Developing IoT-LoRaWAN Ambulance Tracking System to Enhance Emergency Response

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***Abstract*—Emergencies pose a significant threat to individual lives and societal stability, necessitating prompt intervention to prevent escalation. Ambulances, serving as medical transport vehicles from hospitals, are essential for transferring sick or injured patients to healthcare facilities for further treatment. The effectiveness of these crucial ambulance services can be enhanced through Internet of Things (IoT) technology. This study presents a design for an IoT-Long Range Wide Area Network (LoRaWAN)-based ambulance tracking system. Leveraging LoRaWAN technology offers an extended communication range. The system integrates a Global Positioning System (GPS) sensor with a microcontroller to track the ambulance's location. GPS data is transmitted via LoRa to a gateway, which then forwards the data to a cloud server for display in an application. Accuracy tests involved comparing GPS readings from the microcontroller-integrated system with Google Maps data. Results indicate an average error of 0.00055736% for latitude and 0.000015648% for longitude coordinates. Additionally, the developed smartphone application displays real-time GPS data with an average delay of 22 seconds.**

Keywords— Internet of Things (IoT), Long Range Wide Area Network (LoRaWAN), Ambulance, Tracking, Emergency

I. INTRODUCTION

Emergencies are critical situations that endanger lives or societal well-being, requiring immediate intervention to prevent worsening conditions [1]. Timely access to medical treatment can help save lives, reduce mortality rates, and enhance the quality of life [2]. A critical factor that accelerates emergency response is the transportation of patients to healthcare facilities.

An ambulance is a medical transportation vehicle used to transport patients to healthcare facilities for further treatment [3]. A major issue frequently encountered in healthcare facilities is the inability to accurately track the location of ambulances [4]. Consequently, health centers struggle to monitor ambulance operations, availability, and predict when ambulances are expected to return to the facility [5].

This study develops an ambulance tracking system to address the existing issues. The system utilizes IoT technology and the LoRaWAN wireless network to track ambulances. LoRaWAN technology is used because it has a wide range, making it ideal for application in tracking systems. This can improve the response to medical emergencies by ensuring the safety of patients and medical personnel during travel.

The rest of the paper is structured as follows. Section II reviews related studies. Section III outlines the research methodology. In Section IV, we analyze and discuss the results. Finally, Section V concludes the paper and suggests directions for future research.

II. RELATED WORKS

Research related to vehicle tracking using various types of IoT networks has been conducted by several researchers. D. Rahayu [6] developed an Android-based vehicle tracking application using Arduino Uno and the SIM808 module. This study also created a tracking device that receives GPS data from satellites and then transmits the location coordinates to a web server via the internet. M. Arif Budiman [7] built a real-time vehicle tracking system using a web-based microcontroller. The system was developed by integrating a GPS sensor and an Arduino Nano processor with a WiFi module on a NodeMCU. It connects to the GSM network via a relay to send data to a web application. Adven Padang [8] designed a stolen vehicle tracking system based on Telegram. Tracking coordinates are done using the GPS NEO6MV2 module. The research demonstrated that the device could accurately track coordinates in outdoor conditions. However, the device has a limitation in that indoor position tracking requires time to connect to satellites.

Meanwhile, several researchers have explored the use of LoRaWAN as an IoT network to support tracking systems. Hayati et al. [9]-[11] conducted a study on utilizing LoRaWAN to monitor the location of patients with mental disorders. In their studies, they designed and performed an experimental trial of the system, analyzing the correlation between battery capacity and movement speed. Mohandass et al. in their study [12] simulated Traffic Clearance for Ambulances during Pandemic Situations and Road Accidents using the LoRaWAN network with the CupCarbon simulator. The results demonstrated the system's capability to control traffic lights and highlighted LoRaWAN's advantages in scalability, range, and low power consumption compared to Wi-Fi and ZigBee. Research conducted by Simanjuntak et al. [13] provides an easy solution for vehicle tracking. Their case study focused on tracking operational vehicles in plantations using LoRa transmission. The GPS module monitors vehicle locations and sends the data to a database. The implementation showed that LoRa effectively transmits vehicle location data.

The proposed study overcome these shortcomings with several approaches. First, incorporating complementary technologies such as WiFi help improve indoor tracking by reducing dependence on GPS signals. Second, wider use of LoRaWAN address communication coverage and cost issues, emphasizing the development of data compression methods or bandwidth quality to support faster and more frequent data transmission. Third, innovation in hardware design and the development of more efficient battery technology can overcome limitations in battery capacity and energy efficiency. Finally, the development of adaptive control algorithms for traffic systems and a focus on interoperability with existing infrastructure improve the effectiveness and implementation of vehicle tracking systems. With this approach, the proposed research provide a more comprehensive and effective solution to the challenges faced in vehicle tracking.

III. Design of the Ambulance Tracking System Based on IoT-LoRaWAN

A. Network Architecture

LoRaWAN-based ambulance tracking system design includes components such as end devices, gateways, TTN servers, MQTT communication protocols, Node-RED, Firebase database, and applications. The end device detects location data and sends it to the gateway. The gateway, acting as an intermediary, forwards data to the TTN server [14]. The TTN server then publishes the received data using the MQTT protocol. Node-RED [15] processes this published data and stores it in Firebase's real-time database [16]. Finally, the app pulls data from Firebase to display the location of the ambulance. The choice of technology in this system is based on several considerations. LoRaWAN was chosen because of its wide communication range, which is important for ambulance tracking devices operating in the field. MQTT is used for its ability to transmit data efficiently and in real-time with minimal overhead, ensuring fast data updates. Firebase was chosen as the real-time database because of its ability to store and present up-to-date data. Fig 1 provides a comprehensive illustration of system architecture design.

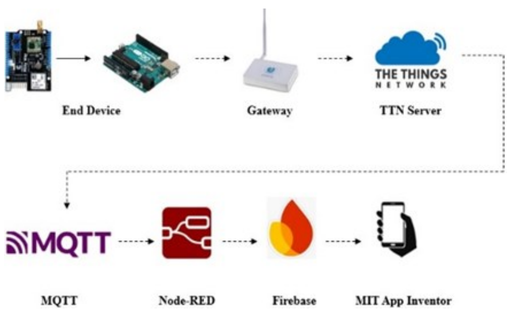

Fig. 1. The illustration of Network Architecture used in the System

B. Schematic diagram of the ambulance tracking system node.

The node serves as the transmitter in the IoT-LoRaWAN-based ambulance tracking system. This design incorporates several key components. The GPS (1) provides location information with latitude and longitude coordinates, which is then collected by the Arduino Uno (4). The Arduino processes and manages the data transmission through the LoRa RFM95W module (2). The LoRa module facilitates long-range wireless communication with the LoRaWAN-based gateway. Subsequently, the gateway transmits the information to the server. This circuit operates using a 9V DC battery (3). Fig. 2 displays the schematic diagram of the ambulance tracking system node.

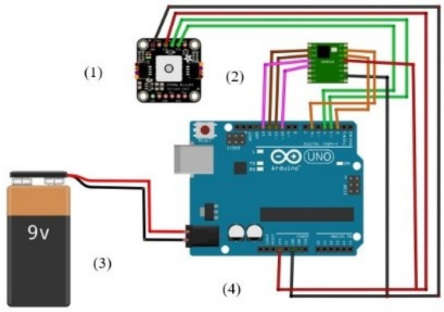

Fig. 2. Schematic diagram of the ambulance tracking system node.

C. System Flow Diagram

The system workflow begins with the node detecting the initial location of the ambulance based on coordinates from the GPS sensor. After detecting the location, the node transmits the data to the gateway, which then forwards it to the TTN server. The TTN server receives the data and publishes it to Node-RED, acting as the MQTT Broker. Node-RED processes the data and then forwards it to the Realtime Database on Firebase. The last, an android based application retrieves and displays the data from the Realtime Database. In this system, we use MIT App Inventor to create an application that displays the vehicle's location points through Open Street Map (OSM) [17]. A flowchart provides a visual representation of the steps involved in the system's workflow, as shown in Fig. 3.

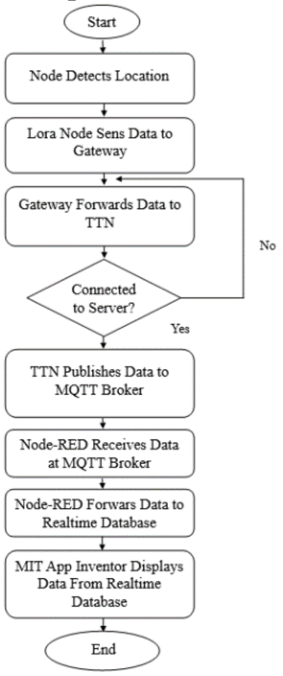

Fig. 3. System Flow Diagram

IV. Result and Discussion

In this section, we discuss the results of system integration experiments. Figure 4 shows the prototype of the node being developed, which consists of Arduino Uno as the main component that controls the system, integrated with GPS which functions to determine location, and LoRa as a communication module to send data, as well as a battery which is the electrical power source for the node. The testing begins by connecting the node to the Dragino LG308 Gateway and TTN server. The server processes the sensor data transmitted by the node and subsequently displays it on an Android-based application.

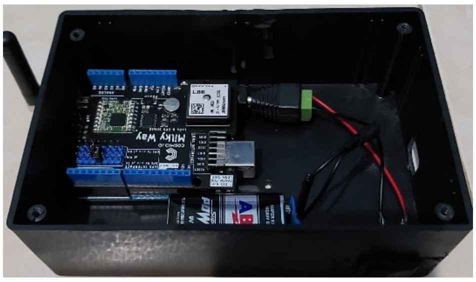

Fig. 4. The Node of IoT-LoRaWAN based Ambulance Tracking

A. The Location Accuracy of Ambulance Tracking System

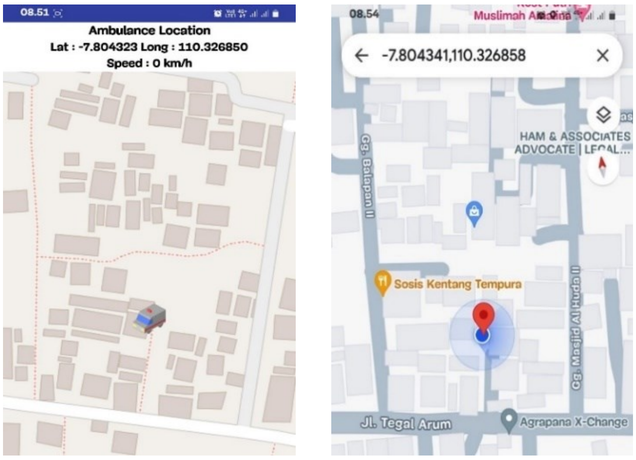

Fig 1 The Ambulance Tracking Application and Google Maps

We evaluate the system performance by assessing the accuracy of GPS sensor readings integrated into the application. We then compare the position readings of the ambulance on the application with the position data from Google Maps at the same location. Fig. 5 shows a

TABLE I. Experimental Results

Tracking System Application		Google Maps Data		Error Latitude (%)	Error Longitude (%)
Latitude	Longitude	Latitude	Longitude		
-7.799183	110.354065	-7.799166	110.354033	0.000218	0.0000290
-7.799363	110.354060	-7.799353	110.354017	0.000128	0.0000390
-7.799508	110.354020	-7.799503	110.354002	0.000064	0.0000163
-7.799567	110.353730	-7.799516	110.353729	0.000654	0.0000009
-7.799490	110.353284	-7.799477	110.353280	0.000167	0.0000036
-7.799478	110.353140	-7.799465	110.353137	0.000167	0.0000027
-7.799463	110.352851	-7.799427	110.352850	0.000462	0.0000009
-7.799457	110.352602	-7.799398	110.352600	0.000756	0.0000018
-7.799435	110.352374	-7.799380	110.352370	0.000705	0.0000036
-7.799459	110.352256	-7.799363	110.352250	0.001231	0.0000054
-7.799242	110.352180	-7.799238	110.352159	0.000051	0.0000190
-7.798937	110.352268	-7.798934	110.352247	0.000038	0.0000190
-7.798843	110.352289	-7.798839	110.352268	0.000051	0.0000190
-7.798760	110.352307	-7.798758	110.352287	0.000026	0.0000181
-7.798649	110.352333	-7.798646	110.352314	0.000038	0.0000172
-7.798562	110.352354	-7.798557	110.352333	0.000064	0.0000190
-7.798459	110.352376	-7.798457	110.352358	0.000026	0.0000163
-7.798271	110.352415	-7.798268	110.352394	0.000038	0.0000190
-7.798143	110.352439	-7.798140	110.352418	0.000038	0.0000190
-7.798032	110.352463	-7.798029	110.352441	0.000038	0.0000199
-7.797906	110.352488	-7.797903	110.352468	0.000038	0.0000181
-7.797811	110.352507	-7.797809	110.352485	0.000026	0.0000199
-7.797716,	110.352526	-7.797713	110.352503	0.000038	0.0000208
-7.797618	110.352544	-7.797615	110.352522	0.000038	0.0000199
-7.797525	110.352561	-7.797521	110.352538	0.000051	0.0000208
Error Average (%)				0.000206	0.0000156

comparison of the location coordinates displayed on the application and those displayed on Google Maps. The field experimental results are shown in Table 1.

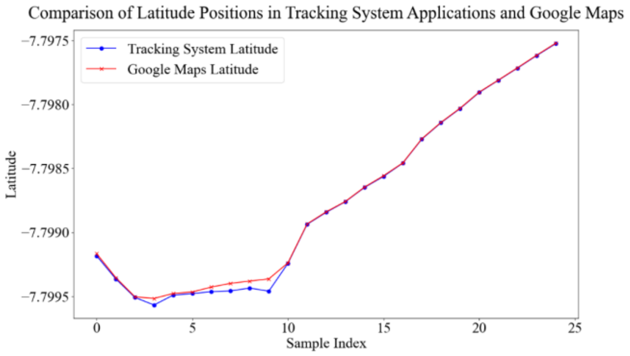

Fig. 5. A Diagram Comparing **Latitude** Positions Displayed in the Ambulance Tracking Application and Google Maps.

Based on the data in Table 1, the comparison of the latitude positions measured by the tracking system application and Google Maps is presented in Fig. 6. The longitude comparison is presented in Fig. 7.

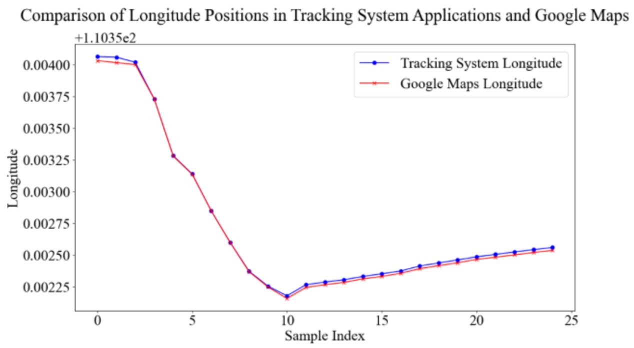

Fig. 6. A Diagram Comparing **Longitude** Positions Displayed in the Ambulance Tracking Application and Google Maps.

Further, we investigate the error percentage of the data produced by the system and by Google Maps to determine the accuracy of the developed system.

$$Error(\%) = \left|\frac{(TS\ Coordinate - GMaps\ Coordinate)}{GMaps\ Coordinate}\right| * 100\% \quad (1)$$

TS = Tracking System
GMaps = Google Maps

Based on the experimental results and calculations, there is a small difference between the latitude and longitude values of the GPS module against Google Maps. The average percentage error for latitude is 0.000206, and for longitude, it is 0.0000156. This difference shows that the GPS module provides position coordinates with high accuracy. Errors in latitude and longitude values on the GPS module are caused by several factors, such as high barrier from buildings, trees, and other objects that block or distort the GPS signal. Multipath effects also contribute to error, where GPS signals bounce off objects before reaching the receiver. In addition, electromagnetic interference from other electronic devices also interfere with GPS signals, thereby reducing the accuracy of the resulting position.

B. *The Time Accuracy of Ambulance Tracking System*

We conducted time accuracy testing to determine the data transmission delay within the developed system. This test measures accuracy by comparing the timestamp at which the node sends the data with the timestamp at which the server receives it. We performed this test over ten iterations to ensure statistical reliability of the results. Table 2 shows the results of delay testing with variations in delay time in sending and receiving GPS data.

TABLE II. DELAY TIME EXPERIMENTAL RESULT

No.	GPS Data Transmission Time Send by Node	GPS Data Reception Time by Server	Time Difference (second)
1.	11:00:15	11:00:26	11
2.	11:05:15	11:05:26	11
3.	11:10:15	11:05:56	11
4.	11:15:55	11:16:07	12
5.	11:20:15	11:20:46	31
6.	11:25:55	11:26:16	21
7.	11:30:55	11:31:16	21
8.	11:35:55	11:36:16	21
9.	11:40:15	11:40:56	41
10.	11:45:16	11:45:56	40

According to our testing experiment, the delay time ranges from 11 to 41 seconds. This variation can be caused by two main factors, namely network latency and server processing time. Network latency is the time it takes for data to move from one point to another point in a network which can be influenced by physical distance, network conditions, and connection speed. Meanwhile, server processing time refers to the duration required by the server to receive, process, and send back data received from the node device. Based on the data in Table 3 the graph is presented in Fig.7.

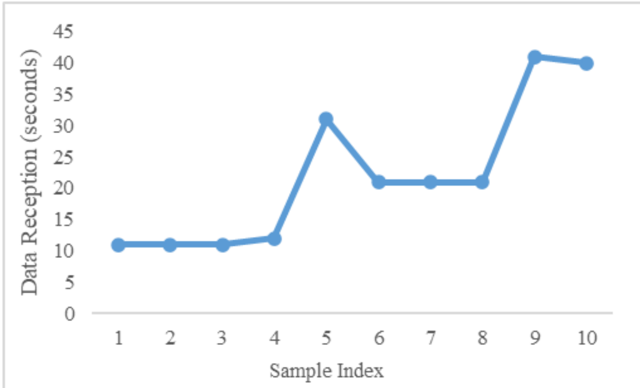

Fig. 7. Graphic diagram of the delay between the device and data reception by the server

V. CONCLUSION

This research successfully developed a high-accuracy LoRaWAN-based IoT ambulance tracking system. The system demonstrated exceptional precision in coordinate measurement. The error margin for latitude coordinates ranged from 0.001231% to 0.000026%, while the longitude coordinates showed an error margin between 0.0000009% and 0.0000390%. These minimal error values indicate the system's robustness and reliability in providing accurate location data. In addition, the developed mobile application display GPS data in real time with an average delay of 22 seconds. Future research could explore optimizing the process of sending patients to the nearest hospital based on the position of the ambulance. Apart from that, information on the estimated time of arrival of the ambulance to the hospital should be added, and the final device should be integrated with the vehicle battery as a resource to ensure more stable energy availability.

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