Vessel Tracking System Based LoRa SX1278

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ABSTRACT

This research presents a vessel tracking system that provides real-time coordinate and speed information. The idea behind the development of this system originated from Automatic Identification System (AIS) technology, which functions as a vessel monitoring system in maritime areas. The system aims to improve navigation safety, monitor vessel traffic, and maritime security. In Indonesia, AIS is regulated by the Ministry of Transportation. However, this technology has not yet been implemented in river waters. In addition, AIS is a complex and expensive system. In this research, geographic location detection information in the form of a vessel tracking system is obtained using the UBlox Neo-6M GPS module based on LoRa technology. The LoRa mechanism periodically sends location data and vessel speed from the node to the gateway. The data is then sent to the ThingSpeak server using the MQTT protocol. On the server, the data can be accessed for further analysis. The developed system shows that the research can be realized and the system functions properly through a series of experimental tests. While in the in situ test, the system displayed good performance on LoRa SF 7 configuration with a signal strength of -118 dBm within the communication range of 1000 meters. This result can be improved by considering the MAPL value of -138 dBm.

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1. INTRODUCTION

In 2019 the government through the Ministry of Transportation has issued a regulation in the form of Ministerial Regulation No.7/2019 concerning the Installation and Activation of Automatic Identification Systems for Vessels Sailing in Indonesian Waters. Automatic Identification System (AIS) is a technology built by observation through satellites (ALOS) [1] and using Synthetic Radar Aperture (SAR) techniques for the presence of vessels on the sea [2]. AIS works by sending information data related to the identity, position, speed, and sailing direction of the vessel [3]–[5]. Data transmission uses Very High Frequency (VHF) [6] in the 156-162 MHz range. AIS itself is intended as an effort to improve navigation safety, prevent vessel collisions, and the level of maritime security [7]–[11].

In South Sumatra, especially Palembang City, small traditional vessels are a manifestation of aquatic society where traditional vessels such as *jukung*, *ketek*, *lesung* are used as a mode of water transportation for the movement of people and goods in the Musi River area. The movement of people and goods through very long river routes should be equipped with a vessel tracking system such as AIS. It is known that building an AIS network involves complex [12] and expensive physical infrastructure, such as AIS-VTS control centers, VTS radar sites, and AIS base stations. As additional information, AIS type B in the market has touched USD 700, of course, this price is too expensive for traditional vessel owners. In addition, the AIS data communication range only reaches 3.7 km in the Line of Sight (LoS) area and 2 km in the Non-Line of Sight (NLoS) area [13]. Practically, the above government regulations have not been able to provide benefits for traditional vessels.

To answer the above problems, it is necessary to apply technology that can act as a real-time vessel tracking system. This system will be able to improve navigation safety, especially related to river traffic management through tracking traditional vessel movement activities in the form of position and speed that can be monitored at any time from a distance. The application is very simple and inexpensive. The system mentioned can be realized with the current technology, namely the Internet of Things-Long Range (IoT-LoRa). IoT-LoRa itself refers to the concept of a network of devices equipped with sensors to connect to the internet and allow them to communicate and interact with each other [14]–[19]. Generally, IoT operations require low power, low cost, and can communicate wirelessly over long distances. This kind of operation characterization can be realized by using Low Power Wide Area Network (LPWAN) technology [20], [21], namely, LoRa. In short, LoRa is very suitable for wide-scale distribution in IoT applications because of its low power and wide area coverage [22]–[24]. It should be noted that the power required by LoRa end-device is only around 13-15 mA and the communication range can reach 15 km. This is the reason why LoRa has advantages when compared to its predecessors such as WiFi, Bluetooth, Infrared, Ultra-wideband (UWB) and ZigBee [24].

There are several studies that discuss and analyze LoRa performance related to its application to vessel tracking systems. This research [25] describes a vessel tracking system that uses GPS to determine location and LoRa modulation to send position data to the nearest port. Due to limited signal coverage from internet providers, analysis of various LoRa devices that can communicate over long distances is carried out. Network resilience was also checked when the vessel traveled from one port to the nearest port (8 km). The installed VTS system is equipped with various sensors to collect information about the surrounding environment, which is then relayed to a web-based platform for real-time tracking. Eight kilometers of transmission was achieved under LoS conditions, and the tracking system was effectively implemented as the object moved across the lake. The use of Lora-based data transmission to communicate between vessels and the database management system for vessels has been demonstrated [26]. The maximum distance of Lora is 10 km, and in order to monitor fishermen along the fishing coast while fishing, multi-gateway Lora is required to expand the coverage of fishermen tracking. The system was developed with Lora multi-gateways located along the coast. Devices built with the Lora client are installed on vessels with GPS input; the method of sending data from the device to the gateway uses a time base with a period of one minute. To reduce the data on the gateway intersecting with the range of other gateways, a time flag is created to ensure the data at a certain time to calculate the trajectory of the vessel. This research successfully built a vessel monitoring system that can provide remote coverage to fishing vessels along the coast. Experiments with multiple gateways by creating the same gateway ID; the Lora client will broadcast to the nearest gateway. The highest achievable distance is 1.35 km NLOS, and 15 gateways are required to cover 20 km of coastal length.

In brief, the contribution of this research is, first, to create a LoRa-based vessel tracking system that functions similar to AIS and can be applied in river waters. Second, based on previous studies, empirically this research presents new things about LoRa-based vessel tracking systems that are rarely found in river territories in Indonesia, especially the Musi River.

Therefore, this research focuses on the design and implementation of the LoRa SX1278 module with the use of Arduino nano as a microcontroller and GPS UBlox Neo-6M as a position receiver which is also integrated with a server in the form of Thingspeak with the MQTT protocol to realize a real-time vessel tracking system. This research also evaluates network parameters to evaluate the performance of LoRa for real-time tracking when determining moving objects at a certain distance. The parameters evaluated are Receive Signal Strength Indicator (RSSI) and Maximum Allowed Path Loss (MAPL).

2. METHODS

2.1. System general design

The system design consists of two main devices, namely nodes and gateways (Fig. 1). The way the block diagram works is that the gateway (LoRa-Rx) can receive data from the sensor node (Lora-Tx). Because of this communication technique, it uses a point-to-point topology. The process of sending data between the node and the gateway uses radio waves with a frequency of 433 MHz. After the sensor reading data is received by the gateway, the data will be forwarded to Thingspeak via the internet network using the write/read API via the Message Queuing Telemetry Transport (MQTT) protocol [27]–[29]. Thus, the data that has been received by Thingspeak [30], [31] can be analyzed, stored, and displayed in the form of graphs or data visualization and can be accessed by the user (desktop/handphone) [32].

2.2. Hardware design of node and gateway

The vessel tracking system consists of two main device units, namely a node that acts as a transmitter (LoRa-Tx) and a gateway that acts as a receiver (LoRa-Rx) (Fig. 2). The node itself consists of a mini solar cell, battery charger module, battery, Arduino nano [33], UBlox Neo 6M GPS module [34], and LoRa RA-02 module [35], and 433mhz antenna [36]. Meanwhile, the gateway consists of a powerbank, ESP32 [37], LoRa RA-02, and 433mhz antenna.

In Fig. 2(a), the mini solar cell is connected to the TP4506 charger module which functions to charge the battery which is the main power supply in the device. The battery will be directly connected to the main component, namely the Arduino nano microcontroller, then the microcontroller will receive data readings from the UBlox Neo-6M GPS module which then the GPS readings will be sent to the gateway via transmission (Tx) LoRa RA-02 (SX1278). Meanwhile, to get data at the node, the node is equipped with a UBlox neo-6M GPS which acts as a signal receiver from navigation satellites. Through the triangulation method, the GPS module obtains a position in the form of latitude and longitude coordinates. The coordinate data can be processed by connecting the GPS module to the microcontroller (Arduino nano) via serial Rx/Tx.

Fig. 2(b) shows the working mechanism of the gateway. It can be seen that the main power supply of the gateway is a power bank connected to the ESP32 as the main component of control on the gateway. ESP32 itself is a microcontroller-based wireless component. ESP32 will process data from LoRa RA-02 (Rx) which successfully receives data from the node which then the data will be published to Thingspeak via the MQTT protocol.

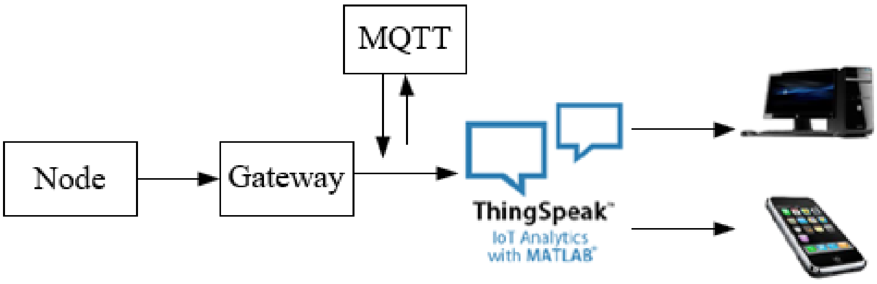


Fig. 1. Vessel tracking system design

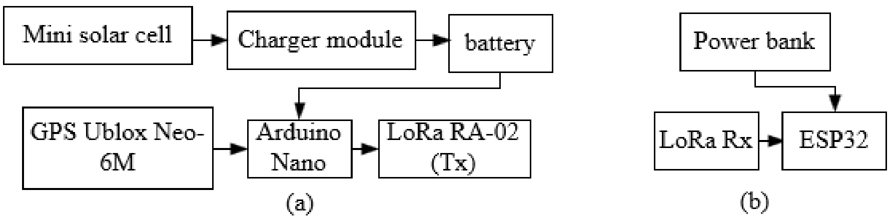


Fig. 2. Tool design chart: (a) node; (b) gateway

2.3. Software design on node and gateway

The configuration of pin connections between components both in the node and gateway can be presented in the form of a wiring diagram to be more detailed in the tool design plan (Fig. 3). Fig. 4 is a flowchart of the node, starting with configuring the GPS communication serial port at 9600 bps and initializing the LoRa Tx component. Next, the GPS scans the navigation satellite signal as an input signal. If the input signal is valid, the GPS module will retrieve National Marine Electronics Association (NMEA) data [38], [39]. In general, NMEA data is in RAW data format. The NMEA data is then extracted into latitude, longitude and speed in string format. The vessel information data package is ready to be sent to the gateway.

Fig. 5 is a flowchart of the gateway, starting with the initialization of the LoRa Rx component and the MQTT protocol configuration consisting of channelID, username, password. The pseudoce for the publish-subscribe (PubSub) mechanism between the gateway and Thingspeak communication is as follows:

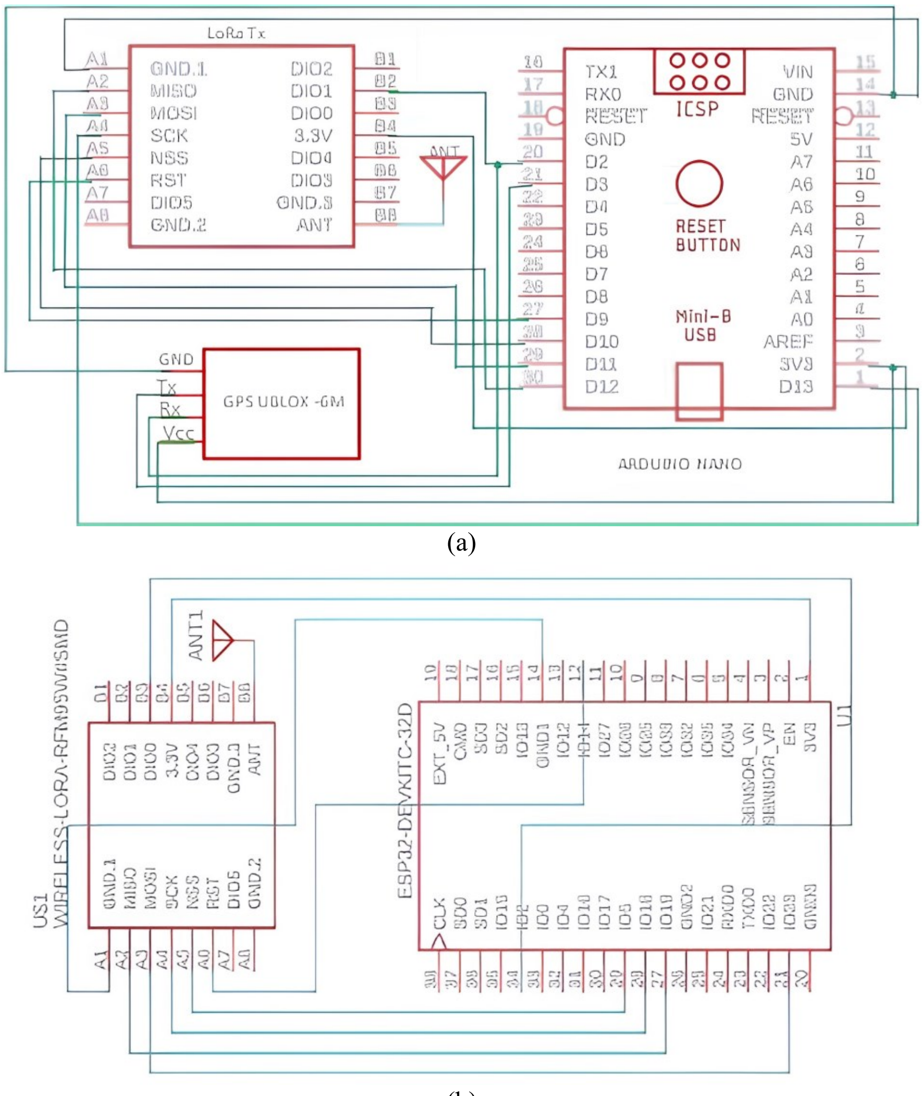
```
// Ensure correct credentials to connect to your WiFi Network.
char ssid[] = "I*****";
char pass[] = "q*****";
// Ensure that the credentials here allow you to publish and subscribe to the ThingSpeak
channel.

#define channelID 21****
#define SECRET_MQTT_USERNAME "Kz****"
#define SECRET_MQTT_CLIENT_ID "Kz****"
#define SECRET_MQTT_PASSWORD "O5****"
```

```
const char mqttUserName[] = SECRET_MQTT_USERNAME;
const char clientID[] = "SECRET_MQTT_CLIENT_ID";
const char mqttPass[] = "SECRET_MQTT_PASSWORD";

#define ESP32BOARD

#include <PubSubClient.h>
#ifdef ESP32BOARD
  #include <ESP32WiFi.h>
  const char* PROGMEM thingspeak_cert_thumbprint = "97****";
#else
  #include <WiFi.h>
      const char * PROGMEM thingspeak_ca_cert = \
```



(a)

(b)

Fig. 3. Wiring diagram: (a) node; (b) gateway

The gateway input data is data that was successfully sent from the node to the gateway. If the data is successfully received, the ESP32 will retrieve the vessel information data. Then the data that has been taken is published via the MQTT protocol. The published data is in the form of google map data plotting for real-time visualization of the vessel's position and is displayed in the form of pop-ups.

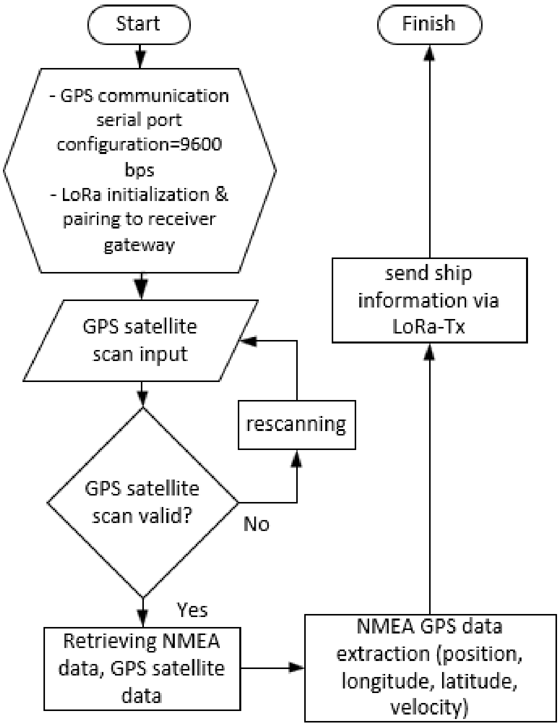


Fig. 4. Node flowchart

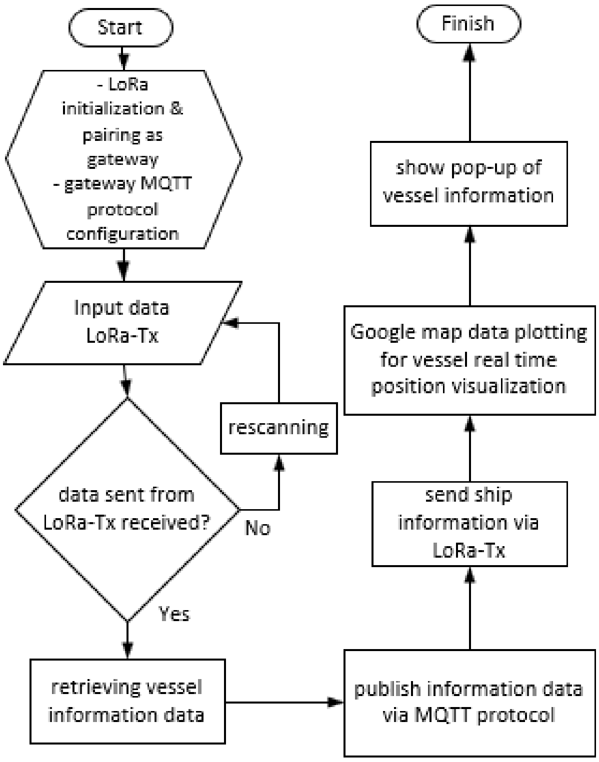


Fig. 5. Gateway flow chart

2.4. Testing and implementation of vessel tracking system

In this section, an experimental testing approach is carried out, which is a method carried out by conducting a series of devices that have been made to get the desired results. This test includes unit testing, system testing, and integrity testing (Fig. 6). In conducting the test, the node and gateway devices are in a workshop.

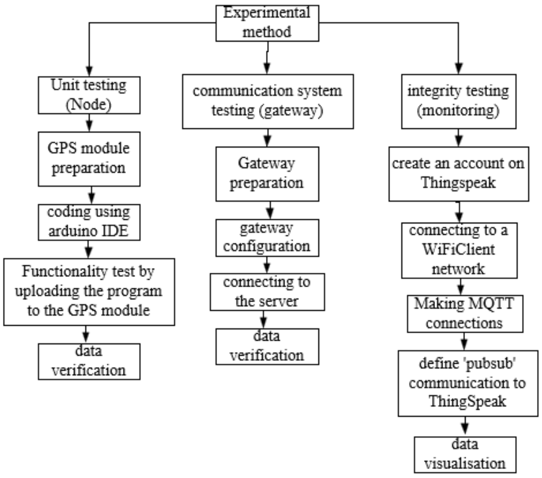


Fig. 6. Experimental testing chart

At the implementation stage, the approach taken is in situ testing. This test is intended to determine the performance of the tool based on the actual environment. The scenario is that the node unit (LoRa-Tx) is placed on the vessel, while the gateway unit (LoRa-Rx) is placed on the Ogan Bridge. The vessel will move away from the gateway with a distance of 1 km. Every 100 m will be evaluated the value of LoRa reliability parameters in the form of Received Signal Strength Indicator (RSSI) [40]–[46] and Maximum Allowed Path Loss (MAPL) values. Mathematically, these two variables can be found using (1) [47].

$$RSSI = EIRP + MAPL \tag{1}$$

where EIRP stands for Equivalent Isotopically Radiated Power whose value is 20 dBm according to the Tx power used in this study. Later the RSSI and MAPL values change as the distance between the node and the gateway changes with the implementation test scenario above.

3. RESULTS AND DISCUSSION

3.1. Assembly result

Fig. 7 and Fig. 8 are the realization of LoRa-Tx (node) and LoRa-Rx (gateway) hardware design, respectively. At the node, the pin configuration between the GPS module and the microcontroller can be seen in Table 1. As for the pin configuration between the microcontroller and LoRa can be seen in Table 2. At the gateway, for the pin configuration between LoRa and ESP32 can be seen in Table 3.

The results of reading a number of satellites in a certain orbit by the Ublox Neo-6M GPS reader produce data records in the form of position coordinates in the form of latitude and longitude. As the satellite readings change in a particular orbit, the position of the node changes as well. The node position data was still in the form of RAW data in NMEA (National Marine Electronics Association) format. Then the data is sent from the GPS to the microcontroller via Universal Asynchronous Receiver Transmitter (UART) with a data transfer rate of 9600 bps. This data information (parsing) is then transmitted to the gateway via terrestrial communication via LoRa-Tx. This scheme does not require an internet network but radio. The LoRa-Tx itself is also connected to the microcontroller via Serial Peripheral Interface (SPI) protocol including MOSI, MISO, SCK, and RST.

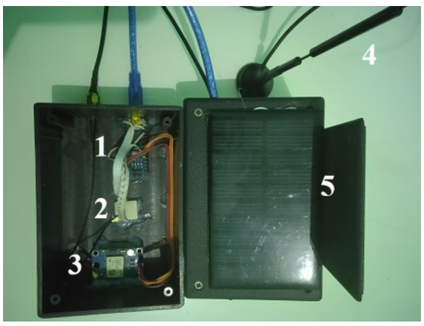


Fig. 7. Node (LoRa-Tx); (1) Board Arduino nano, (2) LoRa RA-02, (3) GPS UBlox Neo 6M, (4) Antena, (5) mini solar cell with modul charger and battery.

Table 1. GPS-microcontroller pin configuration

Arduino nano	GPS Ublox Neo-6M
D2	Rx
D3	Tx
3V3	Vcc
GND	GND

Table 2. Pin configuration of microcontroller-LoRa

LoRa RA-02	Arduino nano
B3 (DIO0)	D2
B4 (3.3V)	3V3
A1 (GND.1)	GND
A2 (MISO)	D12
A3 (MOSI)	D11
A4 (SCK)	D13
A5 (NSS)	D10
A6 (RST)	D9

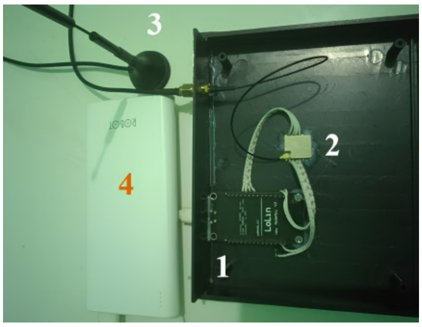


Fig. 8. Gateway (LoRa-Rx); (1) ESP32, (2) LoRa RA-02, (3) Antenna, (4) Powerbank.

Table 3. LoRa-ESP32 pin configuration

ESP32	LoRa RA-02
D2	B3 (DIO0)
3V3	B4 (3.3V)
D19	A2 (MISO)
D23	A3 (MOSI)
D18	A4 (SCK)
D5	A5 (NSS)
D14	A6 (RST)
GND	GND

3.2. Test result of the device connectivity

Fig. 9 shows the results of the arduino IDE serial monitoring of the UBlox Neo-6M GPS module at the unit testing stage. Testing is carried out outdoors with fairly sunny weather. The NMEA message reading results of serial monitoring are shown in Fig. 10. The NMEA message is a sample taken as many as 9 messages. Of the 9 messages there are 4 invalid messages and the rest are successfully read. Messages that were successfully read by the GPS module included: one GGA message (time, position, and fix type data), one GSA message (GPS receiver operating mode, satellites used in the position solution, and DOP values), one RMC message (Time, date, position, course and speed data), one GLL message (Latitude, longitude, UTC time of position fix and status), and one VTG message (Course and speed information relative to the ground).

In system testing, where the gateway shows the success of receiving data from the node. The data successfully received by the gateway is in the form of a coordinate value header with string type and contains vessel speed information. The vessel speed is obtained from the articulation of the NMEA message in the form of $GPVTG. The values for lat, long, and speed are -2.967509, 104.746681, and 0, respectively. These values are obtained from a separation scenario between the node and the gateway at a certain distance, where the node is in a static condition outdoors. The display of the serial monitoring results of the Arduino IDE application is in Fig. 11.

Fig. 9. Preparation of the GPS module connected to the PC in order to display NMEA messages through serial monitoring Arduino IDE

```
COM5
$GPGGA,001308.00,0258.04740,S,10444.78999,E,2,05,1.69,27.4,M,4.3,M,,0000*4E
$GPGSA,A,3,23,26,18,31,29,,,,,,,,3.27,1.69,2.80*05
$GPGSV,4,1,13,02,02,146,,09,,,15,18,34,169,21,22,,,21*70
$GPGSV,4,2,13,23,59,088,34,25,33,056,16,26,38,201,23,27,04,236,09*76
$GPGSV,4,3,13,28,49,312,,29,11,125,32,31,51,295,25,47,08,089,37*76
$GPGSV,4,4,13,50,64,082,34*41
$GPGLL,0258.04740,S,10444.78999,E,001308.00,A,D*70
$GPRMC,001309.00,A,0258.04613,S,10444.79050,E,4.140,0.23,280123,,,D*76
$GPVTG,0.23,T,,M,4.140,N,7.667,K,D*38
```

Fig. 10. Scan of GPS serial monitor with Arduino serial monitor (unit test results)

For example, there is a message that reads:

*$GPRMC,001309.00,A,0258.04613,S,10444.79050,E,4.140,0.23,280123,,,D*76*

The message has a meaning consisting of: Date 28/01/2023, Time 00:13:09, Latitude -2.9674355 Longitude 104.74650833, Altitude 31.7. This NMEA message will be sent to the gateway via LoRa Tx.

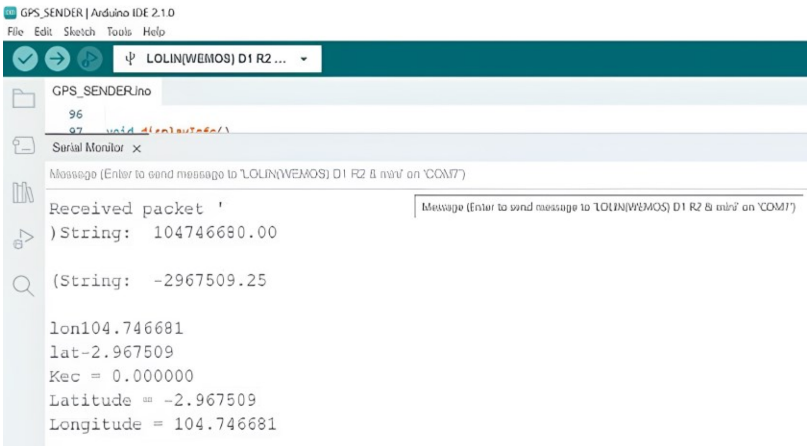


Fig. 11. The results of testing the gateway through serial monitoring Arduino IDE

In integrity testing, a monitoring system was created with Thingspeak that utilizes MQTT as a communication protocol between the gateway and the server. This system helps in monitoring communication activities between nodes and gateways. This Thingspeak application consists of 3 new published channels, namely Field1 (latitude), Field2 (speed), and Field3 (longitude). Meanwhile, for the gateway to server communication broker, the MQTT subscription ClientID has been enabled (Fig. 12). For setting the communication model on the device, it has been setup in the form of publish-subcribe (Fig. 13). MQTT protocol access automatically runs when ESP32 starts sending data.

Once the communication authority is active, the gateway starts publishing data to the MQTT protocol where Thingspeak will receive the corresponding fields and values. Henceforth, the Thingspeak channel will examine the received data and record it in the form of a graph (Fig. 14).

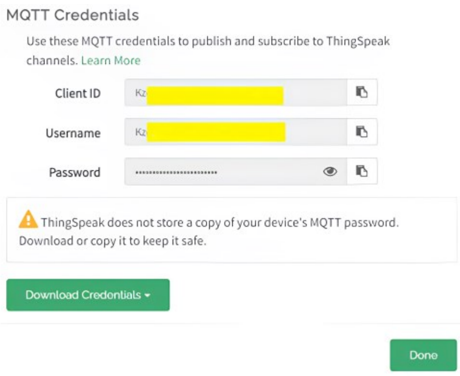


Fig. 12. Client MQTT credentials

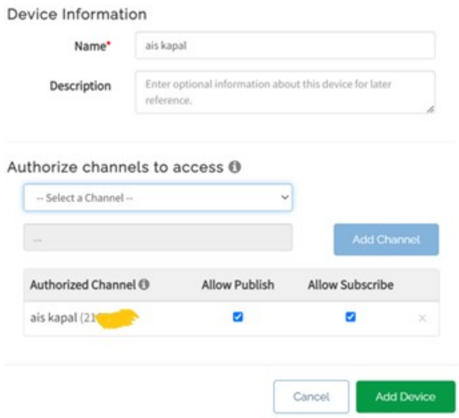
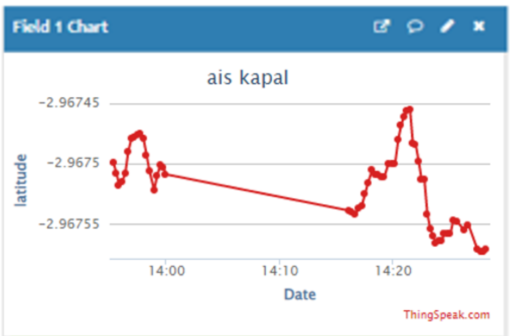
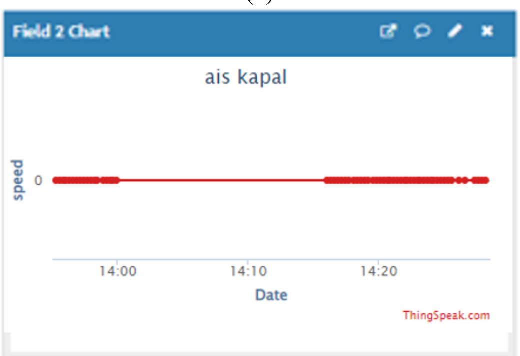


Fig. 13. Authorize channels to access

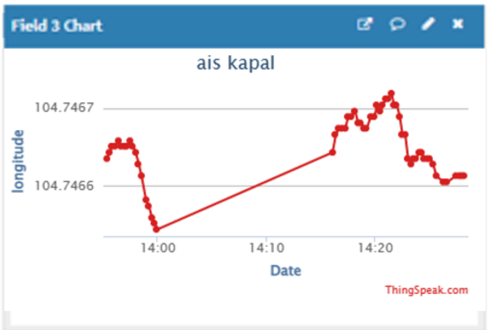
At the end of the integrity test, the nude reading data is displayed in the form of a pop-up map in the form of tracking the position of the vessel. In Fig. 15, there is information related to date, time, vessel name, call sign, speed, longitude, and latitude.



(a)



(b)



(c)

Fig. 14. Channel published; (a) latitude, (b) speed, (c) longitude.

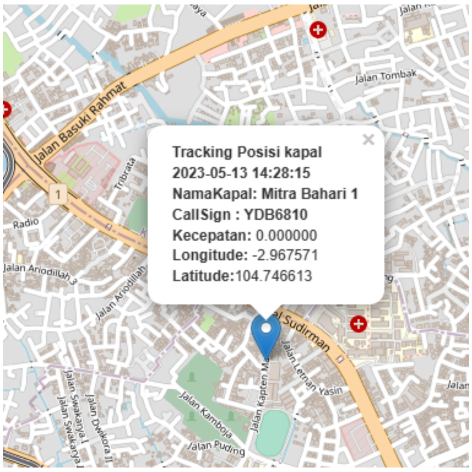


Fig. 15. Pop-up vessel tracking map

3.3. Results of the implementation system testing

In the in situ test, LoRa was setup at a transmission power of 20 dBm, using an antenna gain of 2.5 dBi working at a frequency of 433 MHz. Fig. 16 shows the location of data collection at Ogan Kertapati Bridge, Palembang City. Communication data between nodes and gateways was measured within a distance range of 1 kilometer. Characterizing the location of the in situ test data collection, there are LoS areas at a distance of 0-800 meters and NLoS at a distance of 800-1000 meters. LoRa-Tx was placed on the vessel (moving), while LoRa-Rx was placed on the bridge (static) (Fig. 17).

Table 4 is the result of RSSI measurements based on changes in the distance between the node and the gateway at every 100 meters interval. The RSSI value is generated from changing the Spread Factor (SF) parameter which is 7, 9, and 10 respectively. The RSSI is obtained based on sending data in the form of 3 data with each 1 bytes header, 10 bytes of latitude, 9 bytes of longitude, and 8 bytes of speed. So, the total data transmission for one send is 30 bytes.

It can be seen that the RSSI value decreases as the distance traveled by the vessel increases. This shows that there is a relationvessel between communication range and signal strength. At a distance of 1000 meters, SF 10 obtained a value of -124 dBm. This value is smaller when compared to SF 9 and SF 7, which obtained -122 dBm and -118 dBm respectively. Thus, SF 7 has a good signal strength at the same communication range, which is 1000 meters, when compared to the other SF values.

Table 4. The measurement results of RSSI based on the distance variations between the two LoRa devices

LoRa SF	RSSI (dBm)									
	100 m	200 m	300 m	400 m	500 m	600 m	700 m	800 m	900 m	1000 m
10	-71	-84	-89	-97	-103	-109	-114	-113	-121	-124
9	-67	-82	-85	-95	-100	-107	-109	-112	-119	-122
7	-64	-78	-82	-91	-97	-104	-106	-108	-116	-118

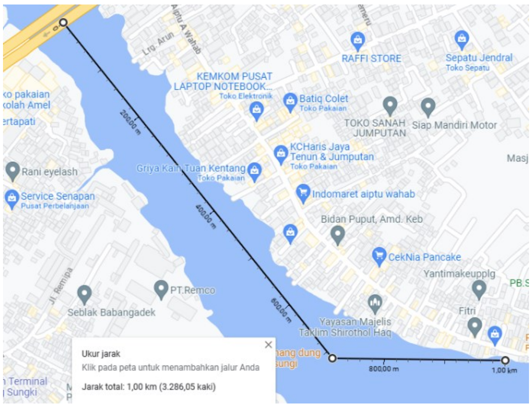


Fig. 16. System implementation test location (source: Google maps)

Fig. 17. Placement of nodes and gateways

The MAPL value trend can be seen in Fig. 18 to Fig. 20. The MAPL value usually follows the RSSI measurement result. Generally, the MAPL parameter is used to estimate the maximum distance that a radio signal can travel before losing enough strength to be reliable. In addition, the MAPL parameter can be used as a guide to estimate the communication range in a given environment. For example, in SF 10 (1000 meters distance), the communication range can be optimized by considering a MAPL value of -144 dBm. With this value, it is possible for the vessel to sail beyond 1000 meters before the signal is completely lost. As for SF 9 and SF 7, the MAPL parameter values are -142 dBm and -138 dBm, respectively. Thus, the estimated optimal communication range of the realized vessel tracking system has the best configuration at SF 7.

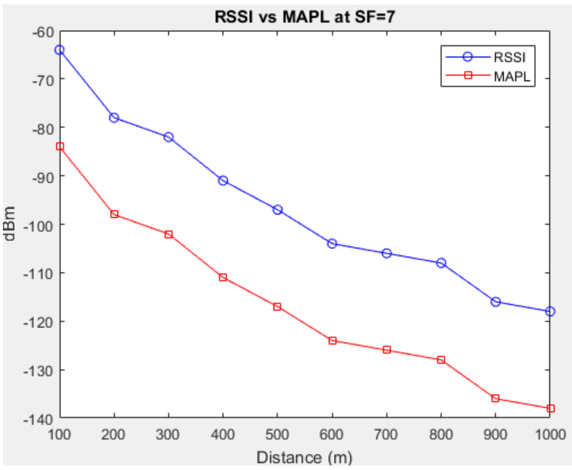


Fig. 18. Comparison between RSSI and MAPL at SF=7

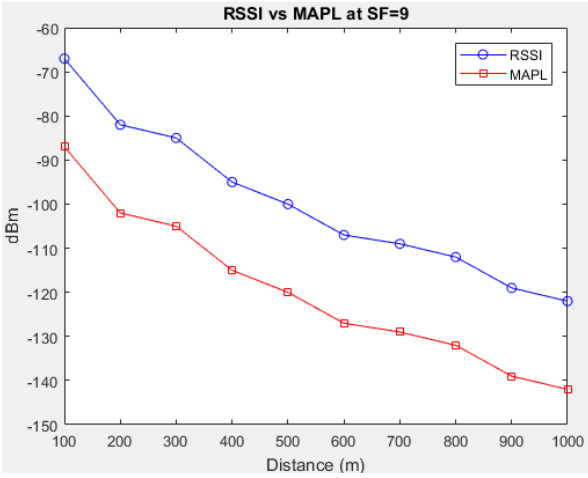


Fig. 19. Comparison between RSSI and MAPL at SF=9

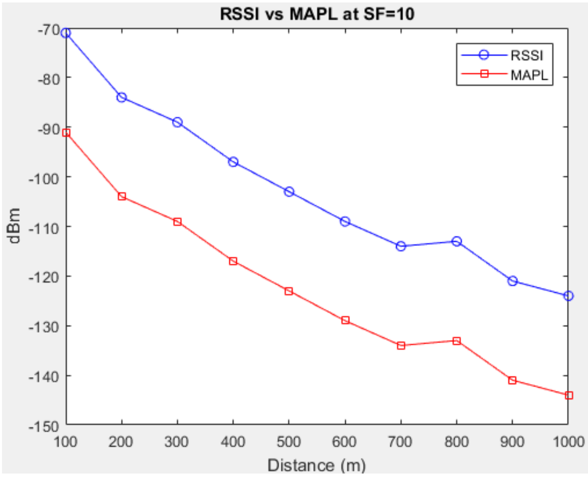


Fig. 20. Comparison between RSSI and MAPL at SF=10

4. CONCLUSION

In conclusion, the LoRa SX1278-based vessel tracking system presented in this research has effectively overcome the limitations of AIS and provides a reliable and efficient solution to improve vessel navigation security. The implementation and testing of the system has demonstrated its effectiveness in tracking vessels and providing real-time monitoring results to users in the Musi River region. In addition, the system is designed to be easy to implement and affordable for vessel owners. However, there were limitations and challenges identified during the implementation phase, such as the weakening of the signal at a range of 1000 meters in the SF 10 configuration. These challenges can be addressed in future work by proposing multiple network topologies for wider coverage and more vessels connected to the gateway. Overall, this project has made a valuable contribution to the field of navigation especially in creating a vessel tracking system applied in rivers developing a reliable and efficient IoT-LoRa based solution. Future work could focus on improving the reliability of the wireless sensor network system, integrating it with other IoT devices, and exploring its applicability in various settings in public areas.

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