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Architectural Model and Modified Long Range Wide Area Network (LoRaWAN) for Boat Traffic Monitoring and Transport Detection Systems in Shallow Waters

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Abstract

Monitoring the movement of boats in shallow waters requires a real-time monitoring system. However, for small-size wooden boats, they are still monitored manually, and data is unavailable in real time, which makes it difficult to effectively monitor them. The integration of IoT platforms with the boat monitoring system is a challenging task, especially in the transport system. This paper has the objective of developing an architectural model of a modified LoRaWAN-based boat monitoring system that is connected to a GPS-based mobile device and base station. The proposed architectural model is an integration of Bluetooth Low Energy (BLE) and LoRaWAN networks, which are also tested in real time to solve the boat traffic monitoring issues. The field tests with parameters of signal transmission, location coordinates, and position of the boats are also presented. The analysis result shows the proposed model is suitable for waters with high noise levels, especially in shallow water and delta rivers. The signal noise can be reduced by extracting the real-time data. In addition, signal interference can be minimized. The performance of this system is also compared to the reference system in real conditions, which shows an adequate correlation result. This proof of concept forms an important basis for deploying it for large-scale applications and commercialization capabilities.

Keywords:

LoRaWAN;

Traffic Monitoring;

Shallow Waters;

Sensor; Network.

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1- Introduction

Advances in information and communication technology have become an enabler for the development of the Internet of Things (IoT), which is important in marine transport activities. A large number of equipment (sensors, networks, activators, etc.) have been connected to the IoT devices mounted on the ship for the purpose of maritime transport safety [1]. Initially, the term IoT was developed in U.S. manufacturing and has been used for connecting gadgets or machines in the field of commercial, corporate, and industrial sectors [2]. With the rapid development of IoT innovation for maritime transport purposes, there are still very few applications for monitoring small wooden boats in shallow waters and river delta areas [3]. One of the problems that many other studies have not answered is the difficulty of monitoring boat traffic around the shallow waters.

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The LoRaWAN system has great potential for wide usage in marine environments. It has the ability to track the signal from the boat's GPS coordinates and receive the boat's signal transmission [4]. However, when harsh weather occurs, the weather can interfere with the signal transmission [5]. This creates a research gap that will be addressed in this paper. To resolve the problem, this paper proposes a new model of IoT-based systems that can be applied to boat monitoring systems to identify boat traffic.

1-1- Components of Architecture

Generally, the IoT model has a three-layer architecture (i.e., service, operational, and management layers). The service level consisted of various functions, such as boat mobility management services and gateway management services. They have functions to monitor GPS signals from boats and send them to the base station and port officer [5]. The services work together by using the GPS parameters with LoRaWAN to create radio communications and network services [6].

At the operational level, they collect radio signals and send them to the LoRaWAN network. Mannino et al. (2021) have shown that IoT systems need key IoT modules to work properly to collect signals and process geolocation information [7]. Various researchers defined maritime IoT platforms such as LoRaWAN as a combination of three-layer architecture, human activities, shipping transport, automation, and the power grid.

Scholars have examined the fact that signal transmission from boats in bad weather is an important factor for boat safety in water transport. However, there are interference limits due to weak signal transduction, such as signal noise and overload of transmission signals. Specifically, in the study of boat signaling, there are various frequency ranges of boat traffic (signal transmission) through a combined three-phase structure, including interference limits, weak signal transduction, and digital communication.

In the first phase, scholars have studied how signal quality can be improved by using the LoRaWAN-based IoT system. Their study results provide insight into how to cover and improve the signal transmission from boat to server. However, other scholars argued about the impact of the noise interference, especially from the boat located in the crowd number of various signals. It impacts the difficulty of detecting the exact coordinates of the boats in shallow waters [8]. To resolve the problem, the detection of the signal needs effective tracking of boat movement through the gateway and a timely response of the signal from the movement of the boat to the gateway.

1-2- Wizblock for IoT Framework

Previous studies have conducted experiments to monitor signals using IoT systems and evaluate the performance of the signal transmission using the Wizblock-based framework. The scholars modeled the network system that was implemented in the marine transport application by using radio parameters to determine the ship's position. Other studies measured Wizblock's performance based on its signal detection and noise interference. The study used the ship to record the signal strength and multidimensional spread. However, the weather parameter is not recorded, which can affect the measurements.

Wizblock IoT is a vaunted technology that facilitates strong signal encryption security and a high standard of privacy for data. Every piece of information in Wizblock is being compiled in the form of code in sequential order. Wizblock technology has totally modified the system for transferring without third-party intervention. Wizblock data is being kept in cyber-cloud storage for the IoT. The Wizblock facility is quite better than the IoT concept as it focuses on the decentralized network, which results in low susceptibility to manipulation of data and illegal copying by venomous participants as compared to the general IoT platform. However, Wizblock is costly, and for the purpose of this study, the installation is complex and needs expert people to operate it.

Various researchers have proposed modified Wizblock models for detecting the signals in bad and normal weather. They use ships connected to the IoT to reduce the level of noise, false negatives, and false positives, which reduce the accuracy of the boat identification. They used a fully controlled environment to test the effects of signal power on the performance of the LoRaWAN system. However, the use of the IoT combined with the Wizblock system for detecting small wooden boats is rarely reported.

1-3- LoRaWAN for IoT Framework

Compared to Wizblock, the LoRaWAN system has a low cost and can be used for transferring signals with gateway receivers. Escobar (2019) has proposed boat communication that is monitored using a LoRaWAN system. The system consisted of sensors, RA transceiver devices, security level opening of WRT software inside the RA gateway receiver [9], and data transmission mechanisms from the signal to the boat using LoRaWAN IoT devices to the port base station.

Figure 1 shows an example of a communication scheme between the boat and the base station with Bluetooth sensors installed on each boat to be connected to the LoRaWAN system at the base station. Karagiannidis & Themelis (2021) showed that LoRaWAN can transmit sensor signals using third-party intervention, such as Bluetooth. The Bluetooth device on the boat is used to transmit GPS coordinates. The scholars have conducted experiments for developing the boat signal detection model [10].

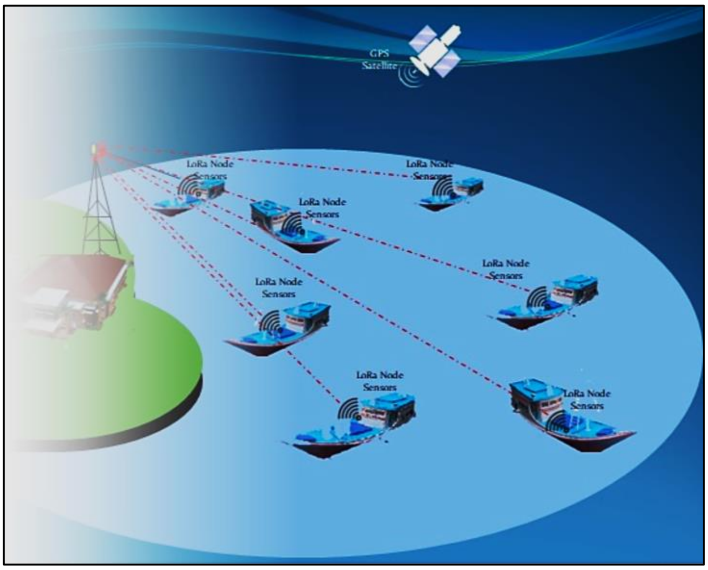

Figure 1. Communication scheme between the boat and Seaport watch base station

At the bottom, all raw sensor data from the use and movement of boat GPS devices is sent to the gateway antenna, and a local server stores a non-structured dataset for further processing and analysis [11]. In the previous study, the LoRaWAN antenna collected the signal incoming from a boat equipped with a Bluetooth peripheral. To find the optimal coordinates of the boat, the Bluetooth devices are mounted in the boat. The most recent version is for so-called Bluetooth Low Energy devices.

1-4- Bluetooth Low Energy (BLE)

Alsufyani et al. (2021) have shown successful experiments on the implementation of the LoRaWAN project for marine data transmission with strong performance. The LoRaWAN antenna collects the signal and delivers it to the transceiver, which converts it into digital data for database processing. The database is then processed through intelligent data identification and classification procedures at different levels of data analysis in real time using MQTT software based on the time of the incoming data [12]. Previous studies have reported the results of combining LoRaWAN with BLE for marine data transmission. However, the model still needs improvement. The model has difficulty identifying the boat identification (boat-id). It impacts how the port officer can identify which boat is on standby near the location. Therefore, it needs further study on how to get the boat coordinate data with the boat owner's identity. The purpose of the boat identification is to protect the ownership of the boat, measure the position and location distance, and conduct traffic analysis.

Other scholars have shown that BLE has the ability to transmit a stronger signal compared to conventional Bluetooth. It can also minimize data loss due to signal friction [13]. The BLE also has internal memory up to 4 MB for storing static data such as boat IDs and owner identification data. In this way, the combination of LoRaWAN with BLE will make it easier to carry out boat identification so that boat ownership can be verified.

2- LoRaWAN Gateway

In Figure 2, the LoRaWAN gateway consisted of a LoRa antenna, which was installed and connected to the LoRaWAN network system with its components. The main component of the LoRaWAN network is the physical structure of the base station layout, with the deployment of the LoRaWAN antenna and sensors as the signal gateway. The peripheral components are sensors with long-wave sensitivity, and their components will be described below.

2-1- Weather Sensor

Pieters et al. (2021) have shown that the optimal position of the LoRaWAN must be located in the base station area. The LoRa antenna is equipped with sensors for air and soil temperature as well as air humidity. Additional sensors can be added to measure more specific purposes [14]. With the help of environmental sensors mounted to the LoRA antenna, the platform can be connected to a GPS-based mobile device or computer located in the base station area. The sensors can also recognize sunny or rainy weather conditions.

For this reason, there should be a number of digital and analog sensor ports in the LoRaWAN network, including three I2C (Inter-integrated circuit), two API (serial peripheral interface), two ports, one cable, and two analogs. Scholars have recommended that the use of digital sensors with built-in ADCs (analog-to-digital converters) will improve energy savings [15]. In addition, the digital sensors can be used over long distances without compromising sensitivity [16]. Environmental sensor data is implemented for some popular temperature and humidity recorders (e.g., DS18B20, SHT3x).

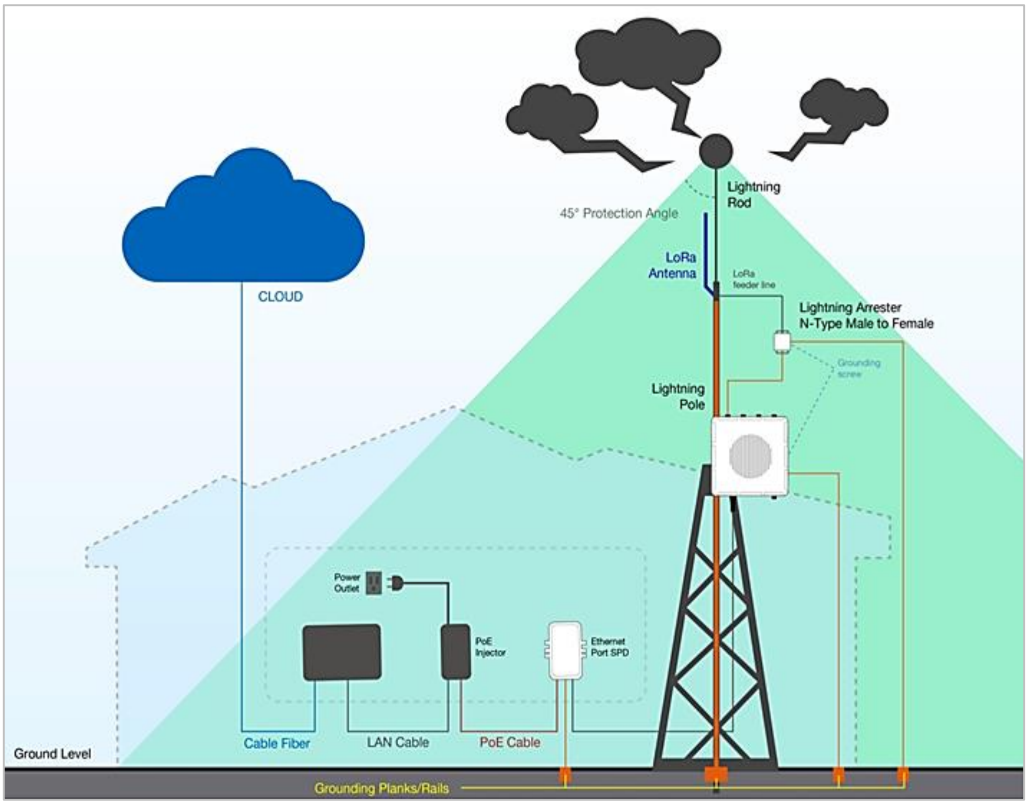

Figure 2. LoRaWAN Gateway

2-2- Data Transmission from the Boat to Gateway

Tassetti et al. (2022) showed that data transmission could be done from the boat to the gateway. The gateway collects the data from the boat, which is processed in three steps. Firstly, the boat data is stored in BLE's internal memory. The goal is to connect the BLE signal from the boat into the LoRaWAN-Based [16]. Secondly, the data from the sensors will be adjusted to monitor the movement of boats [17]. When the gateway goes offline, sensor nodes store sensor values in their 4 MB (up to 210,000 characters for three sensor readings over time) [17]. Similarly, the gateway stores data if the main server is offline. As a result, LoRaWAN networks still collect signals in situations where offline monitoring from one place is sufficient and is installed without internet uplinks [14].

2-3- Lightning Protection and Environmental Disturbances

Previous studies have added Special printed circuit boards (PCBs) and lighting boards to monitor lighting incidents, air temperature, and relative humidity at the LoRaWAN antenna. The components can be easily connected to any I2C port. It has the purpose of monitoring boat activities around the port in real time, even in bad weather. The system combined real-time monitoring systems with desktop applications to mitigate power failures and lighting. The signal filter is added because the sensor can accept a wider signal in normal and heavy weather. The sensor will determine that direct sunlight corresponds to intensities ranging from 100,000 lx to 120,000 lx, which can exceed the maximum value of 1,048,575 (20-bit configuration) when multiplied by the maximum analog gain value.

2-4- LoRaWAN Gateway and Its Component

Various RF modules are available in the wireless industry [18]. Stranahan (2020) reported a higher preference for using the LoRaWAN module. The LoRaWAN module facilitates a variety of functions, such as different sample rates, signal speeds, and digital output levels, associated with two types of operating modes. The module is connected to an application programming interface (API) and a transparent application (AT).

For transmitter purposes, the system has gateways and sensor nodes. The default time of the current battery life of the sensor nodes is 434 days. The main battery life is about 1552 days (when using a battery with 2.6 amps per hour) [14]. Odukomaiya et al. (2021) reported that the gateway can monitor the boat over a relatively long period of time and in real-time in port and traffic. With this gateway system, three sensors are read every 20 minutes. Data from gateways is uploaded to servers and stored in databases on a daily basis. Normally, the service life of a lithium-ion battery is about 3 years and 6 months at full capacity. However, with the increase in temperature, the effective capacity of lithium-ion batteries decreases rapidly [19]. This will reduce the effective service life of BLE and will depend on weather conditions.

2-5- RAK Transceiver as a Core Component of the Built-in LoRa Server

Overmars & Venkatraman (2020) reported the importance of using RAK transceivers to process data from signal to digital according to LoRaWAN standards. RAK4631 was used as a transceiver connected to the LoRaWAN core module for this study (Figure 3). It supports Bluetooth 5.0, Bluetooth Low Energy (BLE), and the latest LoRaWAN receiver. It is also supported by Arduino libraries. After RAK 4631 is installed, the data is transmitted to the server and finally to the database. The module must be connected to the antenna when using a LoRaWAN low-power receiver or Bluetooth. Scholars have warned that using this receiver without an antenna can damage the component [20].

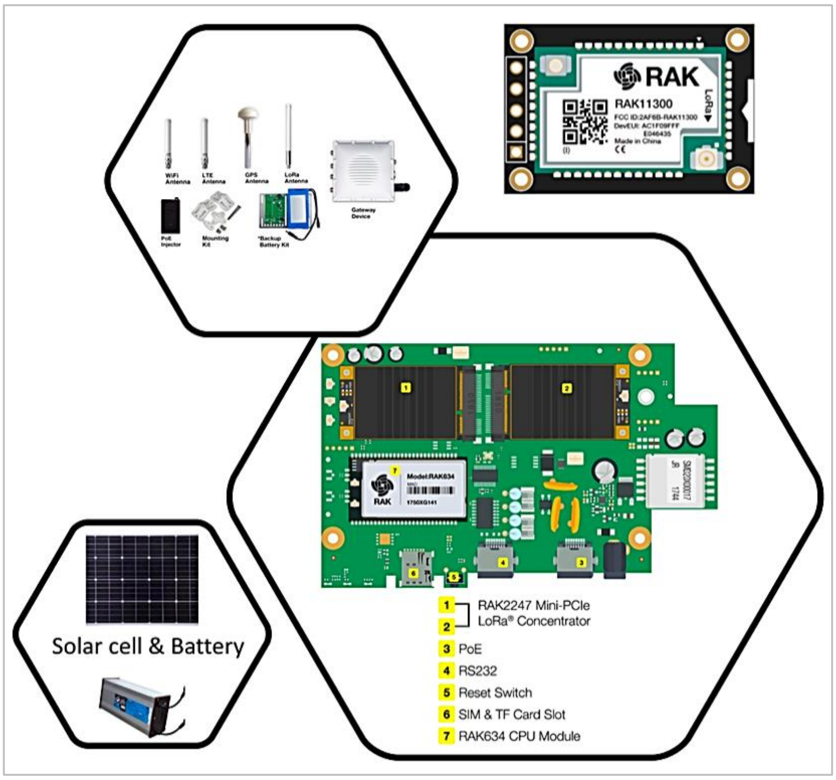

Figure 3. RAK Transceiver

2-6- Open VPN for Data Security

Gentile et al. (2021) reported that boat data transmission was prone to cyberattack. To reduce the risk in the port and ensure real-time communication from boat to port unit, network security must be activated. The scholars also suggested improving network security between the boat and LoRaWAN Gateway through VPN [20], especially by securing access to all gateways/base stations (via SSH, Web, etc.) regardless of LAN/VLAN/3G/4G connection type [21].

To establish a secure connection between Gateway and the LoRaWAN and IoT network server platforms, the Open VPN service must be activated. To do so, choose the Open Cloud IoT service that will connect the VPN to the computer desktop. OpenVPN will provide a new IP address and IP configuration for the server for encryption of the data from the boat to the system. Scholars also recommended that the use of openVPNs will reduce security attacks on IoT systems [21]. In addition, OpenVPN works with most IoT devices, including the LoRaWAN RAK Gateway. The gateway security has encryption features to protect the data from client to server using HMAC packets (Figure 4).

Scholars have reported the performance of transmitters connected to LoRaWAN gateways, which are mediated by openVPN. The transmitter at the base station is installed with the LoRaWAN Gateway HMAC package for the purpose of authentication and encryption. OpenVPN also protects data transfers with pre-shared keys and peer validation. It operates in the user's local space with rooted privileges. Angelo (2019) has reported that OpenVPN has an advantage since it will not limit local authorities from connecting to multi users. The local authorities can create a local OpenVPN as a TCP (Transmission Control Protocol) or UDP (User Datagram Protocol) service that functions as both a server and a client [22]. To do so, OpenVPN will request a connection from the client. With this feature, OpenVPN can give local authorities more control over server configurations. OpenVPN will encrypt the boat data, including the Bluetooth ID address from BLE devices and the coordinates of the location. It will be protected with strong authentication, easy access, and high flexibility, which reduces the hacking risk.

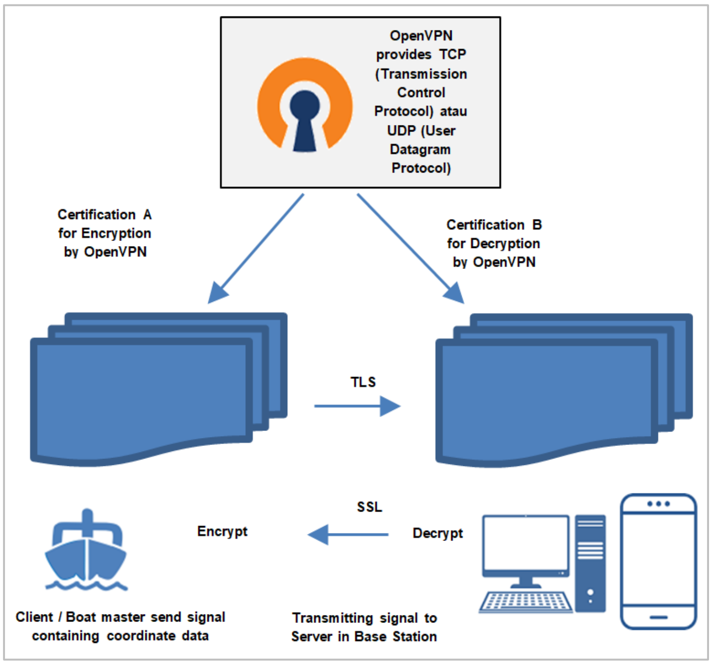

Figure 4. Security scheme for LoRaWAN gateway

2-7- LoRaWAN Network Mechanism

Angelo (2019) reported that GPS coordinates can be detected using the RAK gateway transceiver [22]. The transceiver is the most important component of the LoRaWAN network mechanism, which is programmed using the open-source WRT software. The RAK gateway transceiver is installed near the Antenna to monitor signals from the boat [23]. The purpose of using this component is to detect signals from boats to base stations via RAK transceivers for identifying and monitoring the boat's route and location based on its GPS coordinates.

(a) RAK transceiver box from top side (b) RAK transceiver box from left (c) Symbol of RAK transceiver box

Figure 5. RAK transceiver box

The RAK transceiver will collect the signal data consisting of GPS coordinates (position of the boat) [24], BLE ID address, and the identity of the boat owner. The GPS coordinates are stored in latitude and longitude, and the boat identity contains the names and identities. Snapir et al. (2019) have conducted experiments with the field test and successfully reported the distance and area of the monitoring system by using GPS coordinates [25]. Other scholars have obtained from the analysis that the system is suitable for working in areas with shallow water and signal coverage in Delta Rivers.

The LoRaWAN network provides a number of specific parameters so that its behavior can be adapted to a specific application. The configurations allow the network to connect with a join request feature. Any network that hears a request will ask for keys, which are processed by the DevEUI Oyster-JoinEUI protocol before transferring any data. By default, it will try to rejoin the LoRaWAN network if it contains a downlink key or token ID. The token ID is stored in the BLE's memory. On the LoRaWAN network, it sends requests to determine whether downstream traffic is normal enough to allow roaming. It can also be configured to combine functionality with personalization.

2-8- Challenges toward Integration of BLE and LoRaWAN

Scholars have proposed that Bluetooth Low Energy (BLE) devices can be implanted anywhere, including on boats. The BLE implant is aimed at transmitting wireless signals through Bluetooth devices. The BLE can collect hydrographic data in shallow water to support safe and efficient boat transport, especially for boat inspection. The instability of traditional wooden boats was identified as a major safety risk for small-scale fishermen. So, the boat can be monitored routinely for inspection. It can also collect boat transport data when the boat routes in riverbed data on shallow areas such as rivers, lakes, reservoirs, oxidation/detention ponds, and other water. So, the boat can be monitored routinely for maritime transport safety. However, it is a challenging task for the LoRaWAN network to collect marine GPS data to accurately locate the boat, jet ski, or any marine vessel in real-time. The system uses satellite signals to determine boating GPS units displayed boat's position in latitude and longitude. Furthermore, there is complexity for BLE implanted in the boat to transmit subsequent data via BLE. This device only transmits a signal on a specified band to locate certain objects. A summary of the challenges of integrating BLE and LoRaWAN is given in Table 1.

Table 1. Issue and challenge in maritime transport safety

Enablers	Description
Maritime transport safety	Maritime safety is a broad term including everything related to company's overall responsibility to provide optimal conditions and resources for propelling the ship safely at sea [26].
Connecting Bluetooth to small wooden boats	The implementation of Bluetooth low energy (BLE) devices implanted on body of small wooden boats [23, 24].
Monitoring small wooden boats in shallow waters	Collecting hydrographic data in shallow water to support safe and efficient boat transport especially for boat inspection [27, 28].
Monitoring small wooden boats in river delta areas	Collecting boat transport data when the boat routes in riverbed data on shallow area [29, 30].
Tracking signal from boat's GPS coordinate	Collecting Marine GPS data by LoRaWAN network to accurately locate the boat, jet ski, or any marine vessels in real-time [21, 31].
transmitting the boat's signal transmission	BLE implanted in the boat will sending/receiving subsequent data which transmitted by the boat which coming through a BLE. This device transmits a signal on a specified band to locate the boat [13, 16].

2-9- Advantage of LoRaWAN

The LoRaWAN system has a low cost and can be used for transferring signals with gateway receivers. The system consisted of sensors, RA transceiver devices, security levels, and the opening of WRT software inside the RA gateway receiver [9]. There was a communication scheme between the boat and the LoRaWAN system at the base station. LoRaWAN can transmit sensor signals using third-party intervention, such as Bluetooth. The Bluetooth device on the boat is used to transmit GPS coordinates. All raw sensor data from boat GPS devices is sent to the gateway antenna and local server base station. LoRaWAN antennas collected signals incoming from boats installed with Bluetooth peripherals. To find the optimal coordinates of the boat, the Bluetooth devices are mounted in the boat. The most recent version is for so-called Bluetooth Low Energy devices. The summary of the advantages of LoRaWAN for the IoT Framework is given in Table 2.

Table 2. Advantage of LoRaWAN for IoT Framework

Enablers	Descriptions
Cost	LoRaWAN system has cheap cost [8, 32].
Easy to custom	The system consisted of sensors, RA transceiver devices, security levels [9, 33].
Communication scheme	There is communication scheme between the boat and LoRaWAN system at base station [14, 15].
Sensor signal	LoRaWAN can transmit sensor signals using third party intervention such as Bluetooth [8, 32]
Gateway antenna	All raw sensor data from boat GPS devices is sent to the gateway antenna and local server base station [13, 16].
LoRaWAN and Bluetooth	LoRaWAN antenna collected signal incoming from boat installed with Bluetooth peripheral [20, 21].

3- Methods and Architecture Overview

In this study, the LoRaWAN signal will be measured based on its parameters. There are some important parameters that will be used in this study, such as strength, transmitter power, packet payload, bandwidth, electronic monitoring unit, packet header and sensor, encoding level, deployment element, and motion monitoring unit. The monitoring mechanism is implemented in several steps. Firstly, the parameters of LoRaWAN Radio in the study, such as operating frequency, transmit power, package payload, and spread factor (distance radius in meters), The parameters are used for monitoring the transmission of signals from the boat to the LoRaWAN network. This monitoring process will receive signal transmissions from the boat to the server on a normal day in shallow water and during bad weather.

Secondly, we will detect the boat signals in bad weather. The combination of signal data from the antenna and data from the sensor is used to detect the boat signal, which is mixed into the header packet. In this way, the boat's GPS coordinates can be sent via BLE devices, and they will be received by the LoRaWAN gateway for further processing and display on smartphones and dashboards. Thirdly, we monitor the noise level from the sea and wind. The noise level is high when the wave speed is fast and the wind direction is far away from the base station. Therefore, we will position the boat in shallow water when the boat is still docking at a nearby port. The noise level can also disturb the BLE's ability to get GPS data. In addition, bad weather has a great impact on boats signals, including BLE and LoRaWAN [34].

Fourth, the detection of boat signals in sunny weather will be compared to bad weather. In sunny weather, the sea air and waves move at stable and low speeds. In bad weather, we will use MQTT to combine multiple signals from different times during the monitoring so that the boats are tracked in real time and interconnected with the LoRaWAN system.

Fifth, the level of false negative and false positive on the boat signal will be adjusted to carry out large-scale deployments and their possible efficiency for boat monitoring. False negatives can be caused by the boat still moving and undocking. Whereas, false positives occur when the boat is docked near other boats in crowding. To resolve the issue, the false positives and false negatives will be processed further for data extraction. The Visual Studio C# graphical user interface is designed to extract and upload raw data to a MySQL server. From a local server, the data will be analyzed and uploaded to the website with the help of a movement sensing unit at a certain time (day or hour of the day).

3-1- LoRaWAN Network Mechanism

After raw data is stored in the database, LoRaWAN will respond via the RAK Gateway transceiver. As open source, WRT software will handle the operation of the RAK Gateway transceiver. The component will be installed on the proposed model to monitor signals from the boat [23]. The purpose of this platform is to detect signals from the boat to the base station via RAK transceivers, which are installed in the LoRaWAN network system. The proposed model is useful for identifying and monitoring the boat's route and location based on its GPS coordinates. The BLE collects GPS coordinates, stores the coordinates, and transmits them to the LoRaWAN Network.

The LoRaWAN network used in this study is 1.0.3. Beside GPS coordinates, the BLE also stores other data, such as BLE ID addresses and boat owner data. The GPS coordinates are stored as latitude and longitude numbers, and the boat identity contains the names and identities of the boat owner. Snapir et al. (2019) with the field test successfully reported the distance and area of monitoring by collecting GPS coordinates in shallow water [25]. In this study, the proposed model will be implemented in shallow-water and delta river areas since it has stable signal coverage. The BLE's signal will be collected based on specific parameters so that the boat's behavior can be analyzed. The BLE configurations allow the device to connect to the network with a join request feature. The LoRaWAN network that hears a request will ask for BLE keys, which are processed by the DevEUI Oyster and JoinEUI before transferring any data.

By default, BLE will try to rejoin the LoRaWAN network if it contains a downlink key or token ID. This ensures continued operation if the network faces a block (for example, if the device has been installed incorrectly). On the LoRaWAN network, it sends requests if the downstream traffic is normal enough to allow roaming. It can also be configured to combine functionality with personalization. The overall process of connecting data from the device to the application/desktop dashboard is shown in Figure 6.

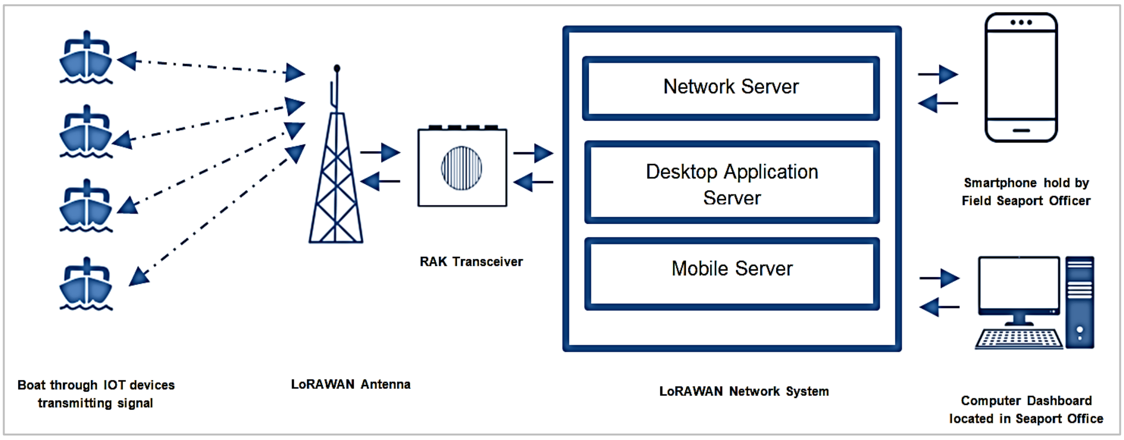

Figure 6. LoRaWAN Network Mechanism

3-2- Data Transmission from Boat to Base Station

The boat sends GPS coordinate by transmitting data from boat to Base Station at Port Office (Figure 7).

The LoRaWAN will receive the signal via an antenna bridge broker. This process is carried out from the boat (client) through the TLSV 1.2 protocol (version 3.3). There is a possibility of starting the data package transmission at this stage by using the security protocol of Hello Handshake Version 3.2 and the cipher suites TLS_DH_anon_ WITH_RC4_128_MD5. After the protocol is accepted, the data packet is connected to the bridge broker, and the handshake code is put in metadata as the secure point of the data package communication. The message is still filtered using the SSL protocol for security reasons (level 2). If a virtual server client also uses a similar SSL profile, it enables message data transfer. The transfer occurred when the boat sent the signal through a secure channel. Otherwise, the network will request asymmetric encryption (public key) [35].

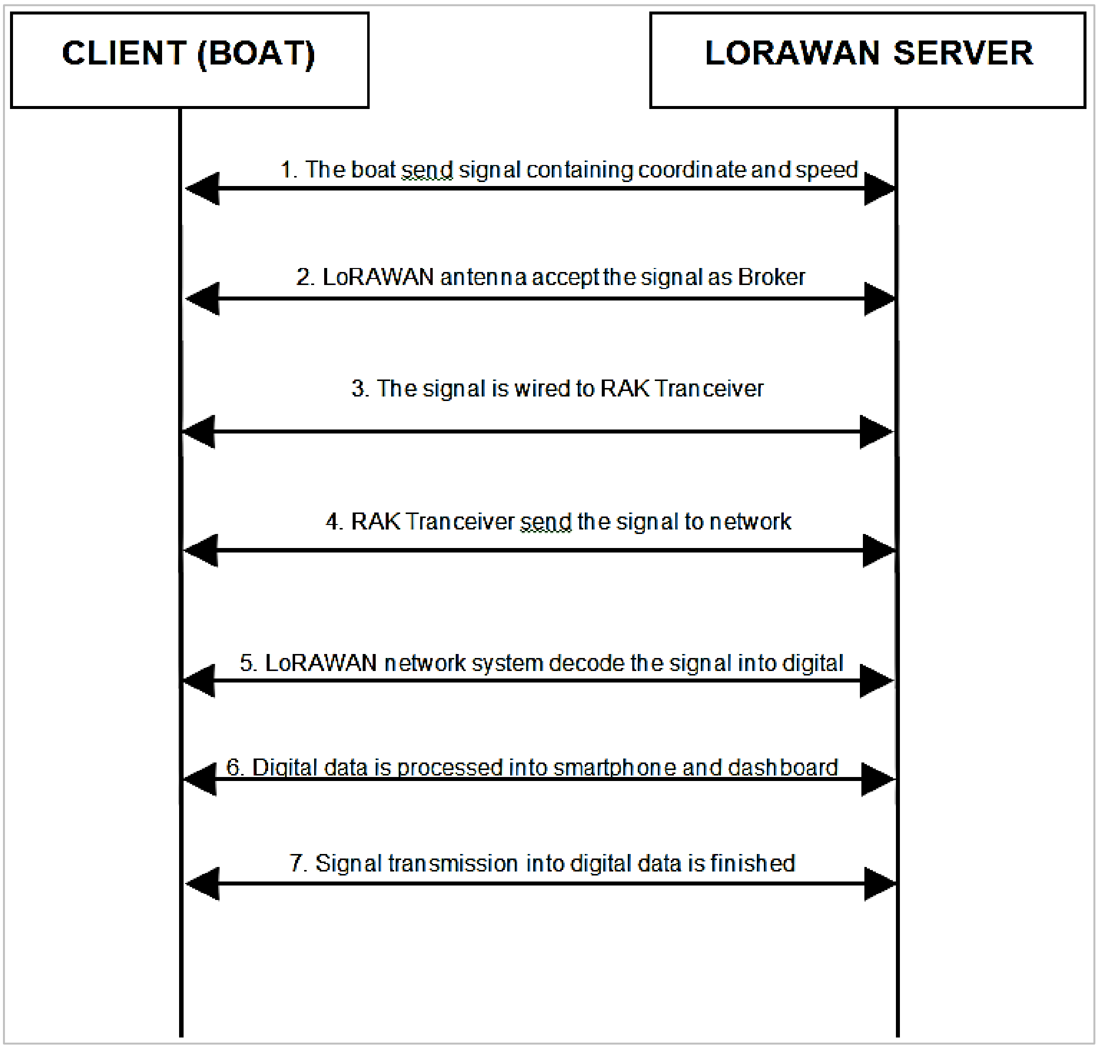

Figure 7. Mechanism of Signal transmission

A failure of the handshake at this stage may be due to incomplete signal transmission, which leads to a false negative. An interrupted transmission will damage data containing SSL messages. Other problems will occur because SSL encryption is processed at different times during cipher processing on the server [36]. The mechanism of signal transmission into digital data starts from the boat's BLE to the base station. The main process is connecting gateways to LoRaWAN networks via RAK transceivers, as illustrated in Figure 7. The RAK Transceiver sends the signal to the network system when the parties open a secure channel to communicate using an asymmetric key (shared key) [37].

The failure of a handshake at this stage may be due to damage to SSL messages or problems with the implementation of SSL itself [36]. Such failure can lead to false negatives. To prevent the problem, after the signal is accepted, the signal is decoded into a digital data packet through verification steps so that the data is successfully decrypted or encoded. Failure in the decryption phase indicates that the data is incomplete, and therefore, the data will be ignored and deleted by the server. If the decryption phase is successful, the data is sent to the computer dashboard and stored in a database. In this step, the computer dashboard also processed the boat data that can be accessed via a smartphone using a web browser or OpenSSL client, and the data exchange occurred between the smartphone and dashboard. When the data exchange activity is fully completed, the server closes the connection, the system becomes redundant or standby, and the process of signal communication is closed (Figure 7).

4- Analysis Results

4-1- Data Flow in Sensor Node to LoRaWAN Gateway

In the data flow from the sensor node to the gateway antenna, both components are used to communicate between sensor nodes and the gateway. The stream from the gateway antenna to the sensor node is measured based on the parameters of the LoRaWAN radio representing its default signal strength, as shown in Table 3. In this study, LoRaWAN radio parameters were developed to determine the topology and configuration of the device.

Table 3. LoRaWAN 868MHz Parameters

Radio Parameters	Selected Values
Operating frequency	868 MHz (European IEE Standard)
Transmit power	10 dBm
Package payload	6 Bytes
Bandwidth	125 kHz
Encoding level	4/5
Battery capacity	1.8V, 1000mAh
Spread factors	10 Areas
ACK Length	2 Bytes

The communication method is configured using two functions: the server update function and the IoT device function to generate device tokens. Each wireless sensor is connected to the gateway antenna (ZC) from the server to the IoT device, as shown in figure 8 below. The goal is to accept the signal, starting with a gate device token and checking the status. Through this approach, the data stream will run smoothly from the server to the IoT device using the token from the sensor device. A sensor requires the transmission of key signals (for example, a network identification number in a private area).

This gateway antenna is a transceiver radio frequency module that receives data from every sensor node in the network [26]. In a mesh topology, sensor routers will increase the network coverage area (see Figure 8). The sensor devices can be configured as sensor end Devices (SEDs) routers. SED needs low-power as well as small battery devices to be installed in the antenna [26]. At sensor nodes, the data stream ends up in shallow water at different distances in urban areas and is sent to the gateway antenna above the data network.

To receive signal transmission from a boat to a server, there is a mechanism to update the IP address from the server to an IoT (boat) device through several steps. Firstly, the boat will create a token ID using the command getBoatTokenID, which is designed to create a new file containing the token ID as the boat's identity through the MQTT protocol. Its purpose is to expose the device token.

If this action is correct, the response will come from the boat that sent the response token (Step 2). In the third step, if the token is valid (ok), the server will ask for the boat response with the boat coordinate, to which the IoT device responds by sending a GPS coordinate to the antenna. The data is then stored on the server as a new file and folder called CERTs. On a Linux server, the system should already have a certificate folder under /etc./mosquitto/ as well as a certs folder. The server will store the Boat data and certificate folder in the certs folder, along with the server IP address and new key.

In the final step, the server will request signal transmission data with a strong signal command. If the signal is still weak or there is too much noise, the command will be repeated after a few seconds. This data will be stored in the cert file as the default listener with the mosquito conf. file format as per the MQTT protocol. Although the backup file will save a weak signal value, which is an additional listening file, the server is still collecting the weak signal as noise using the MQTT protocol. The next part exposes how the boat condition affects signal performance. We will consider two scenarios, the first of which is a normal day in shallow water and the other during bad weather.

4-2- Detection of Boat Signals in Bad Weather

In bad weather, the signal data from the antenna is used to detect the boat signal, which is mixed into the weather sensor. Header packets in the axis block from the weather sensor are used to calculate the amount of air pressure in bad weather. Its purpose is to record real-time data from the sensors for an extended period of time to minimize data loss due to signal friction. The results of this system are very important for the reference system in real-life situations in this area and show an excellent correlation with the data collected by established data loggers. The output voltage can increase when accepting the received signal.

The range of resistance varies across power sensors found in different types of sensors. In this case, the sensor is connected to the air conditioning circuit with 9V power supply. These strength measurements are combined to identify patterns of boat movement. In the boat monitoring system, the radio signal often does not get a linear communication channel and only accepts weak signals as noise to reach the LoRaWAN antenna. Under real-world conditions, radio signals are typically prone to depletion caused by barrier-absorbing material properties. These boats made of wood material will absorb and weaken the signals. It causes more noise.

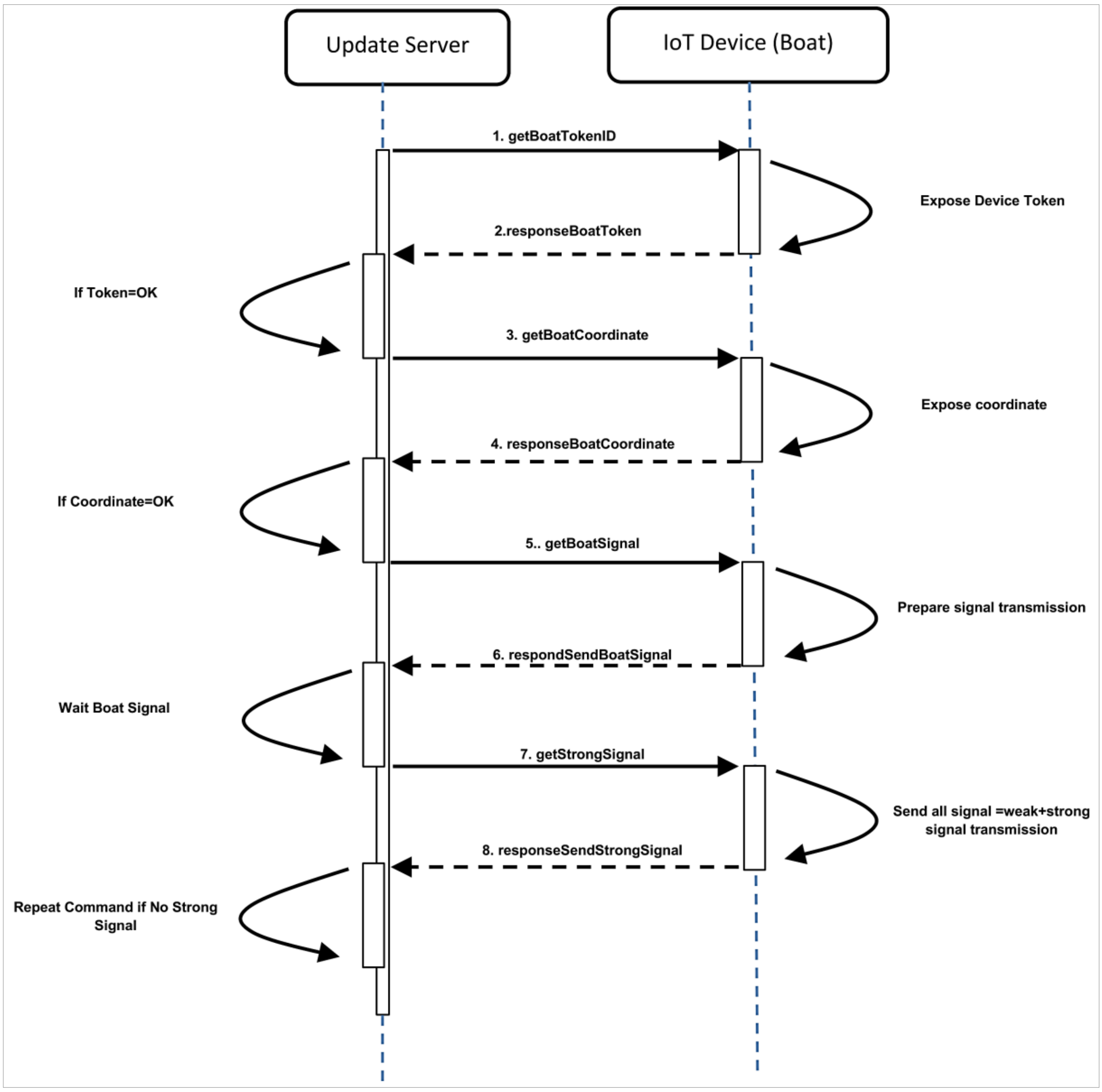

Figure 8. The mechanism of getting signal transmission from Boat to Server

4-3- Client and Server Communication

Understanding client and server communication during messaging is essential to understanding the connection between BLE and the LoRaWAN network. Client (device) data is represented by protocol support. If the server does not support the client protocol version, it must send a "protocol version" warning message and close the connection. If the server responds with a lower version of the protocol, the client decides whether to reduce the protocol or stop the SSL handshake. Client Data also offers a list of auxiliary cipher sets in an orderly manner. The server then typically selects the highest level of password owned by both secure connections. If the server does not support the cipher from the client (device) list, the connection stops.

The server will select the desired cipher from the client list together with Handshake data from cipher suites TLS_RSA_WITH_RC4_128_SHA TLS_RSA_or Handshake Server Hello version 3.1. Through these protocols, the client and server successfully establish the SSL protocol in the first instance and the SSL Cipher in the second instance. In this way, the boat's GPS coordinates can be sent through BLE devices and received through the LoRaWAN gateway for processing in the network system and display on smartphones and dashboards.

Figure 9 shows two types of boat signal detection zones in bad weather in areas of 10 locations, which resulted in two zones of high noise zones and low noise areas. The sensor data result showed that the sea waves and wind moved towards the sea. High-speed waves heading towards the sea can interfere with the boat's signal due to excessive noise. In figure 9, the noise level in area A is high and the signal strength is low, so the signal detection of the boats is weak. Area B has less noise and higher signal power, which increases boat signal detection. The signal is weakened due to the wind and speed of the boats. The boats were also detected from the base station. The red color represents a signal detection zone with high noise when the boats are moving at high speed and the wind direction increases rapidly.

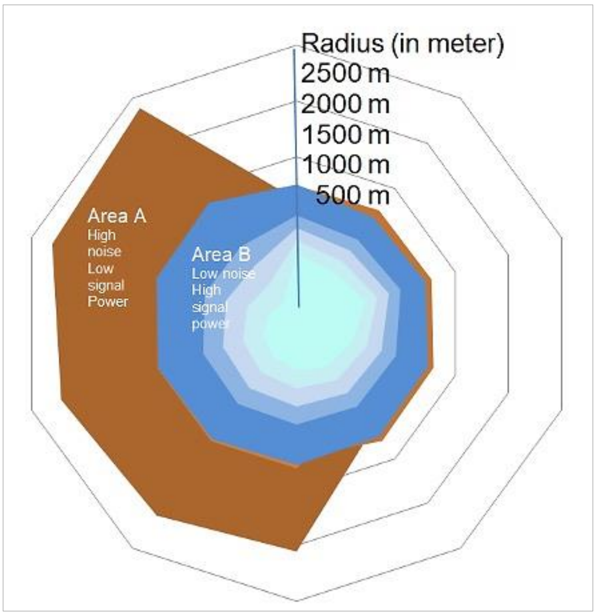

Figure 9. Two kinds of boat signal detection zones in heavy weather are shown in 10 patrol areas representing sea patrol areas, division of zones by noise level

There is a signal detection zone with less noise due to the nearby location of the boat from the base station, so the noise is small. The red color represents a signal with high noise (Figure 10). The signal detection zone contains higher noise as the boat moves faster and the wind direction moves faster toward the sea. The experiment is not perfect due to external factors. In the field experiment, the outdoor environment of the base station can result in a signal echo caused by boat material and other boat equipment that causes obstruction. However, we strengthen the transmitted signal to get an accurate measurement of the signal strength due to the material.

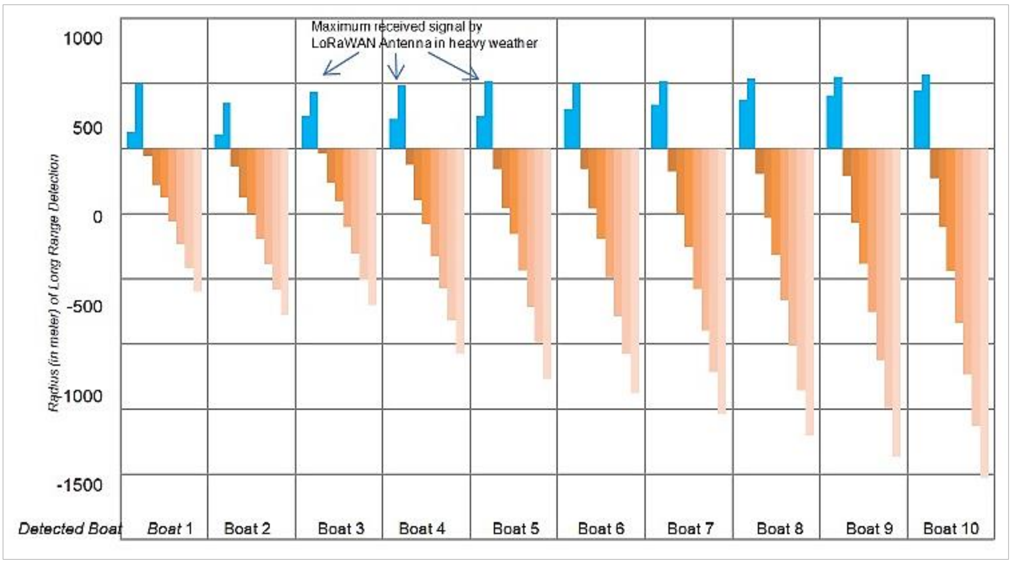

Figure 10. Maximum received signal by LoRaWAN Antenna in heavy weather

Although different boats are anchored, which can create signal interference and noise, we try to implement realistic scenarios so that only boats with volunteers will become participants in this study to record their signal strength and multidimensional spread, which affects the measurements [38]. The setting is done to obtain a fully controlled environment to test the effects of signal power on the performance of the system. The transmitter and receiver are separated by a particular type of material, and the distance is fixed to estimate the loss of signal strength.

In the case of a low noise signal (Figure 9), the blue color represents the low noise signal detection zone due to the location of the boat, which is still close to the base station, so that the noise is small. Initially, the value of the transmission signal is recorded on the channel line and compared to its noise. The noise can reduce the signal power. The loss of signal power is caused primarily by the wind and waves, including bad weather and different types of boat direction. In addition, the wind direction produced different levels of noise (Figures 11 and 12).

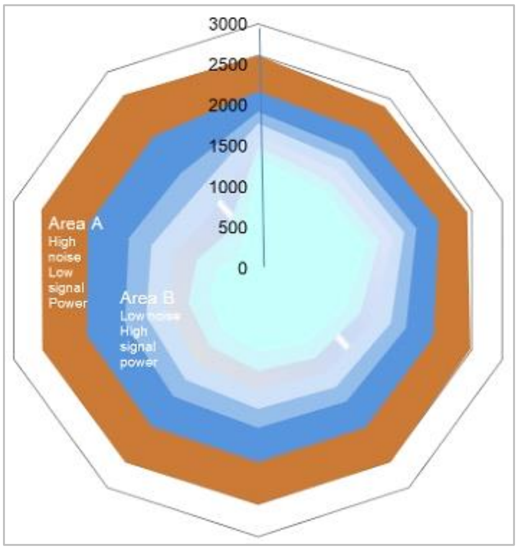

Figure 11. **The signal from the boat in sunny weather**

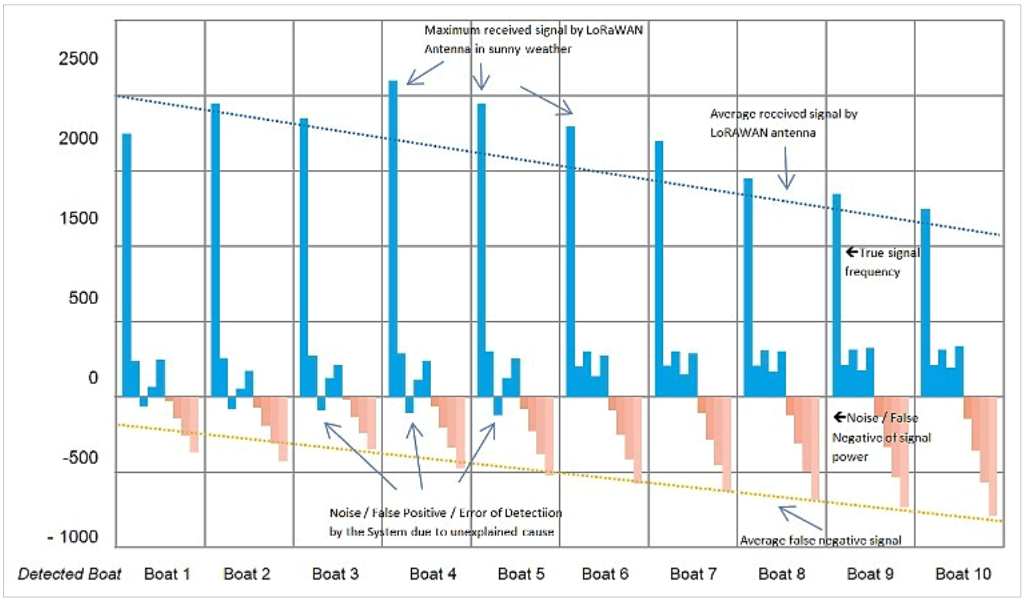

Figure 12. **Maximum and average received signal by LoRaWAN Antenna in sunny weather**

Besides strong winds, bad weather also contributes to signal loss or significant fluctuations, leading to large echoes and higher noise. Therefore, it is important to find a solution so that LoRaWAN can receive the weak signal. We then remotely tested the effects of these parameters in the field on the distance and area of the activity monitoring system, as well as the position of the boat based on the parameters. The parameters are high waves, wave speed, boat speed, and high-speed boat direction of sea waves.

4-4- Noise Level

The noise level is formed when the wave speed is fast and the wind direction is far away from the base station. The noise level can also be caused by boat parking locations nearby, so that the GPS coordinates create a similar value. The weather also has a great impact on LoRaWAN [34]. The results of the experiment at this point showed that the signal generated by high wind speeds could be detected only below a radius of 1 km. This will be discussed in the limitations section.

From Figure 10, the signal power decreases when the boat is detected to be stable at a maximum distance of 500 meters due to high noise. This curve is the test result in bad weather with ten volunteer boats. Bad weather is evidenced by strong winds (windy weather), wind direction turbulence, and the speed of active and high tide waves, especially in the tropical seasons of June and July [39]. The two terms can be distinguished in Figure 10. The first situation with a blue color is the signal detected by the LoRaWAN antenna from the boat transmitter. Then the noise of the red color signal is caused by strong winds. A number of boats departing from the seaport (local base station) have been identified and represented in batch performance. In shallow-water applications, each packet has a significant effect on a strong signal. When the boat is stopped or anchored at a distance of about 500 meters from the base station, the boat is recorded at very low speed as a discrete signal that is stationary and motionless. The boat's wet condition and its wood material are not measured since the focus of this study is to detect the boat signal with weather parameters [28]. The experiment results show the average boat size and distance between the boats are approximately 500 meters from the base station in bad weather.

4-5- Detection of Boat Signals in Sunny Weather

The next experiment was to determine the detected signals in sunny weather [29]. In the weather situation, which is reflected by slow waves and the normal path of the boat, the signal is more evenly distributed near the circle, which means that the entire boat can be detected normally. The traditional boats are about 70% made up of wood or plastic in sunny weather [41]. The signal strength due to boats and people in the ISM range is about 3 dB, and in the 5 GHz band it is about 5 dB. As shown in Figure 11, signal transmission from the boat in sunny weather shows the noise is still high due to the condition of the boat and the fisherman/passengers on board.

In sunny weather, the sea air and waves move at stable and low speeds. From Figure 11, the signal detection results provide two types of zones for detecting boat signals, which display 10 deployment zones representing marine patrol areas (Figure 11), for example, high noise zones and low noise zones. Low-speed waves going towards the sea do not interfere with the boat signals, making less noise [39].

A large area of high signal strength indicates that boat signals appear strongly. Area A is narrower than area B, with higher signal strength in sunny weather. This data is obtained from Figure 11, when the speed of the wave is slow, so that the signal of the boat can be received uniformly as long as all the boats can be detected. It is assumed that the base station is located in the center because it emits signals that are evenly distributed 360 degrees in the direction of the ocean.

Data is obtained from boat signals recorded by LoRaWAN antennas during a sunny day when the weather clears from 9 a.m. to 3 p.m. If the wave speed and the wind speed are slow, the boat signal can be received with a uniformly distributed circle of all the discovered boats. When the boat moves fast, the signal is still strong, and it is possible to determine the direction of the boat. This makes sense because the higher the speed, the stronger the boat signal from the base station, which is about 3 to 5 kilometers away. Signal noise is caused by two different scenarios: one is noise interference, and the other is in the counter direction of wind and sea wave direction toward the location of the base station. The signal loss cannot be measured by the LoRaWAN receiver. The minus sign in Figure 12 indicates that the boats were moving away from the original base station, which caused high noise.

The detected signal from the boat departing/going away from the base station has resulted in a weak signal that can be detected well up to a distance of 300 meters. To amplify the signal, we enable the feature that certificates and generated keys can be used on web servers to collect weak signals over a longer duration of time by following the MQTT protocol together with the broker. The broker uses this key of the IoT device, called a token ID, to create a certificate application. In this way, this signal becomes stronger so that the observations of boats anchored in the port and the direction of boats are tracked in real time and interconnected with the LoRaWAN antenna.

4-6- Level of False Negative and False Positive on the Boat Signal

For the purpose of monitoring the traffic of domestic boats coming and going from the base station, we made a wireless contact sensing system and connected it. For this reason, the encoding level must be adjusted to the contact sensing unit of the boat. This has the goal of identifying the frequency of boat traffic for the gate server. The goal is to be able to carry out large-scale deployments and their possible efficiency for boat monitoring. We then want to measure the error of detection, which we refer to as false negative and false positive in boat signals. We do it when the weather is sunny (Figure 12). According to the purpose of this research, namely to detect the boat's signal and attenuation level, a comparison of the signal strength captured and the noise received by the LoRaWAN antenna can be obtained. In this experiment, it was directed to be able to measure the signal from the boat to the base station.

The mechanism runs by means of the MQTT protocol and SSL TLS Configuration. For that objective, we will configure the MQTT broker to use TLS security [30]. OpenSSL is used to create Certificate authorities (CA), Server keys, and certificates. To test the broker, the Paho Python client is used to connect to the broker using an SSL connection. The data is collected by LoRaWAN antennas through PKI mechanisms, certificates, and keys before proceeding.

After LoRaWAN accepts the SSL Certificates and MQTT broker, the MQTT client will open the connection between the client and Web Server [30]. In this way, the signal level becomes stronger so that it can detect the boat's signal in sunny weather. The minus sign represents that the noise is detected about 1000 meters away from the base station, which is different for each boat. The Maximum and average received signals by the LoRaWAN Antenna in sunny weather are also tested (Figure 12). The blue color represents the maximum received signal by the LoRaWAN Antenna in sunny weather. The red color represents Noise / False Positive / Error of Detection due to an unexplained cause. The detected boat was also transmitting noise/unfavored signal due to other causes that were not analyzed in this study. The minus sign represents detected noise about 1000 meters away from the base station.

Signal power gets stronger when the wind comes towards the base station even though the boat is moving away from the base station, which is measured between the transmitter (boat) and receiver (LoRaWAN antenna) [42]. Boats that move against the wind will have a stronger signal because the wind direction goes to the base station. The red color indicates the size of the noise / false signal frequency, which means it reduces the signal strength. Noise can be formed due to unstable boat speed or constrained by interference from fluctuations in wave speed and sea breeze speed.

If the wave speed is slow, the boat's signal can be received evenly by all detected boats. This data was obtained from signals recorded by the LoRaWAN antenna during the day from 9 a.m. to 3 p.m. To strengthen the signal, the MQTT section also made modifications so that a trusted server certificate on the Boat Client can be obtained [43].

Figure 12 also represents the comparison of noise with toward average false negative signal. The false negative signal is caused by the slow processing of the LoRaWAN network when the boat is still moving away in shallow water. Such a slow computation process is caused by the fact that the data from a local MySQL server is raw data, and from this raw data information is extracted through software. The movements of the boat on a given day are detected from the motion sensor data files. The collected boat signals are processed and analyzed with a dashboard to determine the pattern of boat activity. To resolve the problem, we have limited the number of motion sensing units, and it is a useful approach to identify the physical location of such vessels in real-time. We have placed a motion sensing unit right near the base station of the entry or exit area so that we can quickly identify the physical location of the boat.

5- Discussion

This study presented the test results of the proposed model of LoRaWAN network system for detecting boats GPS signals. The test results show that this model is feasible in MQTT-based IoT scenarios. In addition, the updated protocol seamlessly integrates our signal-to-digital data transmission mechanism from the boat IoT device to the Port Office base station. It also describes the ontology and architecture-driven devices of server and hardware applications.

The proposed model has the ability to detect signals from IoT devices implanted in the boats. To do this, we have included a method of receiving signal transmission from the boat to the LoRaWAN network that consists of a boot token ID to ensure the security of data transmission. Important parameters such as boat speed and boat detection troubleshooting are also analyzed based on its strong performance. All this is implemented using the MQTT protocol, equipped with TLS and SSL.

The results of the experiment showed that the speed of the boat impacted the received signals. The Investigations were also carried out to detect the boat signals in bad weather. In bad weather, there are two types of noise zones: high noise zones and low noise zones. This affects the speed of the boat moving away from the base station. The weak signal is also caused by the boat being docked in a crowd.

To prove this assumption, we tested the noise levels of the boats docked in the crowd and the weather parameters around the base station. As a result, it was achieved that the noise level forms at a distance from the base station with high wave velocity and wind direction. It shows that the weather has a big impact on LoRaWAN's ability to detect the boat signal.

The results of the experiment showed that the signal generated by the rapid movement of air from the base station was very high, and the boat was detected only below a radius of 1 km. The results of the test showed that the signal from the LoRaWAN antenna decreased drastically in bad weather. The high noise led to a decrease in signal strength with a stationary detection boat at a maximum distance of 500 meters. The strong winds blowing in the middle of the sea away from the base station also impact signal detection. We then compared the detection of boat signals in clear weather.

When the waves are slow and the boat moves normally, the signal is more evenly distributed closer to the circle, which means that the entire boat can be detected normally. The signal of the measured boat is formed between the transmitter (BLE) and the receiver (LoRaWAN antenna).

The 10 deployment zones representing naval patrol areas in bad weather have been used to show two types of boat signal detection zones, such as high noise zones and low noise zones. It found that sea air and waves move at stable and low speeds. The experiment results show that the low-speed waves going towards the sea do not interfere with the boat signal and produce less noise. A large area of high signal power indicates that more boats are strongly detected. This means that signal strength will increase in sunny weather. The experiment results also reveal that in sunny weather, the boat signal from the base station is about 3 to 5 kilometers away.

To amplify the signal, we enable the certificate function, and the key generated can be used on the mosquito/server broker as well as on the web server, which increases signal strength and data security. In addition, false-positive and false-positive error rates are also investigated. Signal force noise or false negatives in high conditions can occur when a boat moves at such a low speed that it disguises itself as seasonal winds and sea waves. In addition, the signal level becomes stronger so that it can reduce the noise interfering with boat signals in sunny weather.

6- Conclusion

The final result shows that the modified LoRaWAN model has the ability to reduce noise and improve safety, as we have also modified the bridge/broker MQTT. As the protocol is integrated with MQTT, the MQTT broker in the test bed supports the ability to stream IoT devices. Our model can detect the boat based on the weather parameters, signal strengths, and volume of transmitted data. In line with the purpose of this study, which aims to create a boat monitoring system that relies on weather parameters, BLE, and LoRaWAN, this study has successfully designed a real-time system that can connect port stations with boats.

We offer the proposed system in combination with secure protocols via MQTT, TLS, and SSL. The model has also been evaluated for detecting boats through gateways and LoRaWAN network mechanisms. The combination of BLE and LoRaWAN has successfully transmitted the data packet in real time to support boat monitoring. The LoRaWAN network processed the real-time data for the desktop dashboard and mobile applications. From the measurement results, it shows that signal transmission is still under LoRaWAN's manufacturing standard.

6-1- Research Limitation

The extent of interference with boats' signals was not studied in this paper due to a lack of equipment and trial time. In addition, the speed coming from the edge of the base station is not read in detail because the speed of the boat is not measured by special equipment but depends only on the recovery and delivery devices of the RA. Another limitation arises from the fact that boat material is not tested due to a lack of tools and limited electrical power installed in the boats.

7- Declarations

7-1- Author Contributions

Conceptualization, D.S., F.L.G., E.A., D.I.S. and T.M.; writing—original draft preparation, D.S., F.L.G., E.A., D.I.S. and T.M.; writing—review and editing, D.S., F.L.G., E.A., D.I.S. and T.M. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

Data sharing is not applicable to this article.

7-3- Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7-4- Institutional Review Board Statement

Not applicable.

7-5- Informed Consent Statement

Not applicable.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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