A Novel LoRa-Based Platform for Remote Monitoring of Large-Scale Rice Fields

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Abstracts: The utilization of wireless sensor networks is widespread across numerous industries, including smart agriculture, where the need to remotely monitor agricultural production environments on a large scale is imperative for improving farm product quality and preserving the ecosystem. In this paper, a novel and efficient wireless sensor network framework is presented, which employs LoRa technology to facilitate remote environmental monitoring during agricultural cultivation. Our proposed network framework possesses the capability of long-range data transmission, secure data transfer from source nodes to gateway, high reliability, and easy deployment for large-scale farm monitoring applications. The effectiveness of our model was evaluated in An Giang province, Vietnam, with monitoring indicators encompassing temperature, air humidity, soil moisture, pH of water, CH4, and NH3. The findings reveal that the wireless sensor network model for remote monitoring of the rice cultivation environment fulfills the requirements of good and complete data transmission, high data network security, and a long signal transmission distance of up to 3.5 km at a reasonable cost.

Keywords: Smart agriculture, Network security, Remote monitoring, Wireless sensor network, Large-scale farms, LoRa technology.

1. INTRODUCTION

Climate change and negative weather phenomena have had a significant impact on agricultural production in Vietnam in recent years, particularly in the Mekong Delta, a key agricultural production area in Vietnam. To adapt to climate change, the Mekong Delta, like many other places, has changed its crop structure, reducing the area of rice cultivation. However, rice remains the primary crop in the farming system. According to the Ministry of Natural Resources and Environment, by 2020, the agricultural sector in Vietnam will emit 104.5 million tons of CO2, accounting for 32.5% of total GHG emissions. In which the rice farming and agricultural land sectors emit the most, accounting for 40% and nearly 28% of the total emissions in the agricultural sector, respectively in 2020. Rice farming is the largest contributor to total GHG emissions in the agricultural sector as it is a large emitter of methane (CH4) and nitrous oxide (N2O). The major contributors to global warming were CH4 emissions from paddy soil (75.3 to 77.5%) and nitrogen fertilizer (12.1 to 16.1%) [1]. Regarding acidification, the emission of fertilizer N is the main impact (90.6 to 92.5%). One of the most reactive elements in the atmosphere is ammonia (NH3), and its release has significant environmental benefits. Rice paddies are particularly sensitive environments in which NH3 volatilisation can be reduced through water management, improving fertilizer efficacy and lowering environmental issues [2]. The ADB estimates that if the temperature rises by 1^0C, the yield of rice will drop by 10%, making rice the crop most susceptible to the effects of climate change. As a result, regular monitoring of environmental parameters is required to ensure good growth of rice plants while minimizing negative environmental impacts. With the rapid advancement of the fourth industrial revolution, wireless sensor network technology is becoming increasingly prevalent in all industries, particularly in the field of applied agriculture high technology. Sensors and smart devices that are linked and controlled automatically help agricultural production save finances, increase productivity, and improve product quality. Additionally, WebGIS technology is being used more and more to meet the growing need for geographic data for online environmental analysis and monitoring. The integration of wireless sensor network technology into WebGIS will promote the benefits of sensor automation in environmental monitoring as well as the benefits of WebGIS in managing and sharing visual information. WebGIS technology, with its data sources and GIS functions, will be an effective solution for communicating agricultural information to everyone [3], [4].

There are numerous studies and publications in the field of IoT for smart agriculture that seek to solve various issues and provide various remedies [5] - [20]. The primary problems for creating such solutions are hardware, networking, and platform challenges. The hardware challenges are linked to hardware execution, high-cost devices, and the harshness of the working environments, which include temperature, humidity, rain, reliance on a limited battery power source, and other hazards that may destroy the electronic circuitry. There is a dearth of communication facilities in rural areas, which makes it difficult to detect big farms and link remote regions. The deployment of Internet of Things (IoT)-based solutions that allow sensor/actuator nodes to share data without human interaction will heavily rely on wireless technologies. The platform difficulties are linked to developing an appropriate framework and applications that will enable real-time monitoring. In order to facilitate the merging of a sizable number of sensor nodes, devices, and tools, this study focuses on the networking difficulties of large-scale fields in Vietnam. Long-range (LoRa) technology is a potential option for providing long-distance communication over several kilometers using low-power consumption battery-powered devices. The primary goal of this study is to create a low-cost IoT-based infrastructure for remote surveillance of large-scale agriculture fields. The prototype created provides a low-cost way to obtain real-time information. This paper contributes by proposing an adaptable hardware and software framework based on LoRa technology for tracking farmland fields of various sizes.

1.1. Related Work

The authors of [5] offered a review and analysis of the current status of long-range wide area network (LoRaWAN)-enabled Internet of Things (IoT) applications for smart agriculture. LoRaWAN constraints and bottlenecks are discussed in detail, with a focus on their implications for agri-tech uses. The authors of [7] suggested a novel sensor node architecture based on the use of low-cost, high-efficiency components like water level, soil wetness, temperature, humidity, and rain sensors. The total sensing network is created and evaluated in the research center, and users can manage actual fields directly or automatically via the mobile application. The authors in [8] proposed a LoRa Module-based intelligent agriculture service infrastructure. LoRa-based agriculture use cases have shown substantial gains, such as a 50% decrease in water consumption for industrial fields. The long range, low power wireless characteristics of LoRa technology allow the use of low cost devices to transmit data from the field to the cloud, where it can be evaluated to enhance operations. In [9], the authors developed and produced a remote-control device that uses LoRa technologies to turn irrigation pumps on and off. The authors of [10] demonstrated a mathematical optimization method for LoRa modulation, namely frequency shift chirp modulation. Mathematical optimization for low power and LoRa has been verified using tailored hardware intended for farming applications. In this research, a new LoRa-based architecture for farm field tracking apps over an IoT platform is intended. The authors of [11] provided a method that makes use of hardware that is inexpensive, efficient, and simple to install and keep. Using open-source devices lowers the cost of setting up the network. Using LoRa wireless transceivers improves transmission distances and battery usage. The authors of [12] suggested an IoT scheme for long-distance connectivity based on LoRa modules applied to smart agriculture. They demonstrate that as the spreading factor rises to 12, the greatest coverage can be conveyed to 1000 m. However, the extensive covering has the drawback of increasing delays. In [13], the authors created a microcontroller-based integrated electrical device that could be applied to soilless farming and smart greenhouse systems. To build a data flow network between embedded devices, LoRa connectivity is used. The authors of [14] created a sensor node, gateway, and handheld device for real-time farming data transfer to a cloud server. Furthermore, they measured specific LoRa field parameters like link budget, spreading factor, and receiver sensitivity in MATLAB to derive the correlation of these parameters on a custom-built LoRa testbed. The authors in [15] described a long-range (LoRa)-based Internet of Things (IoT) system that includes a succession of IoT units in the field as well as several servers for agriculture tracking and pump management in water bamboo fields. The authors in [16] introduced an intelligent irrigation system design based on soil and meteorological circumstances. The soil and weather factors in Agriculture 4.0 are chosen from different study papers. The authors in [17] conducted a survey on the use of LoRa in the agricultural sector, reviewed cutting-edge approaches for Smart Agriculture, and examined the technology's promise in various infield uses. The authors in [18] created a smart agricultural irrigation system using IoT and LoRa networking technology. LoRa can send data over long distances without requiring an internet link. The findings demonstrate that their technology can autonomously manage farm irrigation without the need for human intervention. The author of [19] concentrated on the creation of a system based on the long-range network (LoRa), which was used for farming surveillance and is currently being deployed in regions of Ecuador's Andean region. The LoRa network is used to analyze climatic factors by tracking temperature, relative humidity, soil wetness, and ultraviolet rays. The authors in [20] developed and executed a flexible IoT-based framework for remote surveillance of agriculture fields of various scales, allowing continuous data gathering from various IoT devices (sensors, actuators, meteorological masts, and drones). This paper contributes by suggesting an adaptable hardware and software framework based on LoRaWAN technology for tracking farmland fields of various sizes. The authors in [6] detailed the LoRa project, which was created to help local remote agriculture businesses by deploying LoRa-based smart agriculture apps. The Reyax RYLR890 LoRa transceiver is used to enable bidirectional communications between numerous nodes in order to directly run two separate farm systems without the use of the internet. However, the disadvantage of earlier studies is that they are expensive, challenging to install, and challenging to use in Vietnam. As a result, we have been developing a novel, cost-effective, and simple-to-install system for use on a large scale. Our proposal employs LoRa and WebGIS technologies in the design, construction, and deployment of a wireless sensor network for collecting environmental parameters during the rice cultivation process in An Giang province, Vietnam. This paper contains the following contributions:

Propose an IoT-based tool for distant monitoring of large-scale agriculture fields. The suggested design is divided into four layers: farm perception layer, sensors and actuators layer, communication network layer, and application layer.

Design and implement a LoRa-based platform using low-cost devices that enable GPS LoRa tracking and real-time monitoring of ambient and soil conditions.

Create a reality database and a simulation model for a LoRa-based communication network of large-scale fields that allows for online tracking of various sensor nodes and measurement devices in the field.

An efficient security system using the AES encryption method and a 128-bit private key. Utilize the Dijkstra's algorithm to improve the wireless sensor networks (WSN) system's data route.

2. MATERIALS AND METHODS

2.1. Environmental Impacts of Rice Cultivation

Iqbal et al. [21] predicted that rising urea dosage would result in higher-than-expected measurements of NH3 emissions from paddy paddies. The first 12 days following fertilization of the crops saw the majority of the NH3 releases. The highest NH3 emission rate was 28 g/day, and the total NH3 emission at 360 kg N/ha/crop was 56.21 kg/ha. In Italy, the contribution of fertilizer use in 1 kg of rice production to global warming is 77.2%, acidification 59.6% and eutrophication 89.5%. In 1990, Japan produced 10.5 million tons of rice while emitting 8.2 million tons of CO2. In 1990, Japan's total CO2 emissions (including other greenhouse gases) were 920 million tons. Rice accounts for 0.9% of Japan's greenhouse gas emissions [22]. In Thailand, one kg of rice produces 780.0 g CO2-equivalent, 5.0 g SO2-equivalent, and 23.0 g NO3-equivalent [23]. However, the global warming effect of one kilogram of rice is 2,926 g CO-equivalent, the acidification effect is 3.186 g SO2-equivalent, and the eutrophication effect is 12,896 g NO3-equivalent [24]. According to Sadin et al. [25], CH4 emissions from rice land in Vietnam are 2.28 kg/ha/day for field water levels 15 cm high, 1.671 kg/ha/day for average water levels 10 cm high, and 0.88 kg/ha/day for drained fields. The authors of [1] implemented a low-GHG rice farming project in Vietnam's An Giang province. The study results revealed that high CH4 emissions were recorded at the sampling periods of 28 and 68 days after sowing for all models. In which CH4 emissions were measured at 28 days after sowing of the controlled trial model (34.7 mg/m^2/h) and Tricho (36.2 mg/m^2/h) and 68 days later (40.7 mg/m^2/h) and water (39.5 mg/m^2/h). When compared to the control model using alternating wet and dry irrigation and nitrogen fertilizer management according to the rice leaf color chart, the total methane emissions by about 31% were reduced. The authors of [26] investigated and measured CH4 emissions from two wet rice farming systems specialized in two rice crops and two rice crops plus one crop in Truc Hung commune, Truc Ninh district, Nam Dinh province. Research results show that the maximum amount of CH4 emissions in two-rice crop fields is 413.7 mg/m^2/day after 61-67 days of transplanting; while CH4 emissions in the fields of 2 rice crops + 1 crop reached the maximum at 540.6 mg/m^2/day after 73 to 77 days of transplanting; The amount of CH4 emitted in the land with 2 rice crops + 1 crop (converted to 2,668 tons of CO2/ton of rice) is higher than that of the land with 2 rice crops (converted to 2,194 tons of CO2/ton of rice).

2.2. LoRa Wireless Sensor Network

LoRa is a LoRaWAN physical layer technology that is free to use in ISM frequencies and has a minimal bandwidth and message capacity [27], [28]. It employs Chirp Spread Spectrum (CSS) modulation, which enables long-range and low-power usage [29]. Some LoRa transmission characteristics, such as the spreading factor (SF), coding rate (CR), and bandwidth (BW) can be modified. Each parameter's value is determined by the area in which the LoRa devices are placed. It operates on 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia [28], [30]. The SF, however, can range from 7 to 12. The greater it is, the better the packet transfer time, signal-to-noise ratio (SNR), sensitivity, coverage area, symbol time (Ts) [31], and time on air (ToA). Two different kinds of packet formats, explicit and implicit, can be used with LoRa modulation to send any number of frames. In general, the packet format is made up of four parts: a preamble, a header (optional), a data payload (limited to 255 bytes), and a possible payload CRC [30], [32]. With low speeds ranging from 0.3 kbps to approximately 30 kbps, support for communication over distances of up to 15-20 km, and millions of network nodes, LoRa devices can maintain connection and exchange data for up to 10 years on battery power alone [33]. A LoRa network can offer similar coverage to a cellular network. Lora antennas can be combined with mobile antennas in some cases when the frequencies are close enough, resulting in significant cost savings [33]. With the exceptional benefits provided by LoRa, the world has used this new LoRa wireless standard to replace the old wireless standard in many previous outdoor or indoor applications such as Smart Campus, Smart Home, Smart Parking, Air Pollution Monitoring, and etc. Electronic component companies have also begun importing LoRa modules into Vietnam in order to provide LoRa network applications. Many successful models for agriculture have emerged, including greenhouses, intelligent irrigation systems, etc. A survey of a number of recent studies shows that there have been many research articles and evaluations on LoRa and LoRaWAN for WSN by performing analysis, simulation and giving positive results about LoRa and LoRaWAN and the use of LoRa networks for long-range applications [34], [35].

2.3. LoRa Sensor Network Security

Ali et al. [36] proposed remote user identity verification and a key agreement protocol for monitoring WSN in agriculture. The proposed solution is applicable in real-time, but its architecture is overly complex and inefficient.

Chen et al. [37] proposed a security solution with six stages: system setup, registration, login phase, authentication and key agreement, password update or change phase, and phase add dynamic button. The proposed solution is a significant improvement over [36]. Ali's schema is made up of four entities: a user/agriculture expert, a base station, a sensor node, and a gateway node. Authentication and key agreement are handled by central entities (base stations) in this scheme. Without these base stations, entities would be unable to trust one another. Kumari et al. [38] raised the issue of authentication to prevent unauthorized use of sensors and network resources. This paper presents BAN-based authentication and security analysis for WSN black holes. BAN ensures mutual authentication attributes and a session key agreement. The security analysis demonstrates its resistance to various attacks. Validate black holes to reduce the possibility of resource loss. The recommended authentication protocol provides strong authentication as well as enhanced security. Turkanovi et al. [39] proposed a new user authentication strategy and key agreement for WSNs. The key agreement protocol was proposed in the paper to allow remote users to securely negotiate session keys with a common sensor node. The proposed solution ensures mutual authentication between the user, the sensor node, and the gateway node, despite the fact that the user never contacts the gateway node. The solution has been tailored to the WSN's resource-constrained architecture, thus it only uses simple hash and XOR functions. Amin and Biswas [40] have designed a new architecture for the WSN environment, based on which a proposed model for user authentication and a key agreement scheme are established. This scheme overcomes the security weaknesses of Turkanovic et al. [39]. The proposed protocol's security authentication is performed using BAN, which ensures that the protocol achieves mutual authentication and session key agreement properties securely between the entities involved. The proposed protocol not only overcomes the aforementioned security flaws, but it also fulfills all security requirements, such as energy savings, user anonymity, and mutual authentication. Yeh et al. [41] proposed a protocol that could solve all of the previous studies' problems while also providing mutual authentication to protect internal and external security. Furthermore, it not only inherits the benefits of the Elliptic-curve cryptography mechanism, but it also improves WSN authentication with higher security than other protocols. Dos Santos et al. [42] recently published a predictive model in agriculture that was researched and tested experimentally. They used a sensor network with a predictive model in Arugula crop monitoring, combining the Auto-Regressive Integrated Moving Average prediction model with LoRaWAN technology. WSN has been developed to collect data on land information and inform farmers about when to plant Arugula. This paper describes the successful implementation of LoRa technology in agricultural monitoring with a predictive model, which aids farmers in anticipating unusual situations. The main limitation of the proposed model is the real-time monitoring application, which will be developed in the future with a mobile application. In general, key updating and session key generation are common issues for the LoRaWAN security model.

Our proposed wireless sensor network model

The overview of our proposed LoRa wireless sensor network model is presented in Figure 1. This model consists of four architectural layers: 1) Farm Perception Layer - This layer contains the various monitoring metrics, such as the weather, soil moisture and humidity, plant monitoring, machine status, and water monitoring. Various sensor nodes, actuators, and measurement tools are present in the farm field; 2) Sensors and Actuators Layer - In the outdoors, various sensor nodes and monitoring devices are placed to gather data. (e.g., temperature sensors, soil sensors, weather stations, light sensors, humidity sensors, images, and videos). The gathered data is delivered to gateways or data gathering sites via wired or wireless transmission; 3) Communication Network Layer - The primary purpose of the communication network layer is to allow data transmission from the field perception layer to the application layer using various long-range and short-range communication technologies; 4) The application layer manages all data collected from sensor nodes and measuring devices via the communication network layer, as well as data storing, analytics, and visualization for various agricultural factors such as temperature, irrigation information, soil quality, and so on. The design and fabrication of the LoRa Node together with the LoRa Gateway are explained in detail below, and the configuration of the user interface is illustrated.

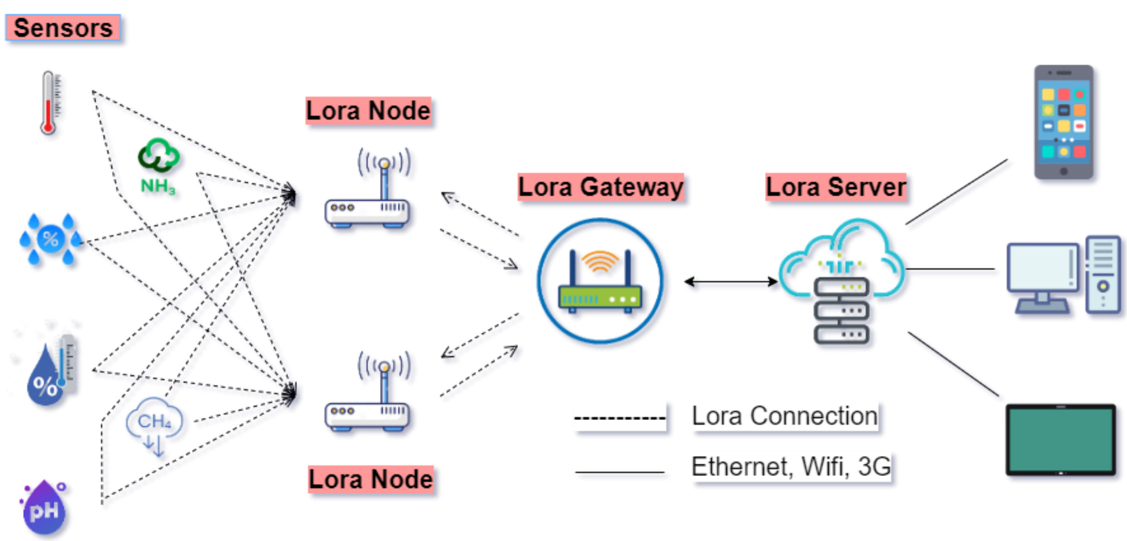


Figure 1. The Overview of our Proposed LoRa Wireless Sensor Network Model in An Giang, Vietnam.

2.4. Design of LoRa Nodes

LoRa nodes are designed to collect data from sensors and transmit it to the Gateway. These nodes were custom designed with adaptability criteria capable of operating autonomously to facilitate deployment on agricultural fields and enable monitoring and control with LoRa wireless communication technology in the Thoai Son region of Vietnam. Figure 2 depicts the block diagram of a LoRa node, which includes sensors, an Arduino Uno control board, a LoRa transceiver module, and a 12V DC battery power source.

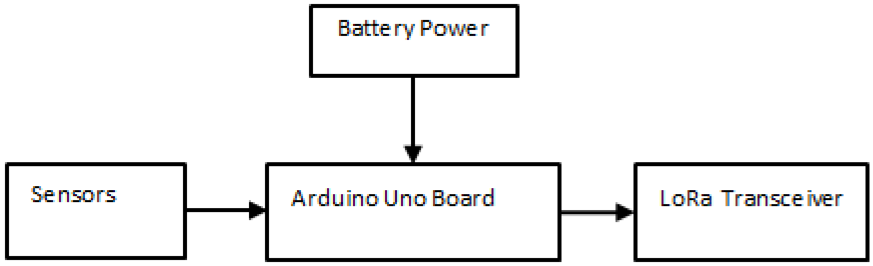


Figure 2. Block Diagram of a LoRa Node.

In this study, the sensors used at a LoRa Node include the following five types of sensor devices: 1) AM2315 temperature and humidity sensor (**Error! Reference source not found.**a). This sensor provides a two-wire digital I2C output suitable for interfacing with most 3.5 V and 5.5 V microcontrollers. The sensor consists of a capacitive humidity sensor and a high-precision integrated thermometer and is connected to a high-performance microprocessor. The temperature measurement range is from -20^{0}C to 80^{0}C with an error of 0,1^{0}C, humidity from 0% to 100% with an error of 2%; 2) Soil Moisture Sensor Corrosion Resistance Probe is equipped with anti-corrosion stainless steel probe for durability and high stability (**Error! Reference source not found.**b). This sensor helps to determine the soil moisture through the probe and returns Analog and Digital values through 2 corresponding pins to communicate with the microcontroller, measuring range of soil moisture from 20% to 99% with 1% error; 3) pH DFRobot Gravity: Analog pH Sensor/Meter Kit For Arduino (**Error! Reference source not found.**a), used to measure the pH in water, the sensor includes a probe and a processing circuit, amplifying the signal so that it can produce an analog signal that can be read by the ADC of the Microcontroller. This is a pH sensor of good quality and high accuracy that is widely used today due to its low cost, pH measuring range from 0 to 14, accuracy is ± 0.1 pH (25^{0}C), response time is less than 1 minute; 4) Methane (CH4) sensor MQ4 (**Error! Reference source not found.**b). Digital MQ4 sensor has high sensitivity, fast response, sensitivity can be adjusted by rheostat, wide detection range from 300 to 10,000 ppm, Analog and Digital dual signal output; 5) MICS-6814 Air Quality CO NO2 NH3 Nitrogen Carbon Gas Sensor Module (**Error! Reference source not found.**), used to sensor gas NH3. The silicon gas sensor chip structure consists of a precision micromechanical diaphragm and an embedded heating resistor with the sensing layer at the top. Three separate gas sensing elements are integrated. It can detect automobile exhaust, industrial and agricultural waste gas in harsh environments. NH3 gas detection range from 1 to 500 ppm. In addition, this sensor is also capable of detecting CO from 1 tp 1,000 ppm, CH4 from > 1,000 ppm, NO2 from 0.05 to 10 ppm.

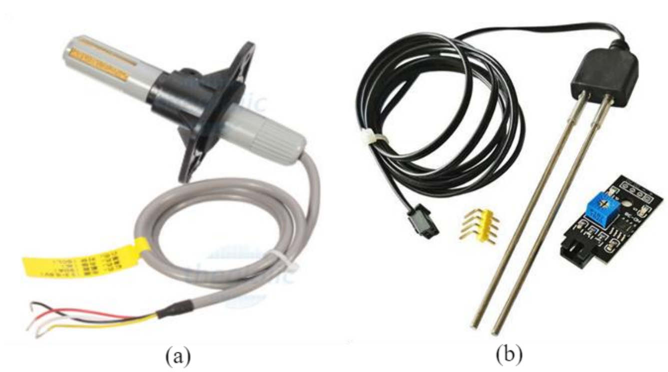


Figure 3. (a) Temperature and Humidity Sensor AM2315;
(b) Soil Moisture Sensor Corrosion Resistance Probe.

(a) (b)

Figure 4. (a) pH DFRobot Gravity: Analog pH Sensor / Meter Kit For Arduino; (b) Methane (CH4) sensor MQ4.

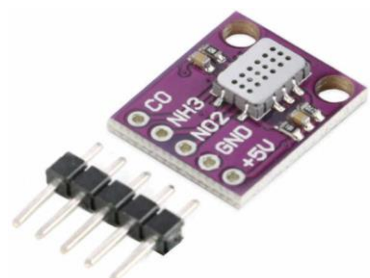
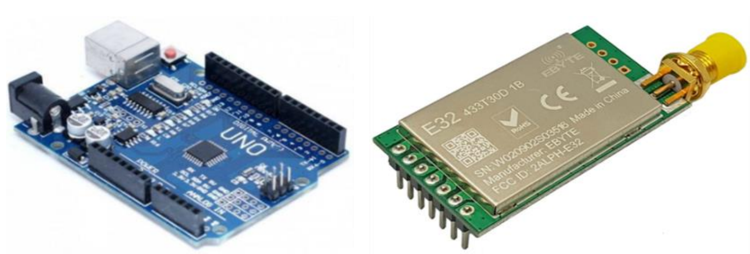


Figure 5. MICS-6814 Air Quality CO NO2 NH3 Nitrogen Carbon Gas Sensor Module For Arduino.

The control board used in this study is the Arduino Uno R3 board (**Error! Reference source not found.**a). It is the 3rd generation Arduino series that like previous versions gives users easy access to programming to create hardware with desired features quickly and at a reasonable cost. The Arduino Uno R3 uses the ATmega328P microcontroller with 32 KB of Flash memory that allows storing the instructions of large applications. Lora transceiver module used in this experiment is RF Module SX1278 Lora E32 type Model: E32-433T20DC1B Lora SX1278 433Mhz 8000m (**Error! Reference source not found.**b). The module uses the SX1278 chip of the manufacturer SEMTECH with the LORA interface standard, which provides two important benefits: energy saving (30 dbm ~ 1 W) and super long transmission distance (up to 8,000 m in ideal conditions). In addition, it also has the ability to configure to form a network to help increase coverage, thus it is currently being developed and used a lot in IoT research. For power supply, this research has found that 20,000 mAh is sufficient to keep a LoRa node running continuously for up to 72 hours.



(a) (b)

Figure 6. (a) Arduino Uno R3 Board; (b) Module RF SX1278 Lora E32.

Signals from sensors at a Lora node will be transmitted to the Gateway periodically after a certain period of time. The flowchart of this signal processing algorithm consists of 3 steps, shown in Figure 3. Step 1 - Initialize and configure the Setup() function: Initialize the UART, configure the signal pins, initialize the 5s timer interrupt. Step 2 -

Build a function to store data series Data(): Format the data string with the following attributes [numNode, air temperature, air humidity, soil moisture, CH4, NH3, pH]. Step 3 - Build a loop() data reading function: including ReadCJMU6814(), ReadMQ4(), ReadAM2350(), ReadSoilHumidity(), ReadPH() functions to read sensor values and transmit price data series sensor value read to the Gateway.

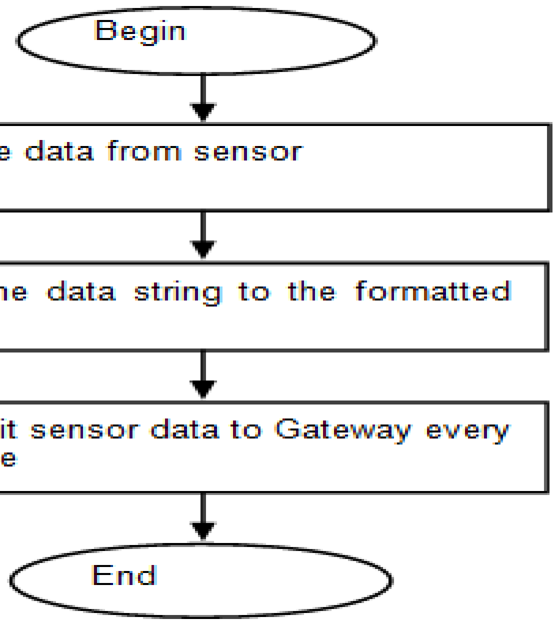


Figure 3. Flowchart of Signal Processing Algorithm at a Lora Node.

2.5. Design of LoRa Gateway

The LoRa Gateway's function is to forward and receive information from the end nodes via LoRa wireless transmission to the IoT server via standard IP internet protocol [43]. The Gateway's communication circuit block diagram is designed to include: Control board (NodeMCU) with built-in WiFi network connection module, LoRa transceiver module, battery supply, as shown in Figure 4.

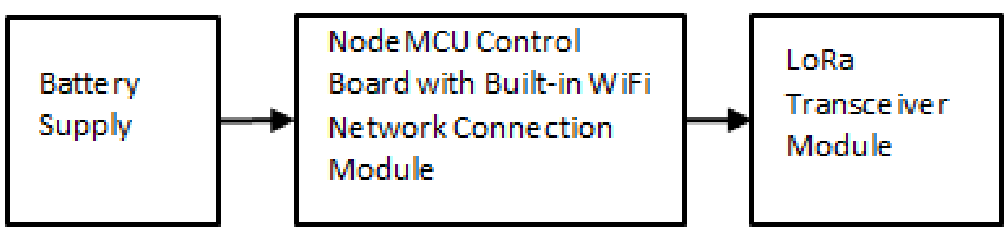


Figure 4. Block Diagram of the Communication Circuit of a Gateway.

The control board used in this study has a built-in WiFi Plus (WiFi+) V3.0 ESP8266 NodeMCU Lua CH340 network connection module, with extremely low power, saving power, stable connectivity, 2 times higher speed than normal WiFi chip version (

Figure **5**). The Lora transceiver module used in this study is RF Module SX1278 Lora E32 type Model E32-433T20DC1B Lora SX1278 433Mhz 8000m (**Error! Reference source not found.**b).

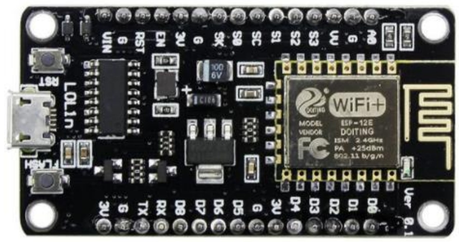


Figure 5. Kit RF Transceiver for Wifi ESP8266 NodeMCU Lua V3 CH340.

The algorithm for processing and transmitting data to the Server of a Lora Gateway is presented in

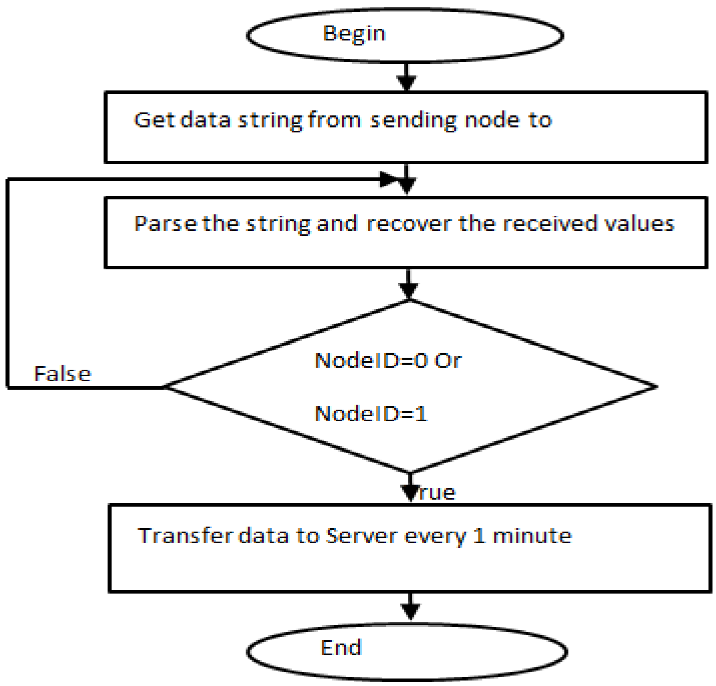


Figure 6, including 03 main steps as follows: Step 1 - Initialize and configure the Setup() function: Initialize the UART, configure the signal pins, configure the WiFi connection, configure the connection to the Server. Step 2 - Build the loop() function: parse the string and recover the values received from node. Step 3 - Build the function PostDataToServer(): to transmit to the Server the sensor values that have been analyzed and recovered from the loop() function.

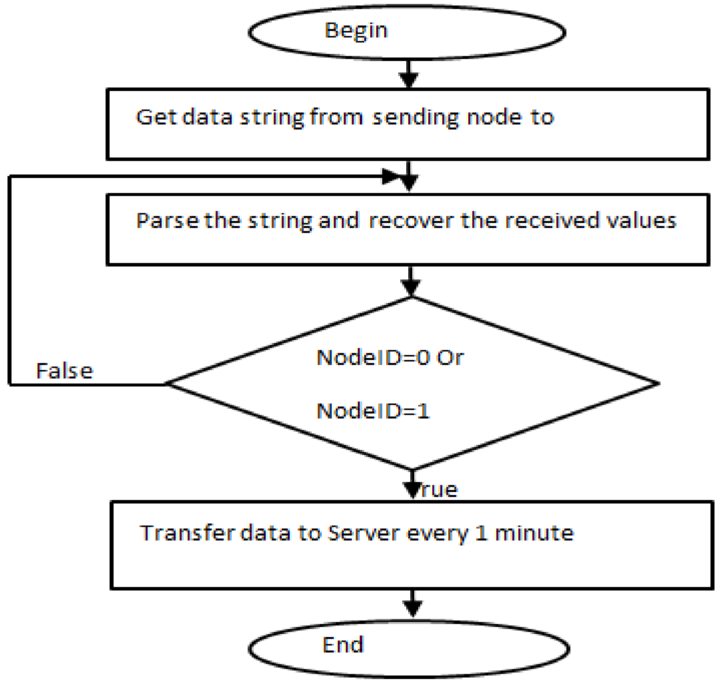


Figure 6. Flowchart of Processing Algorithm for Lora Gateway.

2.6. Design of LoRa Server

LoRa Server is in charge of receiving and processing the data packets coming from the LoRa Gateway and administering and managing the configuration required by the network. In this study, LoRa Server is integrated with Web Server of the WebGIS system. The overall process of building WebGIS is done according to the diagram Figure 7, includes the following main stages: Data collection, Analyze, design, build database and build WebGIS site.

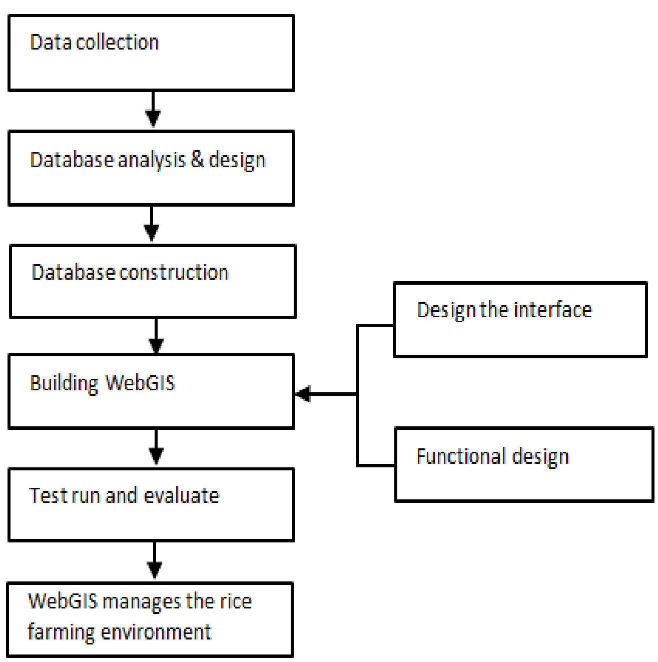


Figure 7. WebGIS Construction Process Diagram.

2.7. Wireless Sensor Network Security Model

The model was designed to address the security needs of WSN. The model's general principle is to define communication and data transfer agents securely. The data is encrypted to ensure the security of the data. This method is based on protecting data exchanged with encryption, digital signatures and Public Key Infrastructure (PKI) during sensor network attacks. Encryption allows data to be transformed in a form that only the person to whom it is intended to be sent can read it. Symmetric cryptography for secret key generation and message encryption is used in the model. Asymmetric cryptography and PKI digital certificates are used to digitally sign messages and protect the secret key. In the experiment, we used cryptographic data encryption. The data content is encrypted using symmetric algorithms such as DES, 3-DES, RC2, AES. The model ensures that the security requirements of the wireless sensor network are met during the exchange of collected data between the two sides of the wireless sensor network using AES cryptography. The sender uses a secret key to encrypt the message using the AES algorithm. The data is then sent to the receiver. The receiver decrypts the encrypted message with the secret key. The receiver conducts digital signature verification to verify the integrity and the sender of the message. The security model in WSN in agriculture is proposed as Figure 8.

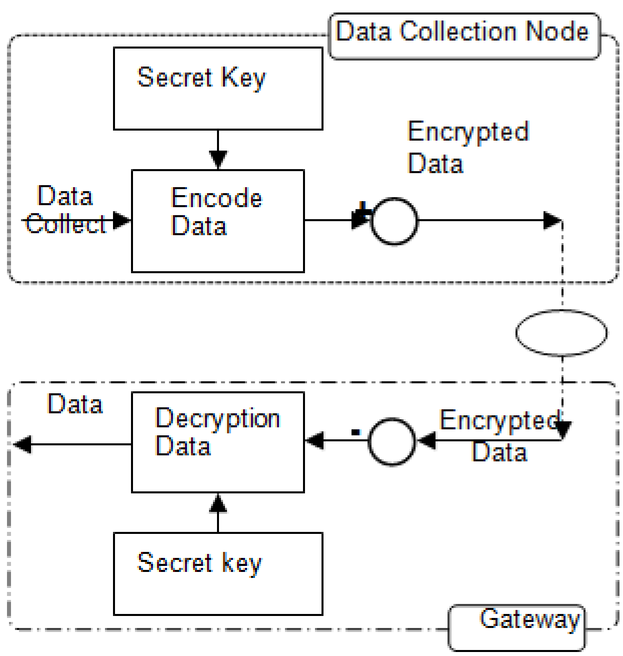


Figure 8. Data Encryption and Decryption Diagram.

2.8. Optimal Data Transmission and Pathfinding for WSN

In practice, the problem of transmitting data on a larger scale at the expense of network equipment is at least a necessity. As a result, we propose using diffuse transmission between nearby LoRa nodes to act as a bridge, assisting in data transmission at more distant nodes, in conjunction with shortest pathfinding algorithms. The shortest path will help to optimize transmission speed and reduce transmission time. To achieve this, the shortest path between a LoRa node and the LoRa gateway is determined using Dijkstra's algorithm. Let $d[u]$ be the shortest distance from Node s to Node u on a field. Initially $d[s] = 0$, other values are positive infinity. Choose the Node u with the smallest $d[u]$ at the time and use its distance to update the shortest distance of the surrounding vertices. Due to Node u is updated by the shortest paths of the nodes around it, its own path is also the shortest.

2.9. Algorithm Description for Optimal Data Transmission and Pathfinding of WSN.

Initialize n-element arrays: label, length, prev.

Let label[k] = 1, length[k] = -1 (inf), prev[k] = -1 where k runs from 0 to n – 1, length[first] = 0.

Chose the Node v in the array such that length[k] is the smallest. Then assign label[k] = 0.

Loop with variable running k, consider if label[k] = 1 and have a path from v -> k: If length[k] > length[v] + weight from v -> k or length[k] = inf, which means if a path is found from v -> k is the smallest, or otherwise the shortest path (inf) => Assign length[k] = length[v] + weight v -> k, prev[k] = v.

If label[last] = 0 **then** the loop ends. **If** not, go back to step 2.

3. EXPERIMENTAL RESULTS AND DISCUSSION

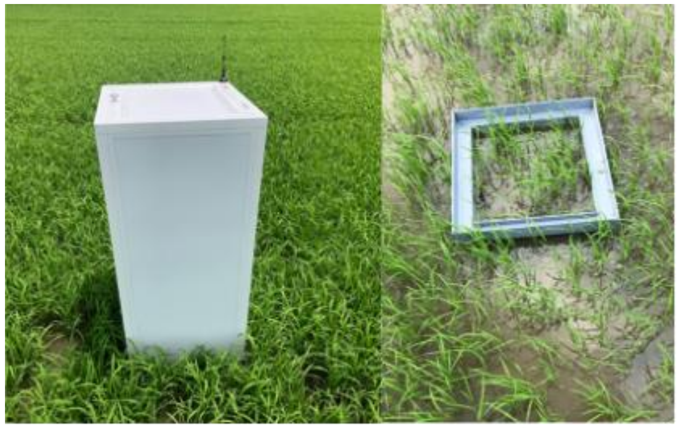
This section explains the design and implementation of the low-cost sensor nodes and data transmission. Three sensor LoRa nodes have been designed and implemented for monitoring different parameters of ambient and soil conditions, including temperature, humidity, moisture, etc.

3.1. Implementation

In the study area, three sensor locations (Sensor LoRa nodes) were set up in three rice fields with three crops per year and different tillage and fertilization techniques to collect environmental indicators, as shown in Figure 9. Lora Gateway is located in the house of the householder of Node 1, connected to the internet via a Wifi network to ensure data transmission to the Web Server. The distance between Gateway and Node 1 is 3.4 km, with Node 2 is 3.5 km and with Node 3 is 3.1 km.

Figure 9. Experimental Diagram of LoRa WSN in Thoai Son, Vietnam.

At each experimental site, a set of emission sample collection equipment with a rectangular shape is used (called chamber). The structure of the chamber consists of two parts as follows: 1) The chamber body as shown in Figure 10a is made of aluminum and mica-coated plastic materials with dimensions of length x width x height of (45 x 40 x 100) cm, the bottom of the chamber is hollow for placing on the base, the top of the chamber has a lid that allows opening and closing, making it convenient to calibrate the sensors; 2) The chamber base as shown in Figure 10b is made of stainless steel with dimensions (45 x 40 x 30) cm. The top of the stand has a groove (5 x 5) cm that holds water to place the chamber body. During gas sampling, the groove is always filled with water so that the body and base of the chamber form a sealed box to prevent air from circulating in and out of the chamber.



(a) (b)

Figure 10. (a) Chamber Body, (b) Chamber Base.

The study used Lora technology to create a wireless sensor network model for collecting environmental parameters in rice farming in Vinh Phu commune, Thoai Son district, which included: 03 Lora Nodes, 01 Lora Gateway, and 01 Lora Server integrated with Web Server. In particular, Lora Node has the function of collecting data from sensors and transmitting the collected data to the Gateway. The actual circuit of the Lora Node as shown in

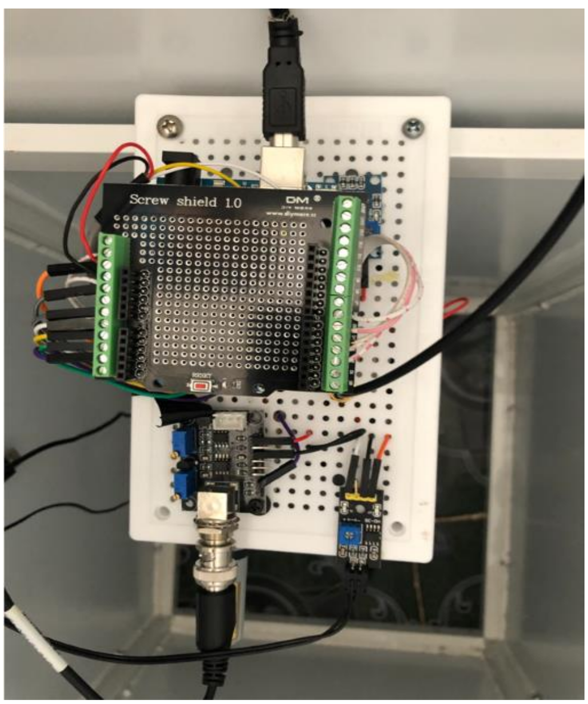


Figure 11 includes: Arduino Uno R3 controller board, SX1278 Lora E32 RF transceiver module, 12V DC battery power, sensors. Lora Gateway has the function of collecting data from Nodes and simultaneously transmitting it to the server. The actual circuit of Lora Gateway as shown in

Figure 12 includes: Control board with integrated WiFi Plus (WiFi +) network connection module ESP8266 NodeMCU Lua CH340, RF transceiver module SX1278 Lora E32.

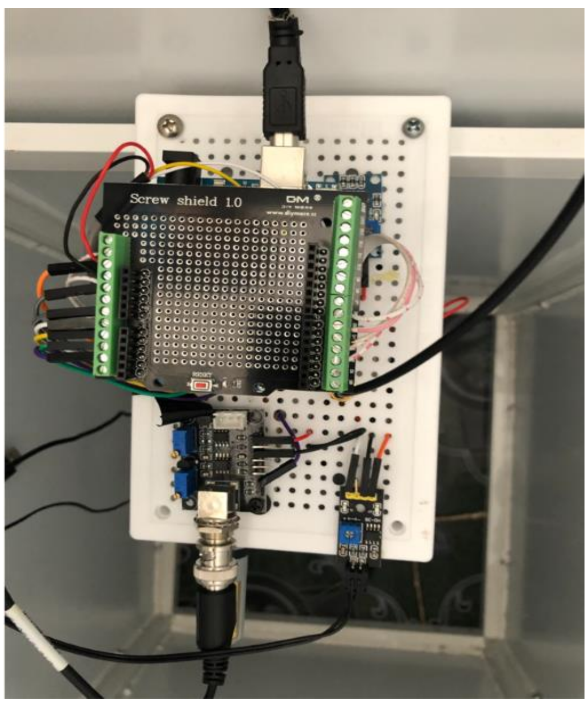


Figure 11. The Actual Circuit of the Lora Node.

Figure 12. The Actual Circuit of Lora Gateway.

To model the sensor network, prepare the device configuration, configure the sensor network parameters, and configure the data encoding parameters on the Arduino Uno, LoRa device, and encoding using AES algorithm with 128 bit key. Arduino Uno board parameters are presented as shown in Table 1. LoRa Module parameters are presented as shown in Table 2.

Table 1. Arduino Uno Circuit Board Specification.

Microcontroller	**ATmega328P**
Operating voltage	5V
Flash	32KB
Sram	2KB
Eeprom	1KB
Clock speed	16MHz

Table 2. Specification Module Lora sx1278.

Frequency Band	**410 - 441MHz, default: 433.0MHz, channel: 32, 1MHz stepped frequency,Recommending frequency: 433±5MHz,**
Connector	1*7*2.54mm,plug-in
Supply voltage	2.8 - 5.5V DC
Communication level	UART, USART
Transmitting power	Maximum 27dBm(500mW)| four optional level(0-3),step by 3dBm

Air data rate	Default 2.4kbps, can be configured to 0.3,1.2,2.4,4.8,9.6,19.2Kbps
Standby current	2.0uA(mode 3,M1=1,M0=1)
Transmitting current	370mA at 27dBm
Receiving current	14.5mA(mode 0 or mode 1) | minimum 30uA(mode 2 + 2s wake-up time)
Communication interface	UART, 8N1,8E1,8O1, eight kinds of UART baud Rate, from 1200 to 115200 bps
Transmitting length	512 bytes buffer,
Receiving length	512 bytes buffer,58 bytes per package
Address	65536 configurable addresses(easy for network, broadcast and fixed transmission)
Antenna type	SMA-K(External thread hole, 50 ohm impedance)

Table 3. Wireless Sensor Network Cost.

Devices	**Cost in USD**
LoRa Node	0
AM2315 air temperature and humidity sensor	16.11
Soil Moisture Sensor Corrosion Resistance Probe	4.83
pH DFRobot Gravity: Analog pH Sensor	33.50
Methane (CH4) sensor MQ4	1.70
MICS-6814 Air Quality CO NO2 NH3 Nitrogen Carbon Gas Sensor Module For Arduino	25.85
Arduino Uno R3 Board	27.73
Module RF SX1278 Lora E32	16.75
LoRa Gateway	0
ESP8266 NodeMCU Lua CH340	3.05
Module RF SX1278 Lora E32	16.75
Total	146.27

4. RESULTS AND DISCUSSION

The LoRa transmission network model is tested using simulation. The simulation models are built on the Open Source (Framework for LoRa) FLoRa Simulator, which is a simulation tool based on OMNeT++ [44], [45], [46]. The FloRa Simulator contains components that simulate the LoRa physical layer, LoRaWAN, gateways, and network servers. All of the physical layer's transmission settings, including transmission power, code rate, bandwidth, central frequency, and spreading factor, could be set in FloRa. Figure 13 shows the configured network topology for sensor nodes located in the playfield of Thoai Son, An Giang, Vietnam. Lora gateway successfully received packets in 80 configurations over a distance of 100 m. Only eight configurations can deliver packets effectively when the distance between the node and the port is doubled. Finally, the node-to-gate data transmission success rate falls to 48.83% when we use 5 values of path loss variance in the range of 0 to 7.08 dB at a distance of 400 m.

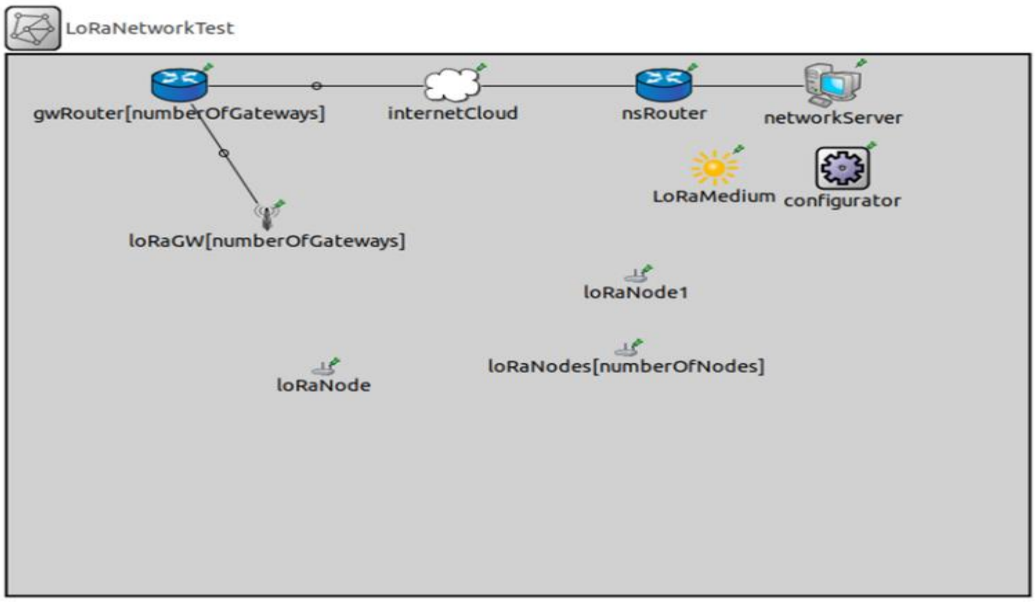


Figure 13. Sơ đồ mô phỏng mạng lora trên OMNeT++.

Our proposed system was put to the test for 11 weeks, from May 3, 2021 (one week after sowing rice) to July 18, 2021. The actual testing process demonstrates that the sensor network model is stable; the signal transmission distances from Node 1, Node 2, and Node 3 to the Gateway are 3.4, 3.5, and 3.1 km, respectively. The signal transmission and reception work well without interruption, and the data collected from the sensors at the LoRa nodes is collected, stored on the WebServer, and displayed on WebGIS.

Figure 14 shows that the average temperature of the samples at the same time at the Nodes is not significantly different. In particular, the average temperature varies at Node 1 from 27.6^{0}C to 34.3^{0}C, Node 2 from 27.2^{0}C to 34.1^{0}C, and Node 3 from 27.3^{0}C to 34.0^{0}C. The temperature variation is within the appropriate threshold for the growth and development of rice from 20^{0}C and 35^{0}C [47].

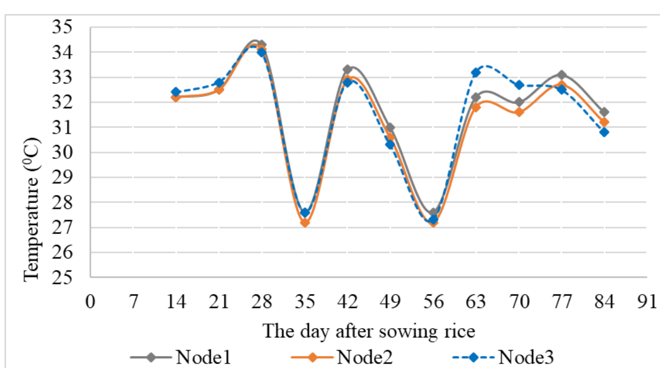


Figure 14. The Chart of Average Temperature at LoRa Nodes.

Figure 15 demonstrates that the Nodes' average relative air humidity ranges from 70.9% to 86.9%. In which, the average humidity at Node 1 from 73.3% to 86.8%, at Node 2 from 73.2% to 86.6% and at Node 3 from 70.9% to 86.9%. In the sampling periods of June and July, high humidity levels of over 85% were noted.

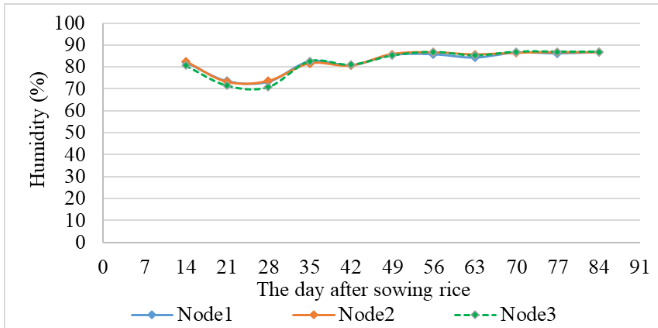


Figure 15. The Chart of Average Air Humidity at LoRa Nodes.

Figure 16 demonstrates that the average soil moisture varies between 24.1% and 37.1% at Node 1, 24.0% to 37.4% at Node 2, and 25.5% to 38.0% at Node 3. Days 14, 28, and 49, which correspond to the second, third, and fourth water supplies, have high soil moisture.

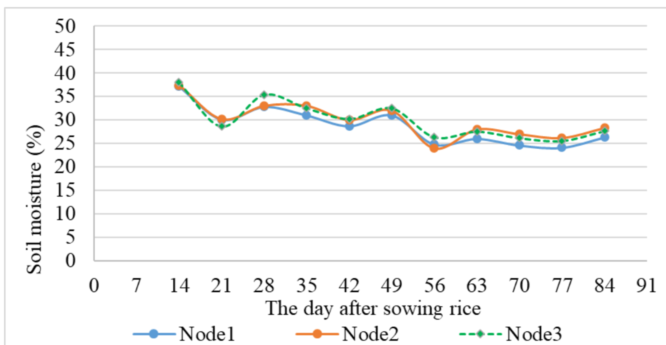


Figure 16. The Chart of Average Soil Moisture at LoRa Nodes.

Figure 17 shows that the water pH at the Nodes ranges from 6.6 to 7.4. In particular, the pH at Node 3 is usually higher than at Node 2 and Node 1. However, it is still within the threshold of good adaptation for rice. According to the Vietnam Research Center for Chemical Technology and Plant Nutrition: the optimal pH range for rice to grow is from 5 to 7, the suitable pH for rice is about 6 [48].

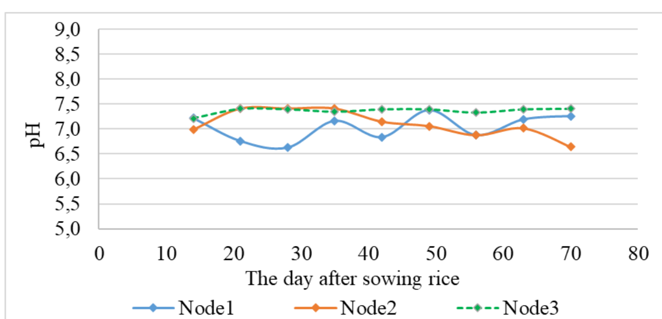


Figure 17. The Chart of Average pH at LoRa Nodes.

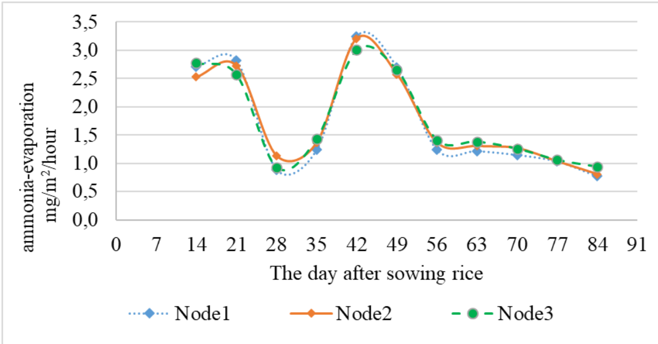


Figure 18 illustrates the comparable amount of NH3 evaporating at the Nodes. Leaching was significant in the first fertilizer application batch (14 days after sowing rice), the second application (20 to 25 days after sowing rice), and the third application (40 to 45 days after sowing rice). Researchers Hayashi et al. [49] and Watanabe et al. [50] found that the amount of NH3 that leached onto rice soil was concentrated in the days right after fertilizer applications.

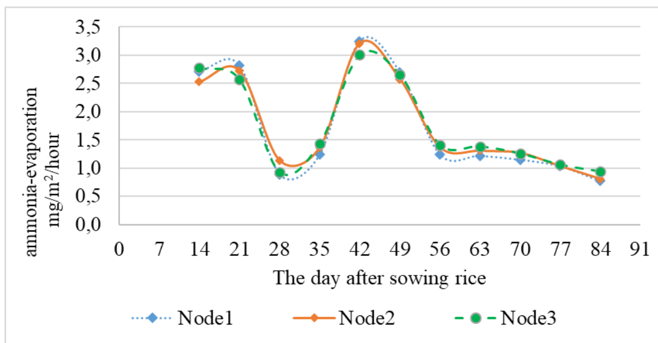


Figure 18. The Chart of NH3 Evaporating at LoRa Nodes.

The variance in CH4 emission intensity between Nodes is depicted in Figure 19. The findings demonstrate that each of the three nodes has two emission peaks that correspond to the third water supply (20 to 25 days after sowing rice) and the fourth time (40 to 45 days after sowing rice). In a rice crop, methane emissions typically peak twice: once during the active growth and flowering stages and once during the late tillering and primary mass stages [51].

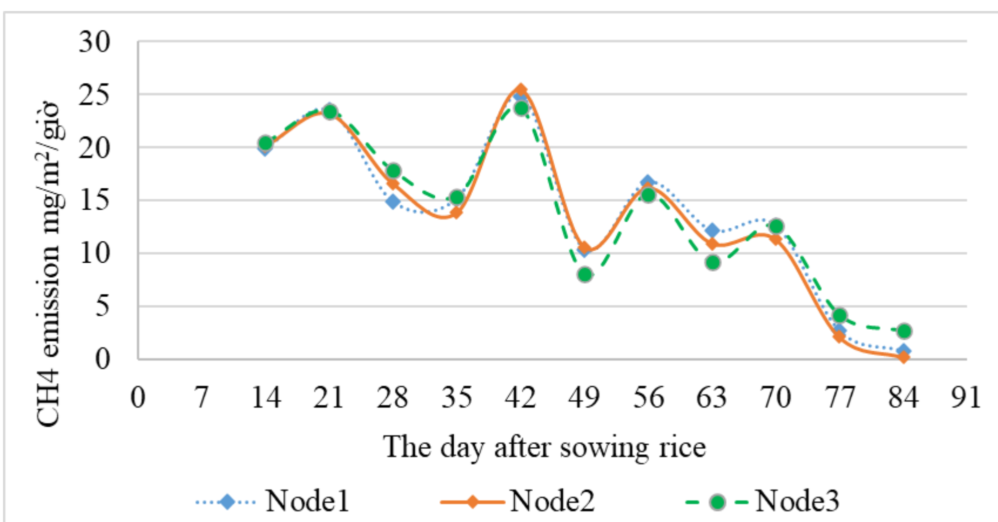


Figure 19. The Chart of CH4 Emission Intensity at LoRa Nodes.

Our proposed model transmitted data using LoRa technology and employed AES data encryption with a 128-bit key. LoRa is a long-range technology that offers effective small data transmission with little power consumption. ISM band technology is used to implement LoRa. Even sensors or transmitters with limited resources can send data up to kilometers away with a lifespan of several years even without power using LoRa technology [52]. In this study, we used the most secure encryption algorithm currently available, AES, with a 128-bit secret key. The system worked reliably and produced the desired results over the course of the 11-week experimental period, as shown in Figure 14 through Figure 19. The environmental sensor indicators are sent and stored on the server for the management of the rice production environment at the Department of Natural Resources and Environment of An Giang, Vietnam.

The data collected from the field are stored in a laptop connected to the LoRa gateway for further analysis. The results of the GPS LoRa nodes are visualized using OpenStreetMap. From the sensor search results, users can choose to view the sensor's values in real time or optionally view the date as a parameter. In addition, WebGIS technology is used to build a real-time map for field monitoring as shown in Figure 20.

Figure 20. The WebGIS System Displays the Value of the LoRa Nodes.

5. CONCLUSION AND FUTURE RESEARCH WORK

This study designed a new efficient framework at a reasonable cost of a wireless sensor network using Lora technology for collecting environmental parameters during rice cultivation. Practical experiments were conducted in Vinh Phu commune, Thoai Son district, An Giang province, with the collected indicators being temperature, air humidity, soil moisture, water pH, CH_4, NH_3. The sensor network model consists of three network nodes, one data collection station, and one data center with a Web server integrated. The signal transmission distances between Node 1, Node 2, and Node 3 and the Gateway are 3.4 km, 3.5 km, and 3.1 km, respectively. Experimental results show that the WSN system operates steadily in actual weather conditions, the signal can be sent over long distances while maintaining a high level of security. Continuous signal transmission and reception are performed without connection loss. The information gathered by the Nodes' sensors is stored on the WebServer and shown on the WebGIS map. Additionally, the open node structure of the network enables the expansion of connections with additional sensors. The entire system costs around $150 USD, making it easily deployable on a large scale setup. Our next work is to study the placement of LoRa nodes on a larger area of rice cultivation to achieve optimal efficiency with the least number of LoRa nodes, longer transmission distance by using machine learning and genetic algorithms.

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