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Towards an IoT and Blockchain-based System for Monitoring and Tracking Agricultural Products

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Abstract

This paper presents the design and implementation of a monitoring and data collection system for agricultural product preservation during transportation to meet authenticity and traceability requirements. The system is built and performed using blockchain and Internet of Things (IoT) technology to use and integrate their benefits. This system comprises a private blockchain network built on the Ethereum platform and powered by the GoQuorum protocol, which enables distributed data exchange among members using a common protocol and cryptographic techniques while ensuring the transparency and integrity of the information. A wireless sensor network has been designed and implemented for collecting data from sensors about the storage environment of agricultural products. This study also proposes using LoRa technology to build low-cost wireless communication networks with broad coverage for data collection from sensor nodes mounted to agricultural products. Furthermore, the integrated online map web assists in real-time monitoring and tracing of information on the process of transporting agricultural products, as well as querying data for completed contracts. Experiments were conducted close to the reality of the application's desire to deploy the system to calibrate and evaluate the functioning, with promising results.

Keywords: blockchain, Internet of Things, LoRa technology, tracing products, wireless sensor networks.

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1. Introduction

Vietnam has recently been a country with rapid economic development, industrialization, and urbanization, but with many negative consequences for the environment and people's health. In this regard, the problem of farming and consuming contaminated food affects not only the country but the entire world. Excessive fertilizer use, incorrect pesticide use, polluted irrigation water, and agricultural product storage, processing, and transportation that do not meet food safety standards are the main causes of contaminated agricultural products [1-3].

To solve the above problem from a technical perspective, a commodities traceability system that can track and monitor the entire process, including cultivation, processing, transportation, storage, and distribution, must tackle the above problem. It assures that the three parties involved farmers, transporters/distributors, and consumers have access to public, transparent, and high-security information [4]. There are now many systems based on the Internet of Things (IoT) that collect real-time quality characteristics in each stage of production using sensor nodes, a cloud database, radio frequency identification (RFID), and a quick response code (QR code) [5-7]. However, these systems are ineffective, owing to a lack of confidence between participants in the access chain, as well as a lack of secure and effective information and output data management throughout the product lifecycle. Centralized databases, in particular, are vulnerable to manipulation and lack transparency. To help solve this problem, this article recommends deploying a system for agricultural goods traceability in the transportation process based on blockchain and long-distance wireless data transmission technology with low power consumption (named LoRa technology).

With the impressive success of the Bitcoin cryptocurrency, blockchain is a technology that has received the most attention recently and is being applied in many areas of life besides the financial sector [8]. A blockchain is a decentralized database that stores data in blocks and connects them using highly secure

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cryptography. The blockchain keeps track of all transactions, and anybody on the network can view and verify the accuracy of those transactions. There is no way to erase or alter a transaction once it has been confirmed and saved on the blockchain. The issue of participant trust is resolved with blockchain technology [9]. Blockchain technology promises to provide a reliable source of data about the entire manufacturing process, fostering trust between producers and consumers. Along with the rapid development of electronic devices and wireless communication technologies capable of transmitting data over long distances, low power consumption enables the large-scale deployment of distributed sensor networks while lowering maintenance costs. One of them is Semtech's LoRa technology, which has been used in environmental monitoring applications, smart cities, and so on. This technology enables the transmission of data via wireless connections over distances of several kilometers in urban areas and tens of kilometers in rural areas [10, 11], making it well suited to assist in monitoring and data collection related to agricultural product preservation during transportation.

The use of blockchain and LoRa technologies in agricultural product traceability will boost product value, make the agricultural industry smarter, and play a key role in ensuring the safety of agricultural products in supply chains. This study designs and implements a support system to monitor and collect information on the preservation of agricultural products during transportation to provide authentic and reliable information to parties involved in the authentication and traceability of goods requirements. Furthermore, the system's use of long-range, low-power wireless communication technology allows it to deploy the sensor network over a few square kilometers and keep it operational throughout the delivery process. Next, Section 2 presents the system design steps. The results of implementation and experimental verification of the system's operation are detailed in Section 3. In Section 4, the authors will summarize the results achieved and present directions to apply and enhance the system.

2. System design

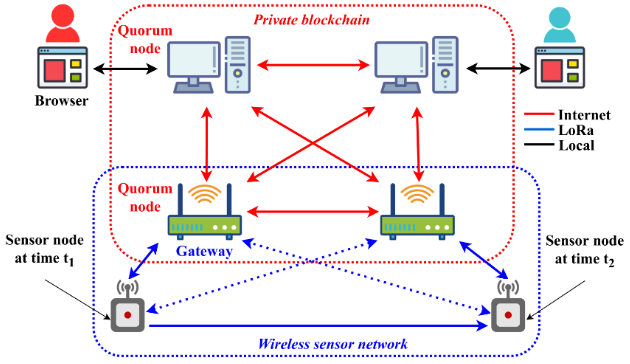


Figure 1. The proposed system overview

The major components of the system are a private blockchain network built on the GoQuorum protocol [12] and a wireless sensor network (WSN), as well as a web interface and map widget for the user application, as shown in Figure 1. The private blockchain network has four quorum nodes, two of which operate on a computer and two of which run on a Raspberry Pi embedded computer. Each sensor node reads sensor data, GPS coordinates, and receives and responds to requests from the gateway in a wireless sensor network made up of two sensor nodes and two gateways. The Raspberry Pi embedded computers serve both as an active node in the blockchain network and as a gateway that controls operations in the wireless sensor network.

A wireless sensor network with two gateways and two sensor nodes is depicted in this diagram (see Figure 2). During the delivery process, the sensor nodes attached to the goods will move, whereas the gateways will be located at specific locations. The sensor node is managed by the gateway that is within range. When a sensor node moves across different gateways' coverage areas, link quality (RSSI values) is used to identify which gateway controls the sensor node.

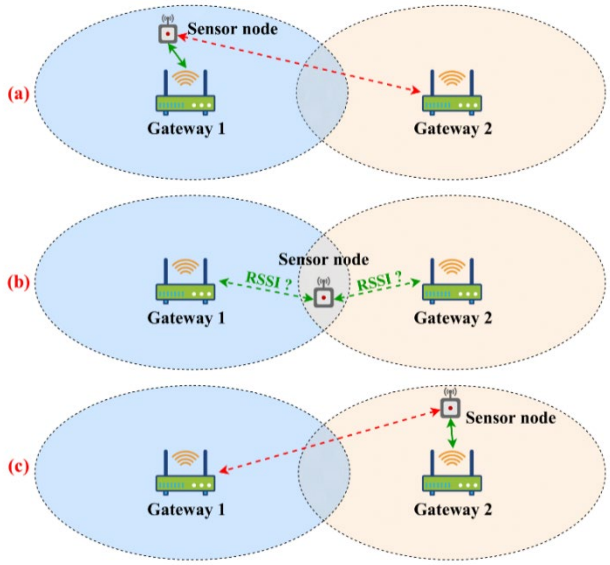


Figure 2. The handover model manages mobile sensor nodes over time

Figure 2(a) depicts the sensor node at time t1 in the coverage area of gateway 1 (represented by the blue ellipse) and outside the coverage area of gateway 2 (shown by the orange ellipse). As a result, a link will be created between the sensor node and gateway 1 (green arrow), but not between the sensor node and gateway 2 (red dashed arrow). In this situation, gateway 1 will be in charge of the sensor node. Figure 2(b) illustrates that the sensor node is covered by both gateways 1 and 2 at time t2 (the intersection of the blue ellipse and the orange ellipse). Here, the gateway that receives the strongest signal strength (Received Signal Strength Indicator, RSSI) from the sensor node will take over management. Figure 2(c) shows that the sensor node is in the coverage area of gateway 2 at time t3, but not in the coverage area of gateway 1, so gateway 2 will manage the sensor node.

2.1. Hardware system design

Node Hardware Design

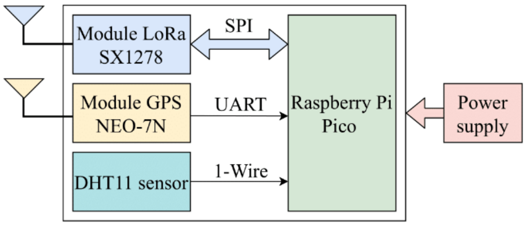


Figure 3. Block diagram showing the components of a sensor node

In Figure 3, each sensor node's hardware includes the Raspberry Pi Pico microcontroller [13], which reads and analyzes coordinate and time data from the GPS module as well as the temperature and humidity values from the sensor DHT11 [14]. The LoRa SX1278 module [11] is used to transmit data between the sensor nodes and the gateway.

Gateway Hardware Design

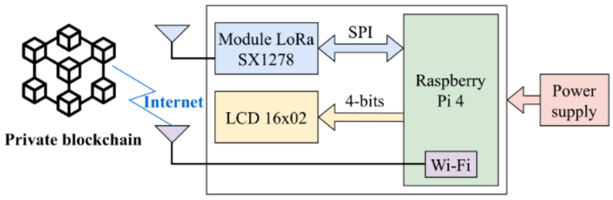


Figure 4. Block diagram of a gateway

Each gateway's hardware (see Figure 4) consists of an embedded computer Raspberry Pi 4 [15], a LoRa SX1278 module for data transfer with sensor nodes, and a 16x2 LCD screen to display relevant information during the operation process [16]. The Raspberry Pi 4 embedded computer will function as a quorum node, connecting to other quorum nodes in a private blockchain network and executing smart contract transactions.

2.2. Software development

Embedded software for sensor nodes

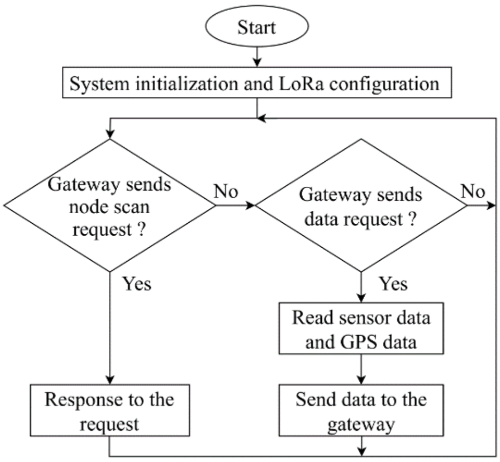


Figure 5. Flowchart for reading sensor values on the mobile node

The flowchart of the program being performed at the sensor node is depicted in Figure 5. Begin the program by initializing local variables and the peripheral interfaces for communicating with the equipped sensors, as well as the LoRa module's data transmission configuration operation. The sensor node then enters standby mode to await commands from the gateway to read and send sensor values.

Embedded software for gateway

The program at the gateway (as shown in Figure 6) begins by initializing the program variables and peripherals that communicate with the sensors and configuring the LoRa module's operation. Additionally, this program also opens a local HTTP connection with the node quorum operating on it for interaction with the smart contract to execute transactions and get management sensor nodes. The gateway will then go into listening mode and process smart contract events. The gateway delivers data requests to the nodes it manages and transfers the received data to the smart contract, in addition to automatically scanning nodes at predetermined intervals. The management of the gateway's sensor node will be done through the following process: explore sensor nodes under its coverage, send node exploration data to the smart contract to process and receive node update events, and retrieve the managing sensor nodes from the smart contract.

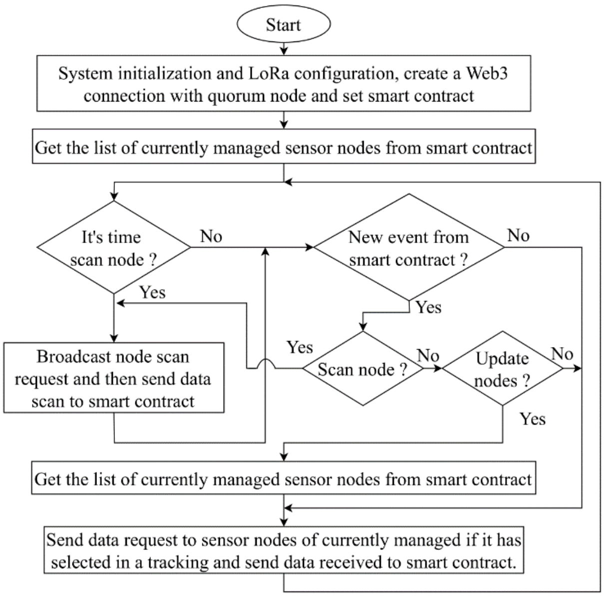


Figure 6. Flowchart of embedded software on the gateway

Web Application

Figure 7 shows a general diagram of the web user interface with interactive parts (front-end) written in HTML, CSS, JavaScript (JS) language, and Web3js library [17]. The data (back-end) provided for a web service will be retrieved locally from a computer running a user's quorum node through the smart contract. The web application will allow users to easily send transactions to the smart contract by simply entering the information. Furthermore, a map utility built on Google's Maps JavaScript API platform [18] allows real-time tracking of transportation processes as well as easy and intuitive querying of transportation process history.

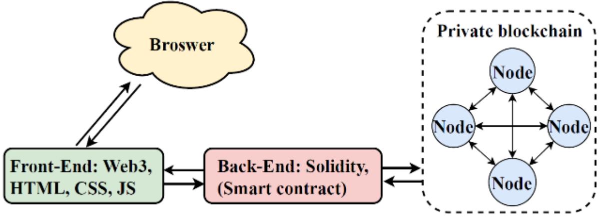


Figure 7. Block diagram of the web application

3 Implementation and experiment

3.1. System implementation

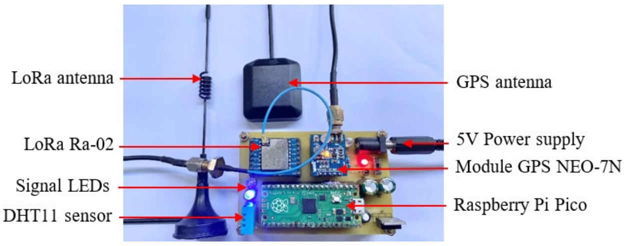


Figure 8. The electronic circuit board of sensor nodes

The wireless node's hardware is shown in Figure 8. A Raspberry Pi Pico with temperature and humidity DHT11 and LoRa Ra-02 modules, as well as a NEO-7N GPS module mounted on a tiny PCB board for stable connections, serves as the central control board. The Raspberry Pi Pico board is equipped with a dual-core 32-bit ARM Cortex-M0+, clock running up to 133 MHz, 8 kilobytes of SRAM, and 2 megabytes of flash memory [13]. The program reads sensor values and transfers them to the gateway through LoRa wireless transmission, which is developed in MicroPython using the pyLoRa package [19].

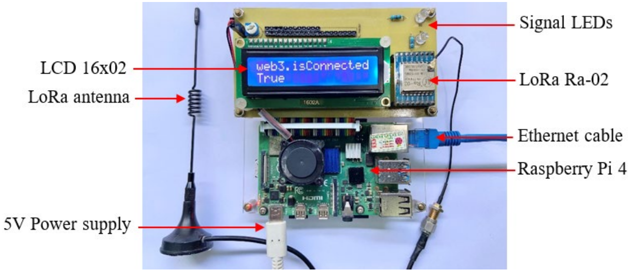


Figure 9. The gateway includes an LCD screen and a LoRa Ra-02 transceiver mounted on a Raspberry Pi 4

Figure 9 shows the electronic circuit of the gateway, including the LCD16x02 display and the LoRa Ra-02 module connected to the Raspberry Pi 4 via a 40-pin bus cable. Raspberry Pi 4 is a compact embedded computer with powerful processing power (Quad-core Cortex-A72 64-bit, system clock up to 1.5GHz 1.5 GHz as well as Internet connectivity (Gigabit Ethernet/2.4 GHz and 5.0 GHz IEEE 802.11ac). Thus, it can serve as both a gateway and a quorum node in a private blockchain network. The gateway function on Raspberry Pi 4 is programmed in Python language using pyLoRa library to communicate with the LoRa Ra-02 module and using Web3py library [20] to interact with smart contracts in the blockchain network.

3.2. Web GUI

Figure 10 depicts the user's web interface. This application is designed with the following primary functions such as creating a new shipping process, completing the previously created transport process, and tracing the history of transport. There are also functions to help with the system configuration, such as sending node scan requests to gateways, updating the LoRa module, and adding and removing gateways in a wireless sensor network.

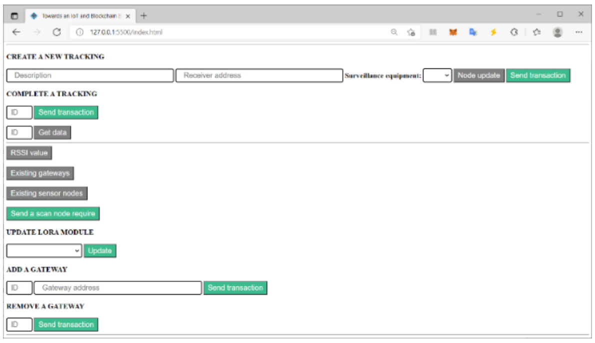
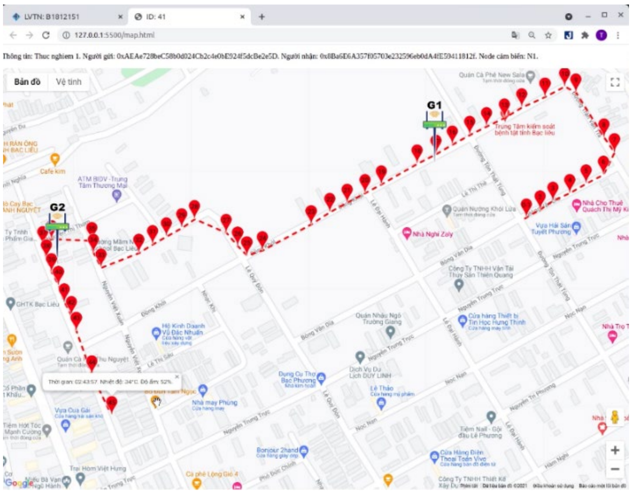


Figure 10. Web GUI of the system for monitoring and tracing agricultural products

3.3 Experiment

Figure 11. System organization in the experimental measurement

Figure 11 depicts the node sensors mounted on a high pedestal with batteries, a LoRa transmitter and receiver antenna, and a GPS antenna. The experimental track has a total length of 1.6 kilometers (from marker A to B), and the distance between the two gateways is 500 meters. Figure 12 depicts the location of the G1 and G2 gateway, both with the LoRa antenna mounted on a tripod 5 meters above the ground.


Thông tin: Thuc nghiem 1. Người gửi: 0xAEAe728beC58b0d024Cb2c4e0bE924f5dcBe2e5D. Người nhận: 0x8Ba6E6A357f05703e232596eb0dA4fE59411812f. Node cảm biến: N1.

Thời gian: 02:43:57. Nhiệt độ: 34°C. Độ ẩm: 52%.

Figure 12. The positions of a mobile sensor node (red markers) and two gateways (G1 and G2) on the map with corresponding sensor values (time: 02:43:57, temperature: 34°C, and humidity 52%)

Figure 13 illustrates the tracking information of a transaction in an experiment. Transaction data was encrypted and stored in the blockchain network so it could be tracked by all blockchain participants. The system aims to ensure shipping in a more transparent, reliable, and secure manner based on the preeminent features of blockchain technology, such as immutability and enhanced security.

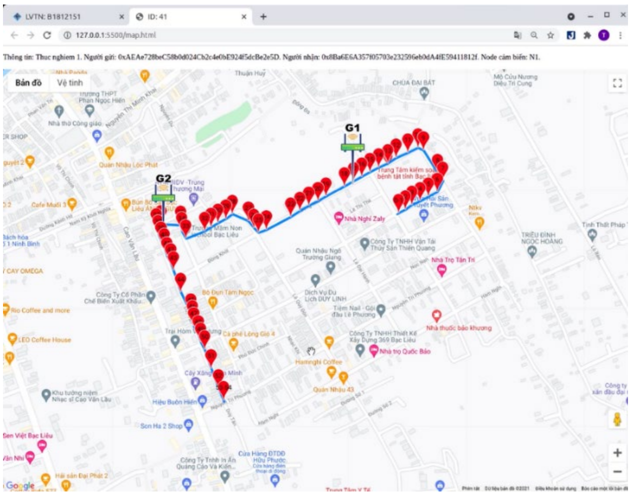

Thông tin: Thuc nghiem 1. Người gửi: 0xAEAe728beC58b0d024Cb2c4e0bE924f5dcBe2e5D. Người nhận: 0x8Ba6E6A357f05703e232596eb0dA4fE59411812f. Node cảm biến: N1.

Figure 13. The typical route is highlighted in blue after the relevant customers confirm the completion of the delivery process

4. Conclusion

This paper describes the design and implementation of a support system for monitoring and tracing agricultural products using blockchain and LoRa technology. The sensor network nodes in this study have a compact hardware design and robust operation software, allowing them to transmit and receive data with the gateways under actual conditions. A web application for easy operation and a map utility that makes tracking more intuitive with continuously updated data in real-time is also included in the system. Besides the benefits obtained, the system still has some limitations, such as the sensors used not having high accuracy, and the gateways being arranged in non-optimal positions for connection to transmit/receive data within the LoRa network. The authors intend to add more sensors, use high-quality sensors, and apply traceability at various phases of the manufacturing process to monitor metrics for various commodities. The authors will need to perform further experiments, and construct and expand more gateways and sensor nodes to be able to monitor different transport processes across longer journey routes.

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