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IoT-based Hybrid Wireless Network for Tourist Boat Tracking towards Smart Cities

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Abstract

Moving and transporting by canoe and boat on rivers and canals is a cultural feature of the Mekong Delta and plays an important role in the economy and society. However, the management and use of equipment to support the monitoring of waterway transport vehicles in this area has yet to receive adequate investment and attention. Given the complicated evolution of the COVID-19 epidemic, it is critical to strengthen oversight of inland waterway management, as well as freight and passenger transportation. This paper presents the design and implementation of an IoT-based support system for managing and monitoring passenger ships and tourism activities in smart cities. This study proposes a hybrid wireless communication network solution that takes advantage of the strengths of LoRa and Zigbee wireless communication technologies, as well as telecommunication networks, to ensure that the system has a wide operating range of several kilometers, low power consumption, and can be deployed in areas where telecommunications are not available. Aside from tracking the journey and managing information about vehicles, drivers, and passengers, the system also aids in the collection of environmental parameters along river routes according to the travel route. An experimental evaluation of the system's operation was carried out for the tourist boat route between two famous tourist sites, Ninh Kieu Key and Cai Rang floating market in Can Tho city, Vietnam.

Keywords: environment monitoring, hybrid wireless networks, LoRa, tourist boat, Zigbee.

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1. Introduction

Most monitoring applications use a standardized network protocol, such as Zigbee2 or LoRa3, to allow for easy management of network nodes. Although Zigbee allows for quick data transmission, the data transmission distance is only a few hundred meters. Mesh Zigbee allows for flexible network routing and is easily adaptable to environmental monitoring applications with many sensors densely deployed in a small area, as well as propagation environments with many mobile obstacles. However, because some applications necessitate a long transmission distance from the node to the gateway, Zigbee wishes to meet and deploy more devices in the middle to serve as relays of data from the sensor node to the gateway. LoRa meets this requirement, but it is not the best solution for applications requiring short transmission distances and high speeds. By referencing much successful research, this paper proposes the establishment of a hybrid wireless communication network for the application of a tourist boat tracking support system to capitalize on the strengths of these two communication standards [1-7]. Many researchers conducted projects for providing information such as train numbers, train drivers, passengers, and so on, as well as monitoring the operating position of the boats [8-11].

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[3] LoRa Alliance. 2019. A technical overview of LoRa and LoRaWAN. Available from: https://lora-developers.semtech.com/uploads/documents/files/LoRa_and_LoRaWAN-A_Tech_Overview-Downloadable.pdf

The Mekong Delta has a nearly 28,000-kilometer-long interlaced river system [12]. Water freight transport volume exceeds 51.5 million tons per year [13]. River tourism activities such as floating markets, tourist boats, and so on are very developed here and attract a large number of tourists each year. According to statistics, the number of visitors to the Mekong Delta in 2019 is expected to be 47 million. The total revenue is estimated to be 30 trillion VND, promoting economic restructuring and on-the-spot exporting [14]. Furthermore, this country is affected by the spread of coronavirus 2 (SARS-CoV-2) and there is no downward trend, causing many economic sectors to freezing. The tourism industry has been severely impacted by the tightening of social distancing and lockdowns as a result of the ongoing spread of the COVID-19 epidemic. Considering the above issues, it is urgent to deploy a monitoring and management system for tourism activities in waterways based on IoT technology. Faced with the complicated situation of the COVID-19 epidemic and the increasing number of tourists returning to Vietnam when the country reopens to tourists, the system must be able to query the schedule and provide information about passengers at tourist destinations. As a result, the Mekong Delta's tourism development is aided by the implementation of safe social distancing. Recognizing this demand, conduct research, design, and implementation of a tourist boat management support system with a small, compact size, broad coverage, and reasonable price.

Applications for smart object tracking in smart cities have received a lot of attention in recent years [15-25]. These can be telemedicine tools, tools for managing land-based and maritime transportation, or even tools for managing population mobility [26-32]. Research on applying artificial intelligence to tracking objects, vehicles, and human behaviors, with many outstanding achievements, especially during the time of social distancing due to the recent pandemic, is attracting much attention from the science and technology community, as is the financial investment for research and application development by large corporations [33-46]. This is essential to keep socio-economic activities going, to reduce the COVID-19 pandemic outbreak, and to lessen the impact of supply chain disruptions.

The hardware in this study is designed to establish a hybrid wireless sensor network capable of performing tasks such as locating the position of passenger ships and collecting environmental parameters (temperature, humidity, pressure, etc.) on board during the voyage. Data such as passenger information and train location should be stored in a cloud database and used to query the information in the event of an incident if any. In addition, a mobile application running on the Android operating system has been developed to aid in the monitoring and management of cruise ship information.

The remainder of this article is structured as follows. Session 1 provides an overview of related studies on the use of wireless sensor networks in traffic management, tourism, and environmental monitoring. The characteristics, significance, and current state of waterway traffic in Vietnam's Mekong Delta are also summarized. Session 2 focuses on the design and implementation of a hybrid wireless sensor network system for tourist boat monitoring applications that employ both LoRa and Zigbee wireless communication technologies. Section 3 describes experiments to assess system performance for the river cruise route between Ninh Kieu key and Cai Rang floating market in Can Tho City, Vietnam. Section 4 wraps up the article by summarizing the achieved results and outlining future development directions.

2. Background

2.1. LoRa Technology

LoRa is a low-power wide-area wireless network (LPWAN) protocol developed by Semtech. With the use of diverse spreading factors, this technology makes use of a spread-spectrum technique derived from the Chirp Spread Spectrum (CSS), which enables many devices to operate separately from one another without interfering with the signal. Unlike Wi-Fi and Bluetooth, which are used in IoT applications with high energy consumption, large bandwidth, and short transmission distances, LoRa is designed to serve applications with wide coverage, low cost, and energy savings [5]. In LoRa networks, the factors that affect transmission distance and rate are bandwidth (BW), spreading factor (SF), and coding rate (CR), which are all configurable for different applications. BW controls the frequency amplitude of the chirp signal, and different LoRa chips can be configured with different bandwidth levels. Large bandwidth allows for faster signal encoding and transmission time, but at the expense of a shorter transmission distance. SF specifies the number of bits needed to encode a character (symbol), which ranges from 7 to 12. The larger the SF, the longer the data transmission time and the higher the power consumption, but the error rate is lower and the transmission distance is greater. CR is the number of bits that must be added to a LoRa data frame for the receiving circuit to recover the incorrect number of data bits and thus recover the transmitted frame data in its entirety. The higher the CR, the more likely it is to receive the correct data; however, the LoRa chip must send more data, increasing transmission time. LoRa wireless communication technology was created for network systems with a star topology, in which the gateway plays a central role in controlling and managing all nodes. The wireless star topology network demonstrates flexibility in deployment and system expansion while maintaining high reliability through this connection. Because of the nature of the point-to-point connection, the system can easily maintain operation and handle errors when data transmission fails. However, that is also the main drawback of this type of network. If the gateway fails or is damaged, all devices on the network will stop working [47].

2.2. Zigbee technology

Some network topologies supported by Zigbee include star, mesh, and tree networks. A mesh network, on the other hand, is a typical Zigbee network; the nodes are interwoven like a honeycomb so that they can connect and exchange data with one another. If there is interference, the mesh network can reroute the data by “switching” through other nodes in the network until it reaches the destination node. A tree network is a type of mesh network with high coverage and scalability. Zigbee includes three types of devices to manage network devices: coordinators (coordinator), routers (router), and terminal devices (end-device). A Zigbee network has only one coordinator who configures the entire network, allowing routers and terminals to connect while consuming a lot of energy due to the inability to sleep while operating. The router inherits all of the network functions of a Zigbee node; it can participate in network packet transmission and data routing. There can be many routers in a network. The coordinator and the router control the terminal, which can sleep to save energy. The channel, PAN ID (Personal Area Network ID), and address parameters define the Zigbee device's internal network configuration. The PAN ID allows devices with the same value to communicate with one another. To determine where the data needs to go, each Zigbee device has a unique address specified by the manufacturer or configured by the user [48].

2.3. Hybrid networks

Many wireless communication protocols arose in response to the advancement of IoT technology. Wireless networks are classified into two types: base-station-based communication networks (BS) and ad hoc wireless networks. Base station communication, which involves devices exchanging data with one another via a single base station, has a high level of performance and reliability. However, even if there are many nodes, the response time of this network is not fast because it only has one central operating node. Meanwhile, hybrid networks are wireless ad hoc networks that combine multiple network protocols to form a unified network [1-7].

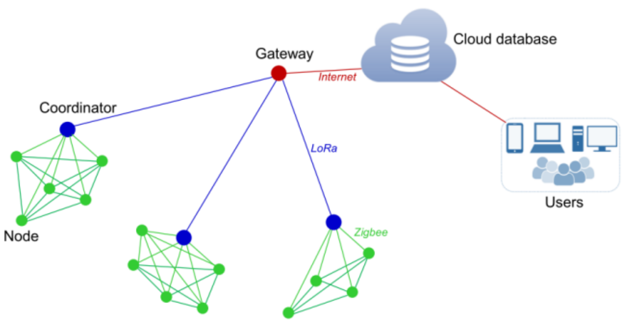

Figure 1. Structure representation of a hybrid network

Figure 1 depicts a basic hybrid network structure consisting of a star topology using LoRa technology and a mesh network using Zigbee technology. These two technologies have different advantages and disadvantages, but when combined, the system will inherit all of the advantages that these technologies bring while also improving the disadvantages such as energy consumption, transmission distance, data rate, number of nodes in the network, and so on. Since then, the system has demonstrated high reliability and adaptability in a wide range of conditions. However, deploying multiple network forms in the same system increases the complexity of data transmission and reception, as well as the possibility of high collision if transmission time is not properly allocated, resulting in traffic congestion. Therefore, the use of hybrid networks necessitates a reasonable design and deployment solution, particularly for the management and regulation of data transmission throughout the network.

3 System design

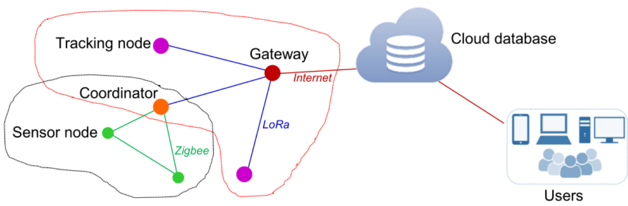

Figure 2. General diagram of the proposed hybrid network for tourist boat tracking

Figure 2 depicts an overview diagram of the tourist boat management support system. The system using a wireless sensor network is a hybrid network; in this network, there are two networks: Zigbee (black dashed line) and LoRa (red dashed line). Between the two networks, Zigbee and LoRa are linked together through the 01 Coordinator (orange circle). The Zigbee network consists of one coordinator and two sensor nodes (green circles) connected in the form of a mesh network. The sensor node collects and encapsulates data and sends it to the coordinator upon request via Zigbee links. The LoRa network is connected in the form of a star network, including the 01 gateway, 02 tracking nodes (violet circles), and the 01 coordinators of the Zigbee network. The tracking node works similarly to the sensor node; the coordinator will aggregate data from two sensor nodes and send it to the gateway via LoRa transmission when required. Gateway receives data from the above nodes, then aggregates, checks, calculates, packs, and uploads data sets to a cloud database via an internet connection such as 3G, 4G, and so on. For convenience in monitoring and managing data, the topic of developing mobile applications running on the Android operating system This application has permissions to access data, either administrative or user rights. User permissions can only monitor and observe data, while administrative rights have all the permissions with the application, including user rights and some special permissions like database administration and editing. The names gateway, coordinator, sensor node, and location node mentioned above will be used in describing the design and implementation in the following sections.

3.1. Hardware design

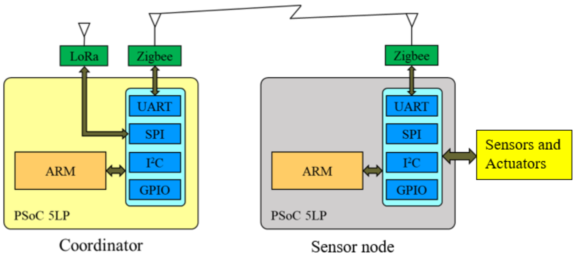

Figure 3. Block diagram and communication between Coordinator and sensor node

The CY8CKIT-059 Prototyping Kit serves as the Coordinator's central processor as well as a sensor node in the Zigbee network (see Figure 3) [49]. Temperature, humidity, air pressure, and CO2 concentration are read from the sensor and then synthesized, calculated, and packaged in a predetermined format while waiting for a request from the coordinator to send the data to the database via Zigbee transmission. After a pre-programmed time, the coordinator will perform a network scan to determine the number of active devices and send a request to those devices to receive data, then check, process, pack, and store the collected data while waiting for the data collection request from the gateway.

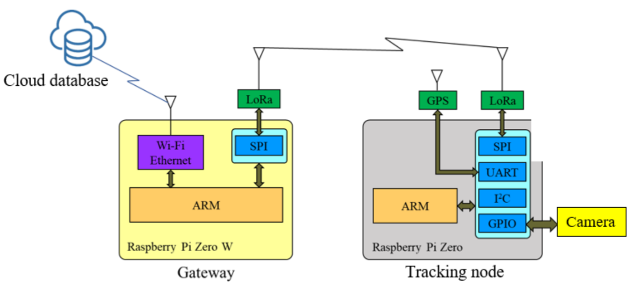

Figure 4. Block diagram and communication between the gateway and tracking node

In Figure 4, the LoRa network's components include a gateway and tracking nodes with a central processing unit built with the Pi Zero W[4] and Pi Zero[5], respectively. The gateway is the sender of the request, and the remaining components are the executor. When the actuator receives the request, it sends the collected data, including the location (for the tracking nodes) and sensor parameters (for the coordinators), to the gateway via LoRa transmission. The data will be examined, processed, aggregated, and packaged before being uploaded to a cloud database via an Internet connection. In addition, on each node, the device is also equipped with a camera that takes pictures and stores them internally on a memory card for querying when each node fails.

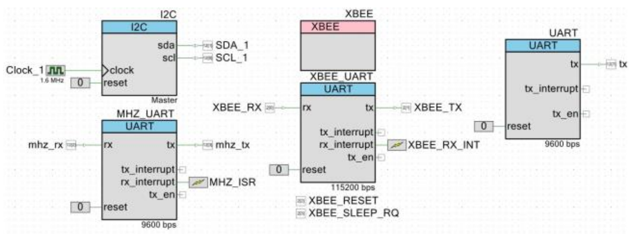

Figure 5. Schematic circuit of the sensor node

Figure 5 shows a block diagram of a sensor node in a Zigbee network created with PSoC Creator 4.2, which includes functional blocks such as I2C, MHZ UART, XBEE, XBEE UART, and UART [49]. The I2C block is set up to communicate with the BME280 sensor[6]. The Clock 1 clock runs at 1.6 MHz, allowing for a maximum data rate of 100 kbps. MHZ UART communicates with the MH-Z19B sensor using the configured parameters of 9600 bps and 8-bit data. To avoid continuous system execution due to data polling, the MHZ UART block uses the MHZ ISR interrupter to receive and process data. The UART protocol is used by XBEE and XBEE UART to communicate with the XBee 3 Pro module (115200 bps, 8-bit). XBEE UART, like the MHZ UART block, receives data via the XBEE RX INT interrupt. The design employs a UART block (9600 bps, 8-bit) configured in the data-only mode for testing and debugging during system development and implementation, which connects to the computer via a COM port.

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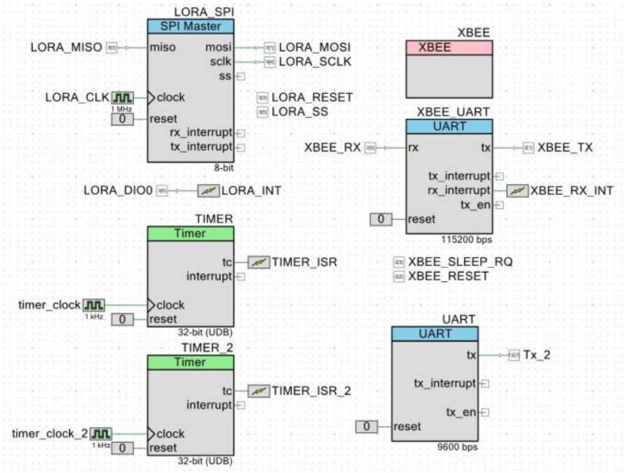

Figure 6. Schematic circuit of coordinator in the Zigbee network

As can be seen in Figure 6, LORA_SPI operates at 1 MHz, serving SPI communication with the LoRa inAir4 module. The LORA INT pin is an external interrupt source input that is connected to the DIO0 pin of the inAir4 module, which is responsible for receiving data in the LoRa transceiver's buffer. TIMER and TIMER 2 are added to the system to update the network state and send data collection requests in the Zigbee network at 60-second and 10-second intervals, respectively (reprogrammable as needed). The interrupt priority order is reset to match the application of the system. In order to send data to the gateway, the coordinator must aggregate data from the sensor nodes in the Zigbee network before requesting to send data, so the XBEE_RX_INT interrupt has the highest priority for the request as well as the request. receive data from the sensor node. The TIMER_ISR and TIMER_ISR_2 interrupt are set with the next priority for state updates and data collection in the Zigbee network. Finally, the LORA_INT interrupt has the lowest priority to receive data requests from the Gateway.

3.2 Data communication in hybrid network

The Zigbee and LoRa hybrid network system has two links: one between the sensor node and the Coordinator (Zigbee) and another between the Gateway or location node and the Coordinator (LoRa).

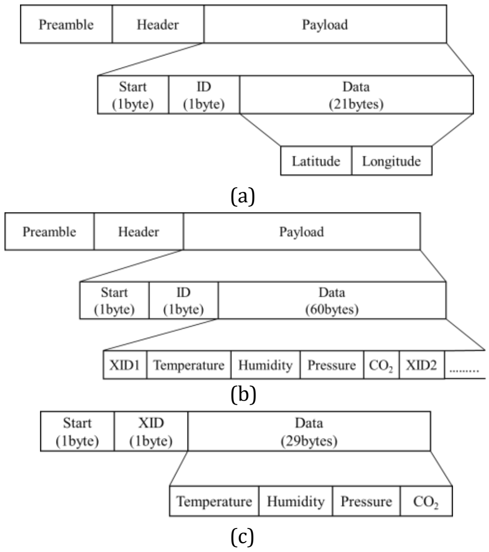

Figure 7. (a), (b) Tracking node packet and coordinator packet structures in LoRa network, respectively, (c) Sensor node packet structure in Zigbee network

The requesting role in a wireless network using LoRa wireless communication technology is the gateway, and the responders are the tracking nodes and the Zigbee network coordinator. The gateway sends a request packet to collect data that includes the IDs of the network's nodes, then waits for a response packet with the corresponding ID from the nodes, then checks, aggregates, and stores the received data. The data-receiving process is complete when the gateway receives the response data from the tracking node and coordinator that were asked to send the data. Otherwise, after the predefined timeout period, the gateway skips receiving data at the current node and continues collecting data for the next node. When nodes receive a data request packet from the gateway, they read Trimble GPS[7] values (for tracking nodes) or aggregate data from Zigbee network sensor nodes (for the coordinator), encapsulate the packet, and send it via corresponding links. If the sending is successful, the nodes will complete their tasks and enter a waiting state for the next request from the gateway. The coordinator plays a requesting role in a ZigBee wireless network, and the corresponding devices are the sensor nodes. The process of requesting data is similar to that of the LoRa network's gateway, except that the value sensor nodes from the sensors are automatically read by the microcontroller after the pre-programmed time so that when the coordinator sends a data aggregation request, sensor nodes can immediately send prepared measured values.

Figure 7(a) depicts the LoRa network packet structure, where the payload includes Start, ID, and Data with lengths of 1 byte, 1 byte, and 21 bytes, respectively. The Start is

[7] Trimble. 2009. Copernicus II GPS Receiver Reference Manual for Modules with Firmware Version 1.05.

used to identify the start of the packet. Each node in the network has a named identifier (ID), which is a unique integer within the network, corresponding to the gateway, coordinator, and two tracking nodes, to ensure that the packet is sent to the proper destination. At the tracking node, Data is a 21-byte-long composite data frame to send to the gateway. Unlike the tracking nodes, the coordinator's data frame is depicted in Figure 7(b). Because the system employs a hybrid network, the coordinator's packet will include two addresses, ID and XID, where ID is the LoRa network coordinator's identifier name and XID is the Zigbee network sensor node's identifier. Figure 7(c) depicts the packet structure of a sensor node in a Zigbee network. Start and XID are defined as LoRa packets. The Data frame contains the parameters read from the sensor as described above and has a total length of 29 bytes. The packets sent to the gateway will be aggregated and packaged, then uploaded to the cloud database.

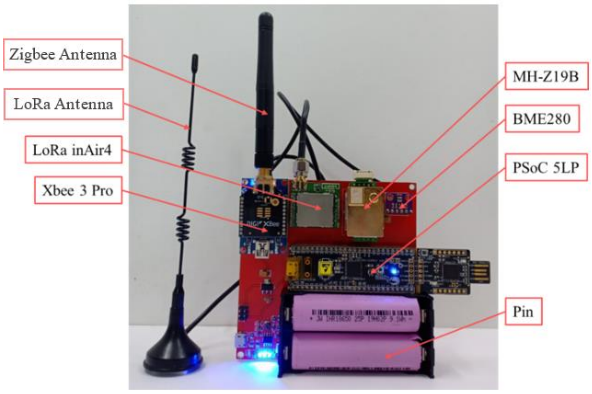

Figure 8. The actual circuitry for the sensor node and the coordinator

4. Experiment

The experimental circuit, after making the PCB board and soldering the components, produces results as shown in Figures 8 and Figure 9, including full electrical functions as described above. The circuit is powered by two batteries connected in parallel and includes a charging circuit with a micro-USB port. To avoid overheating other components in the circuit, the power block is placed separately.

Figure 10 shows the position and distance between nodes in an experiment to test the operation of the proposed system, with points numbered 1, 2, and 3 corresponding to the coordinator and two sensor nodes, respectively. The sensor node in position 3 will be located so that the coordinator cannot send the request packet, but node 2 can receive the signal from the coordinator and node 3. The coordinator sends data requests to each sensor node after verifying signal transmission between nodes 1, 2, and 3. It should be noted that nodes 1 and 2 communicate directly. However, because node 1 is too far away to establish a direct connection, packets between nodes 1 and 3 will be relayed by node 2. When transmitting data between the gateway and network nodes in the LoRa network, the antennas must be arranged reasonably to satisfy the line-of-sight condition. Therefore, the location of the antenna must be placed in a high position, avoiding obstacles, for the best data transmission.

An Android application is being developed with the primary functions of displaying the location of tracking nodes on a map in real-time and managing information about cruise ships, train drivers, and passengers (see Figure 11). Furthermore, the application includes utilities for monitoring environmental parameters and taking pictures on board while in operation. A strict permission mechanism will be used to store and share the collected data. The information that can be accessed is determined by the account's permissions. Only administrators have access to a vehicle and passenger information. Ordinary users are only permitted to monitor the ship's position and environmental parameters.

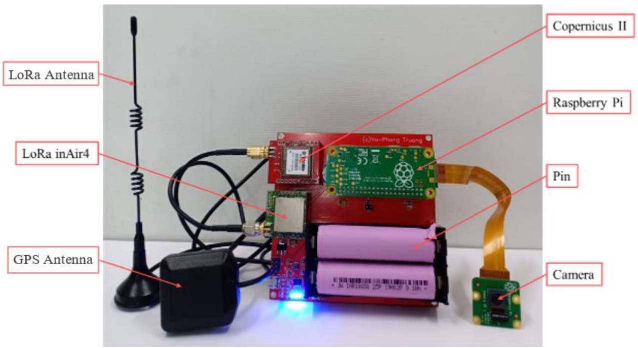

Figure 9. The photo of the sensor node and coordinator circuitry

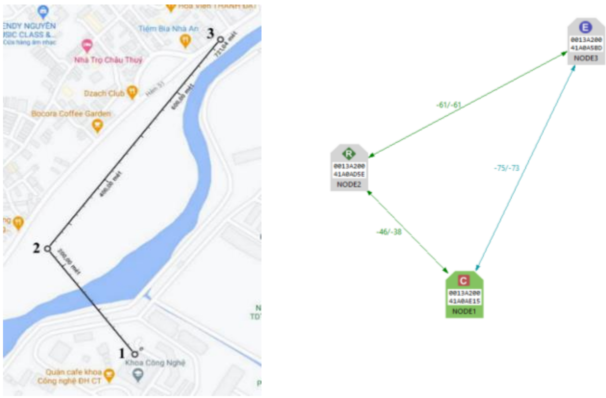

Figure 10. (a) Location of nodes on the map, (b) Zigbee network recorded on XCTU software

Figure 11. Android smartphone application for tourist boat management

5. Conclusion

The design and implementation of a hybrid wireless communication network system to support tourist boat management toward smart city development are presented in this paper. The system proposed in this study has a compact hardware design, a low implementation cost, and stable software that enables the nodes in the sensor network to transmit and receive data stably in the obstacle environment, exploiting the advantages of both ZigBee and LoRa technologies. The system also includes an Android application with continuously updated data in real-time to help users easily observe the ship's position and related information. Aside from the benefits gained, such as flexibility in system deployment even in areas without telecommunications coverage, the system still has some limitations in value update rate due to the LoRa communication standard's low transmission speed. Research to improve the system's features and data transmission rate is ongoing.

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