP consists of all portals in the smart agriculture ecosystem physically as shown in Fig. 2. Those portals are also nodes of blockchain Peer-to-Peer (P2P) system. There are two types of nodes in the system: one is equipped with full functionalities of blockchain node, such as symmetric encryption and decryption, consensus algorithm, Merkle trees building, distributed ledger, etc.; another is the thin node that is just a simplified payment verification (SPV) node with simplified payment verification function and stored transaction related data.

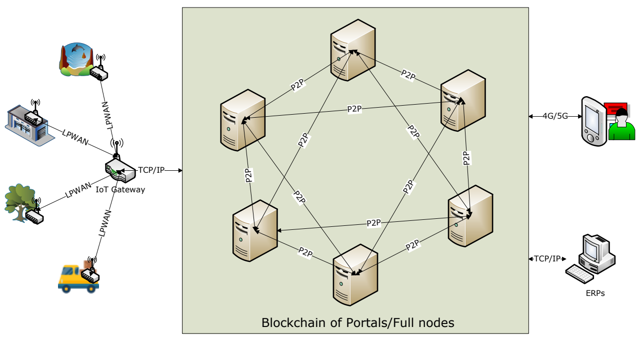

Figure 2: Blockchain System Architecture.

3.3 Data Processing Flow and Structure

There are two types of transaction data that will be stored in the blockchain, as shown in Fig. 3: one is that generated from traditional ERP legacy systems, such as the trade, logistics, delivery, warehousing information etc.; another is that generated from IoT devices, such as the air temperature, air humidity, soil PH, soil nutrition, ground moisture data etc. After hashing and digital signing, those data will be sent to the entire nodes of blockchain system directly or through the IoT gateways, where they will be verified, added into transaction pool, and stored into blockchain.

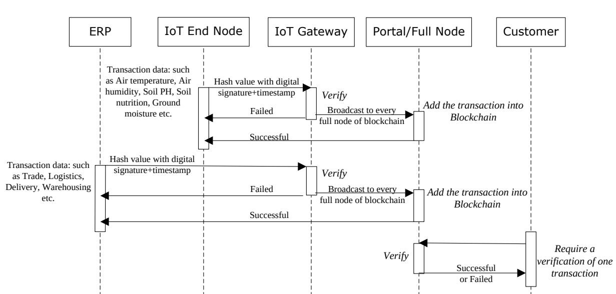

Figure 3: Transaction Data Process Flow.

Customers can use their computers or mobile phones to retrieve all transaction data and verify them. For example, one buys a box of milk from a supermarket, and then he/she can use a smart phone to scan the 2-D barcode to retrieve all transaction data related to it, including which farm the milk was produced from, on which day and time it was produced, the ID of cow in the farm, the ID of the staff who collected the milk, collecting device information, packaging information, all the temperature and other environment data for the milk's production, process, logistics, storage etc. All those information can be verified by the blockchain system without the human intervention.

Fig. 4 shows a sample of the blockchain data structure.

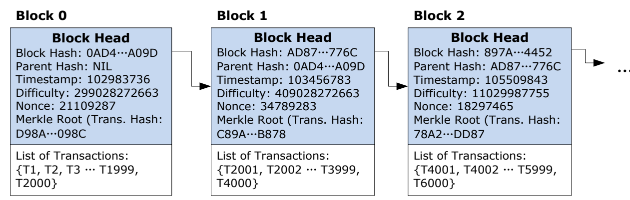

Figure 4: Blockchain Data Sample.

4 CONCLUSION

In summary, blockchain and IoT technologies can help us to build a trusted, self-organized, open and ecological smart agriculture system, which involves all parties in the ecosystem, even they may not trust each other. To the best of our knowledge, this is the first work that applying blockchain technology and IoT technology on traditional smart agriculture ecosystem to solve the food safety issues. The proposed method tries to use IoT devices instead of manual recording and verification, which reduces the human intervention to the system effectively. In the future, we also can use the smart contract script technology to define a set of automated warning code in the system, to help law-executors to find problems and process them timely.

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