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LoRa Mesh-Based IoT GPS Tracking System for Mountain Climbers

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ABSTRACT

Indonesia's natural landscape, especially its mountains, attracts increasing climbers. However, the growing interest has led to more accidents in these areas. Given the lengthy evacuation processes for mountain accidents, an effective climber tracking system using IoT technology is essential. This study employs literature reviews and data collection on IoT-based monitoring systems utilizing Meshtastic LoRa devices and protocols. LoRa is chosen for its ability to overcome limited cellular signals in mountainous regions by using radio signals and mesh networks. The developed GPS tracker functions well, automatically sending data in coordinates and text every 5 minutes. In the LoRa mesh communication method, data is forwarded between interconnected nodes to avoid duplication, ensuring efficient communication. Stability tests showed the system operates reliably up to 1km in LOS conditions and up to 500 meters in NLOS conditions. More devices are needed to extend the mesh network, minimizing packet loss and delays. This research contributes to creating an effective GPS tracking system and alternative communication tool for mountain climbers, enhancing safety by reducing accident risks and improving location monitoring.

1. INTRODUCTION

Indonesia is renowned for its natural beauty, encompassing seas, mountains, and waterfalls. Due to this abundance, mountain climbing has become popular for enjoying Indonesia's natural splendor. However, with the increasing number of mountain climbers, accidents in mountainous areas have also risen [1]. Mountain climbing involves a lengthy ascent from the base to its peak, necessitating thorough preparation. During climbing activities, unexpected situations often arise due to unforeseen natural factors, which climbers must address with limited resources. Over the past five years, 50 climbing-related accidents resulting in fatalities have been recorded, highlighting the need for improved safety measures.

According to the Indonesian Mountain Guides Association (APGI), significant causes of mountain accidents include hypothermia and getting lost. These accidents can be attributed to subjective factors (individual or group errors due to lack of preparedness, physical and mental health, and unfamiliarity with the climbing route) and objective factors (unpredictable natural events like weather changes, fog, and landslides). Evacuation processes for accident victims are often prolonged due to the challenging terrain of mountainous areas.

To address this issue, leveraging the advancements of Industry 4.0 technology, a tracking system has been developed to aid in monitoring and evacuating mountain climbers. This system uses Internet of Things (IoT) technology to enhance climbers' safety by facilitating real-time location tracking and communication in areas with minimal cellular coverage [2]. IoT technology encompasses various networks, including GSM, Wi-Fi, Bluetooth, and radio. Long Range (LoRa) technology, which utilizes Radio Frequency (RF), is particularly suitable for mountainous areas with limited cellular networks, similar to its application in monitoring agricultural fields [3].

Recent studies have highlighted the potential of IoT and LoRa technology in improving mountain climbers' safety. For instance, a study conducted by researchers at Universitas Telkom, Bandung, designed an IoT-based tracking system using LoRa modules to transmit climbers' location data to a central server, demonstrating significant improvements in tracking and monitoring capabilities. This research found that LoRa technology could effectively overcome the limitations of cellular networks in mountainous areas, ensuring reliable data transmission over long distances [4].

Similarly, Telkom University, Bandung, researchers designed an IoT-based tracking system using LoRa modules to transmit climbers' location data to a central server, demonstrating significant improvements in tracking and monitoring capabilities. This research found that LoRa technology could effectively overcome the limitations of cellular networks in mountainous areas, ensuring reliable data transmission over long distances [5]. On an international level, research from the Muhammadiyah University of North

Sumatra developed a GPS-based tracking system using Arduino and Neo-6M GPS modules. This study emphasized the importance of reliable communication networks in ensuring the safety of climbers. By integrating LoRa technology, the system significantly improved tracking accuracy and communication reliability [6].

To tackle the problem of accidents and improve evacuation processes, this research proposes an IoT-based monitoring and communication system for climbers using LoRa and LoRa mesh networks. This system is designed to ensure efficient communication and accurate location monitoring, significantly reducing the risks associated with mountain climbing.

2. RELATED WORK

2.1 Global Positioning System (GPS)

The Global Positioning System (GPS) is a navigation system that relies on a network of satellites, a receiver, and specific algorithms to ascertain position, speed, and timing for travel across various modes of transport, including air, sea, and land. This satellite network consists of 24 satellites arranged in six orbital planes around the Earth, with each plane housing four satellites orbiting at an altitude of roughly 13,000 miles (or 20,000 kilometers) and moving at speeds of 8,700 miles per hour (or 14,000 kilometers per hour). To accurately determine a location on the Earth's surface, signals from three satellites are necessary, and a fourth satellite is usually included to confirm the information from the other three, as it also aids in calculating the device's elevation. The development, management, and operation of this GPS satellite network were carried out by the US Space Force [7, 8].

The Global Positioning System (GPS) consists of three interconnected components, called segments, which work together to provide location information on Earth. These are the space segment (comprised of satellites), the ground control segment, and user equipment. The satellites orbit the Earth and send signals to users, which convey their geographic position and the accurate time [9]. The control segment comprises ground monitoring stations, a central control facility, and ground antennas that are essential for tracking and managing satellites in orbit and monitoring their transmissions. These monitoring stations are strategically located across almost every continent, including North America, South America, Europe, Asia, Africa, and Australia. The third segment comprises user equipment, such as GPS receivers and transmitters, commonly found in devices like smartwatches, smartphones, and Internet of Things (IoT) gadgets [10, 11].

The GPS operates based on a method known as trilateration, which determines a person's location, speed, and altitude by gathering signals from satellites. This method is frequently confused with triangulation, which involves measuring angles. GPS satellites orbiting the Earth emit signals received and interpreted by GPS devices on or near the Earth's surface [12]. For a GPS receiver to determine its location, it must receive signals from at least four satellites. These satellites orbit the Earth twice daily, transmitting distinctive signals, orbital data, and time information. At any point, a GPS device can detect signals from six or more satellites [8, 13].

A satellite transmits microwave signals, which a GPS device uses to calculate its distance from the satellite. However, if the GPS receiver only provides distance information, it cannot determine its location [14]. Satellites do not provide information about angular positions, which enables the GPS receiver to be located anywhere on the surface of the Earth [15, 16]. When a satellite sends out a signal, it forms a circle whose radius is determined by the distance from the GPS receiver to the satellite. Suppose a second satellite transmits a signal that the GPS device detects. In that case, it will create another circle, with its radius indicating the distance from the GPS receiver to this second satellite [17, 18]. A satellite emits a signal that generates a circular area defined by the distance to the GPS device. Suppose a second satellite also sends a signal that the GPS receiver detects. In that case, it will produce another circle, with its radius reflecting the distance from the GPS device to that particular satellite [19, 20].

A GPS Tracker is a device that uses the Global Positioning System (GPS) to determine accurately and regularly record a person's whereabouts or a particular object, depending on satellites for reference [21, 22]. The GPS is a service the United States provides that delivers capabilities for positioning, navigation, and timing [23]. The system consists of three main parts: the space, control, and user segments. It is designed, governed, and managed by the United States Space Force [24, 25].

The Global Positioning System (GPS) acts as a tracking mechanism for users, utilizing GPS positioning services to determine the location of a person or object with a GPS-enabled device. The GPS sensor receives signals to generate position coordinates and sends this information to other devices via a communication network [26, 27].

A GPS Tracker is a device that provides real-time location data about an object, allowing users to pinpoint its exact position. In car rental scenarios, the owner can monitor the vehicle’s location. A GPS Tracker is intended to remotely track an object's movements [28, 29].

2.2 IoT with LoRa

Internet of Things (IoT) is a computing concept that refers to a device connected to the Internet that provides processes. It transfers digital data from input from intelligent sensors such as radio frequency identification (RFID) and computes with other smart equipment connected to the Internet. IoT is a long-distance communication system capable of transmitting data over the internet with a real-time data control process [4, 30].

The phrase "Internet of Things" has two main components: "Internet," which refers to connectivity, and "Things," which means any object or device. IoT represents devices capable of gathering and transmitting data online, allowing other devices to access this information [22, 31].

The Internet of Things (IoT) communicates data between several connected devices. It makes automatic decisions based on programs set up and uses the Internet network as a link for interaction between these devices and the data. It can be monitored and regulated in real time [32, 33].

2.3 Protocol flood routing (Meshtastic)

Meshtastic is a LoRa communication protocol project that runs on LoRa hardware and can be installed on open-source microcontrollers such as Arduino or ESP32 for outdoor use with poor telephone networks, such as climbing, skating, and paragliding.

Figure 1 shows that mesoblastic technology enables peer-to-peer communications and mesh network formation without dependency on cellular network communications or Wi-Fi because mesoblastic technology uses LoRa radio devices [34, 35]. The Mesh protocol in mesoblastic uses the Dynamic Source Routing (DSR) algorithm approach and ad hoc on-demand distance vector routing (AODV), a routing algorithm discovered by C. Perkins at the Nokia Research Center in 2003 specifically for wireless devices. In 2007, this algorithm protocol was published with experimental status at the IETF with code RFC 4728 [36, 37].

The Meshtastic LoRa algorithm continues to be developed and updated by the community involved because Meshtastic is open-source software for use with Mesh LoRa devices that can be implemented and adapted to user needs and the LoRa mesh network environment used [9, 38].

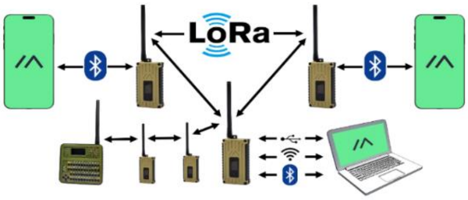


Figure 1. Topologi meshtastic

3. RESEARCH AND METHODS

3.1 Block diagram system

Figure 2 has a proposed system that employs a modular design, where each node is structured into three main components: input, processing, and output. The input stage integrates a Neo-6m GPS module, communicating with satellites to extract geolocation data from latitude and longitude coordinates. This data is transmitted to the ESP32 microcontroller, the central processing unit. The ESP32 is equipped with custom firmware to handle data acquisition, processing, and communication tasks. It processes the GPS data by parsing NMEA sentences, such as $GPGGA or $GPRMC, converting the raw coordinate information into a more user-friendly decimal degree format. Additionally, it verifies the GPS fix status to ensure the validity of the location data.

The processed information and system diagnostics, such as battery status, are encapsulated into packets following a predefined structure that includes sender and receiver identifiers, GPS coordinates, and device status. This packet is transmitted via the LoRa SX1276 module operating at 915MHz. The communication protocol incorporates acknowledgments and time-to-live (TTL) mechanisms to enhance reliability and avoid redundant data propagation. The LoRa module is configured for optimal performance by adjusting parameters such as the spreading factor and bandwidth to suit the application's range and data rate requirements.

The ESP32 decodes the incoming packets at the receiving nodes and forwards the information to an OLED display for visualization. The system also includes Bluetooth integration, allowing users to pair their smartphones with the device for real-time monitoring through a custom application. Powering the system is a rechargeable 18650 battery managed by a charge controller, ensuring efficient energy utilization. Furthermore, power-saving techniques, such as adaptive duty cycling and module sleep modes, are implemented to extend the device's operational life.

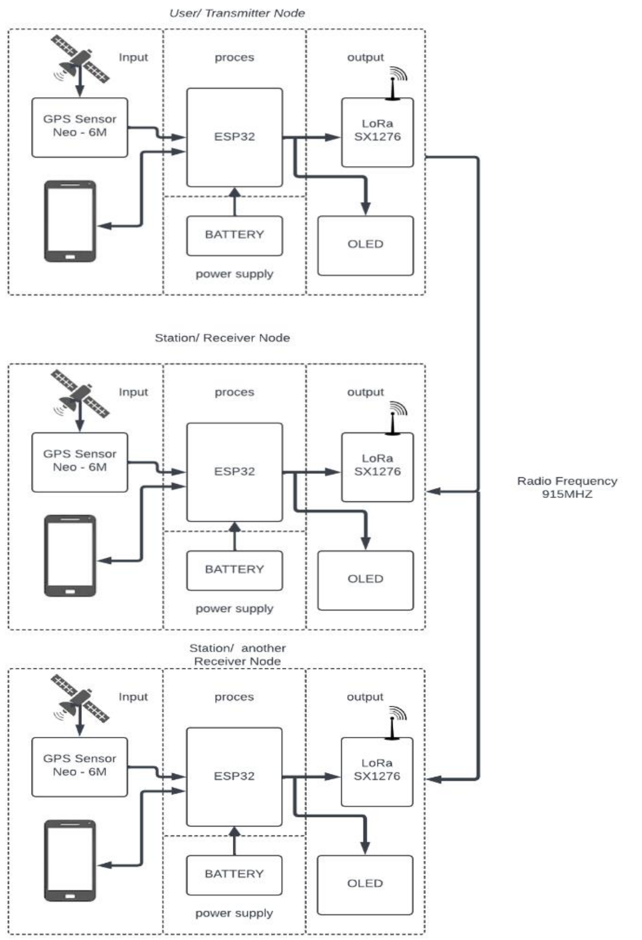


Figure 2. Block diagram system

This design leverages a robust LoRa mesh protocol to enable long-range communication, where each node can act as both a transmitter and a relay to facilitate multi-hop data transmission. This approach ensures network scalability and reliability, making the system suitable for remote monitoring applications. By combining precise GPS tracking, efficient data communication, and low-power operation, the proposed system represents a versatile and energy-efficient solution for geospatial data collection and dissemination.

3.2 Sending data processing

Based on Figure 3, the process of sending data packets begins with initializing the input and output pins of the TTGO ESP32 LoRa; when the device is turned on, the device will check the state of the GPS Neo-6m and LoRa SX1276 sensors. If an error occurs during checking, the system will check again until the input and output are expected [39]. If the device is typical, the device needs to be paired with a smartphone via Bluetooth via ESP32 to connect the device with the mesoblastic application that has been paired on the smartphone. After successful pairing, the device periodically processes and sends Neo-6m GPS sensor reading data every 5 minutes to nodes reached by the device's mesh network via LoRa SX1276. If an error occurs in the sensor reading, the system automatically repeats the reading process until the GPS coordinate data is obtained [40, 41]. Then, the GPS data can be observed on the map available in the mesoblastic application installed on the user's smartphone [3, 42].

Apart from sending GPS data, the device can also send data in the form of text messages via the mesoblastic application. When a text message is sent, the device automatically sends other data, such as the results of reading the last coordinates from the Neo-6m GPS sensor, so that the data sent is in the form of a detailed data package [34, 43]. If an error occurs when sending a data packet, the system will automatically repeat the sending process until the data packet is sent [44, 45].

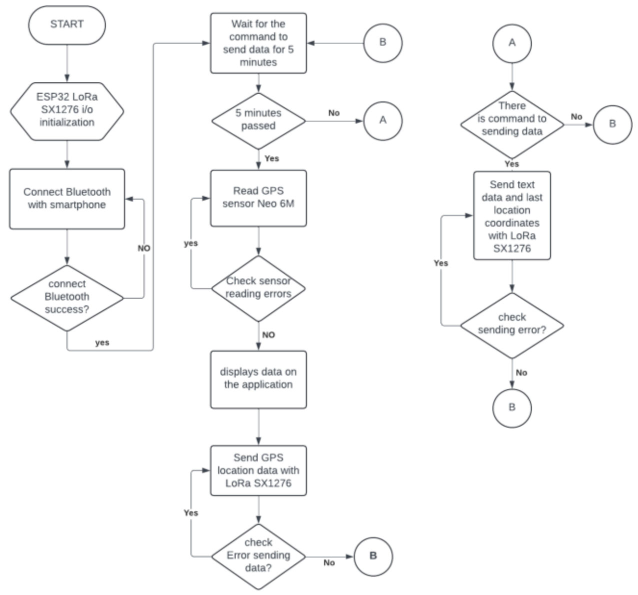


Figure 3. Transmit flowchart system

3.3 Receive data processing

Based on Figure 4, the process of receiving data packets begins with initializing the input and output pins of the TTGO ESP32 LoRa. When receiving data, the device must connect to a smartphone via Bluetooth from the ESP32 to connect the device with the mesoblastic application to display the data packets that have been received. After the device is connected to a smartphone, the device will be in a state waiting for data to be received. When the SX1276 receives an incoming data packet, the data will be processed by the microcontroller and then displayed on the OLED and the mesoblastic application.

After receiving the data, the system will check the condition of neighboring nodes within the device's mesh network coverage to be included in the routing list of data packets that have been received. The system will only update the node information if the neighboring node has been identified. If it still needs to, the system will record the neighbor node information to be included in the routing list. If previously received data needs to be carried out in a routing process, the system will look at the condition of the neighboring nodes, such as "Do the neighboring nodes already know about the data packet or not?" If neighboring nodes do not know the previously sent data, the system will forward it to the node that has not received it. If neighboring nodes already know the data, the system will ignore forwarding data to that node.

After the data packet has been sent to the neighboring node, will the system check whether the data routing process has been completed? If so, the system will delete the data packet and return to data packet waiting mode. If a data routing process still needs to be completed, the system will re-process the data routing to neighboring nodes that have yet to receive the data packet.

The monitoring system proposed in this research is to monitor several sensors. The sensor results are then sent to Firebase via the internet via ESP-01.

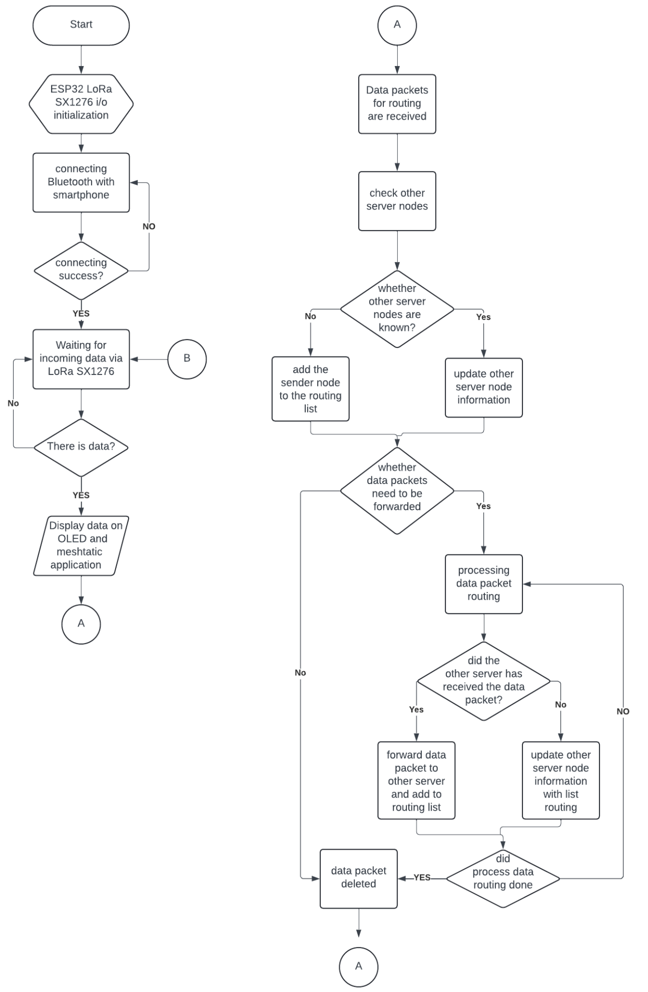


Figure 4. Flowchart system of receiving data packets

3.4 The system details

3.4.1 Schematics electrical system

The system circuit has several essential components, such as the TTGO ESP332 LoRa as a microcontroller with input in the form of a Neo-6m GPS sensor, Bluetooth, and a Li-Ion 18650 battery as a device power source. There is not much difference in the type of configuration and series of devices on each node because the mesoblastic network used is regulated for each node to be able to send and receive data in the form of coordinate points or text messages via the radio network via the mesoblastic application that has been installed on the smartphone, which is connected to each device where detailed images can be seen in Figure 5.

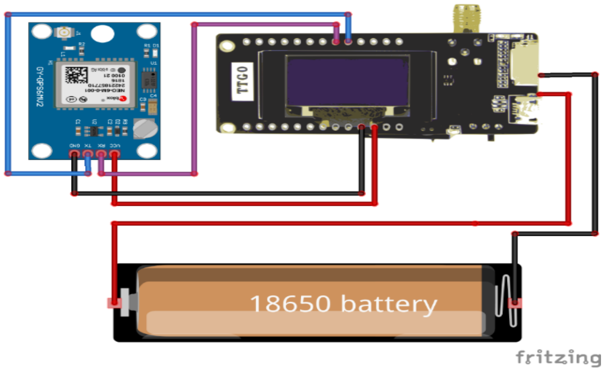
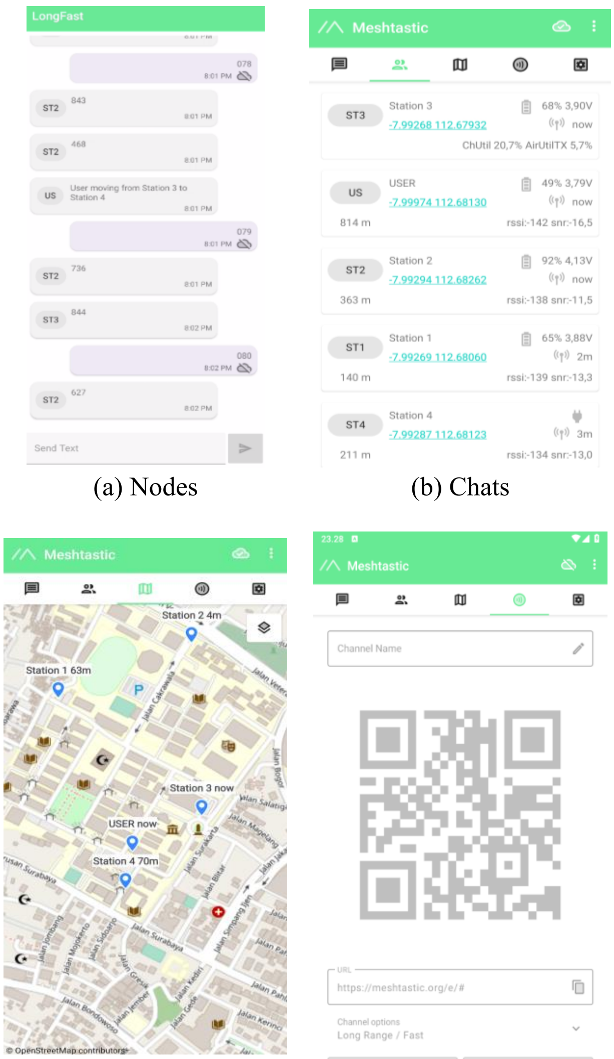


Figure 5. Schematics electrical system

3.4.2 The software application

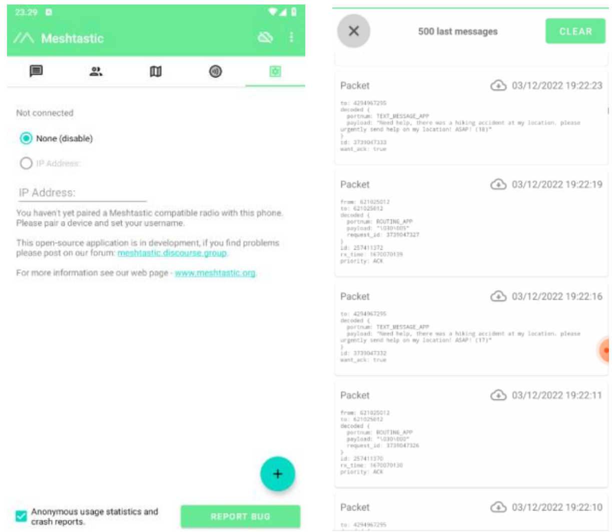
The software used to monitor data communication results between devices can be displayed on the mesoblastic application installed on a smartphone. This application is expected to be a medium for monitoring coordinates between devices and a communication system between users via the LoRa network.

This mesoblastic application is designed for every device user, enabling them to monitor and communicate with one another. As illustrated in Figure 6, the application features five main pages: the node list, chat list, map, channel scan, and settings.



(a) Nodes (b) Chats

(c) Maps (d) Channels



(e) Setting (f) Logs

Figure 6. Front end application

4. RESULT AND DISCUSSION

4.1 Routing pada jaringan mesh LoRa

Routing testing on a mesh network is carried out by turning on 5 nodes with conditions as in Figure 7.

Under the initial test conditions, each station/receiver node could receive the data the user/transmitter sends appropriately. Then, the test was repeated with the conditions shown in Figure 8.

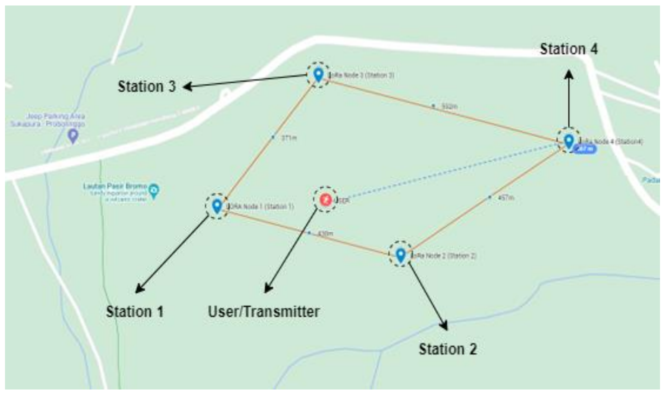


Figure 7. Initial test routing conditions

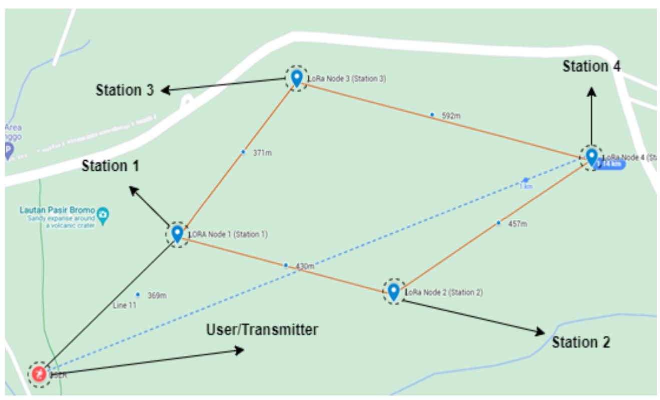


Figure 8. The second test routing condition

Figure 9. Third test routing condition

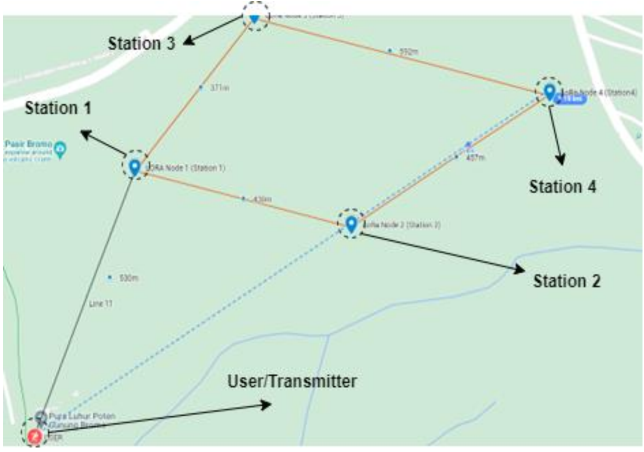


Figure 10. The fourth condition of routing testing

In the second condition, the distance between the user/transmitter node and receiver/station 4 is very far. However, the distance between the user and station 1 (nearest receiver node) is still within reach, so the test results obtained at each station/receiver node can still receive the data. The data is sent by the user/transmitter properly and forwarded to the nodes connected to the mesh network. Then, the test was repeated with the conditions shown in Figure 9.

In the third test condition, it is still in the same condition. The distance between the user/transmitter node and receiver/station 4 is very far. The third is still in the same condition; the distance between the user/transmitter node and receiver/station 4 is very far, but station 1 is still close. Then, the receiver node that connects the user and station 4, namely stations 2 and 3, is disabled. In the third test, the data received by station 4 was complicated without help from other stations. In the third test, 2 out of 5 data could be received by station 4 because there were disturbances such as obstacles and the influence of the distance between the two nodes. This is different from station 1, which gets all data sent by the user. So, to get more accurate test results, testing is carried out under conditions as in Figure 10.

In the fourth test, by restarting each station, the user moves away from node station 1 until a certain distance. This test results show that 4 out of 5 data are received by station 1, and this also affects other stations because they are connected. So, when each receiver node is turned on, if one of the stations gets data sent by the user, the other stations also get that data.

4.2 Device performance in line-of-sight conditions

Device performance testing in Line-of-Sight conditions is carried out by the user moving from station 1 to another station in sequence until ending when returning to station 1. During testing, the user periodically sends data to each station once every 30 seconds. Tests were carried out in the Bromo sand sea area with the device node placement conditions as in Figure 11.

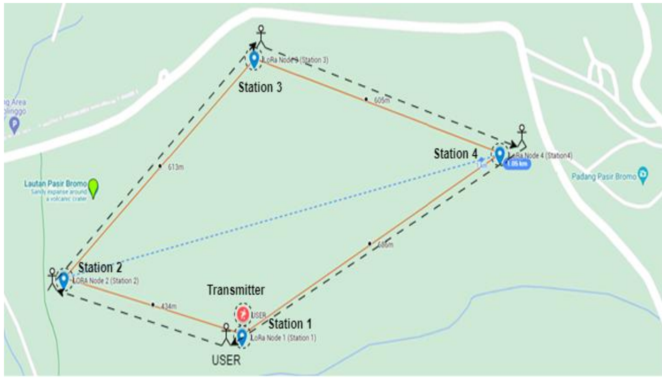


Figure 11. Selection of node positions in LOS conditions

The following is Table 1 of data generated during testing in LOS conditions, which can be seen in the results in the following tables.

In LOS conditions, the delay value for each distance created has a relatively low difference, but the greater the distance created, the more time it takes to send data. So, distance significantly influences the delay in data transmission time in LOS conditions; with every increase in distance, the delay value also increases.

It can be seen in Table 2 that during LOS conditions, the packet loss values are interconnected between devices, which means that if the station closest to the data sender experiences packet loss, then the next station also experiences packet loss.

Table 2 shows Line of Sight (LOS) conditions with minimal obstructions; the increase in distance directly influences the Received Signal Strength Indicator (RSSI) values. Table 2 shows that RSSI diminishes with greater separation between devices, primarily due to free-space path loss. This attenuation results from the inverse square law, where signal power decreases by a factor of four with every doubling of distance. Additionally, even slight environmental factors such as air humidity and temperature can impact signal strength, though their effects are relatively minor in LOS scenarios.

Table 1. The effect of distance on data transmission time

Distance	Delay(s)				
(m)	Station 1	Station 2	Station 3	Station 4	Average
0	6	5	5	6	5.5
50	7	7	7	6	6.75
100	8	7	8	7	7.5
200	8	8	8	8	8
300	9	9	9	8	8.75
400	9	10	10	9	9.5
500	10	10	11	9	10
600	10	10	11	11	10.5
700	11	11	10	11	10.75
800	12	12	12	11	11.75
900	13	12	13	13	12.75
1000	13	14	14	14	13.75

Table 2. The effect of distance on packet loss and RSSI values

Distance (m)	Amount of Data	Packet Loss (%)					RSSI (dBm)				
		Station 1	Station 2	Station 3	Station 4	Average	Station 1	Station 2	Station 3	Staton 4	Average
0	10	0	0	0	0	0	-38	-33	-34	-38	-35.75
50	10	0	0	0	0	0	-48	-41	-42	-44	-43.75
100	10	0	0	0	0	0	-59	-58	-59	-59	-58.75
200	10	0	0	0	0	0	-70	-69	-63	-66	-67
300	10	0	0	0	0	0	-78	-72	-71	-75	-74
400	10	0	0	0	0	0	-86	-90	-90	-84	-87.5
500	10	0	0	0	0	0	-92	-93	-95	-94	-93.5
600	10	0	0	0	0	0	-106	-106	-107	-105	-106
700	10	0	0	0	10	2.5	-111	-113	-116	-117	-114.25
800	10	0	0	10	10	5	-127	-125	-126	-121	-124.75
900	10	10	20	10	20	15	-132	-130	-131	-139	-133
1000	10	20	20	30	30	25	-138	-141	-110	-143	-133

Then, packet loss, a critical metric in network performance, arises from several factors, including signal interference from other devices, weak signal strength at extended distances, and network congestion. Interference from other wireless devices operating on the same frequency can disrupt signals, leading to packets being lost. When signal strength is weak, as shown in the RSSI table at greater distances, the likelihood of packet errors increases, causing packet loss. Network congestion, particularly in busy environments, can result in dropped packets due to collisions and overcrowded data channels.

The system exhibits robust performance at shorter distances (0-600 meters), demonstrating minimal packet loss and strong RSSI values. However, significant degradation is evident beyond 700 meters, with a notable decline in signal strength and increased packet loss. This susceptibility to interference highlights potential areas for improvement in real-world scenarios. Expanding the analysis of these underlying factors provides a comprehensive understanding of the system's strengths and weaknesses, offering valuable insights for enhancing its reliability and performance. By thoroughly examining the causes of signal attenuation, packet loss, and latency, we can identify key areas for optimization and develop strategies to mitigate these issues in practical applications.

4.3 Device performance in non-line-of-sight conditions

Device performance testing in non-line of sight conditions is carried out by the user moving from station 1 to another station sequentially until it ends when returning to station 1. During testing, the user periodically sends data to each station once every 30 seconds. Testing was conducted in the Malang State University campus area with the device node placement conditions as in Figure 12. The following is Table 3 of data generated during testing in LOS conditions, which can be seen in the results in the following tables.

In the NLOS condition, there is test result data, and the delay value found is not much different from that found when testing with LOS conditions. However, there are other delays, such as at station 2 when within 300 meters, there is a high delay jump because, in the test area, many obstacles affect the signal power rate in communication between system devices, resulting in delays. The delay value cannot be recorded due to the limited size of the testing area. However, it can be confirmed that the distance value significantly influences the delay time.

Based on Table 4 in the NLOS condition, there is uncertainty in the data results as in Table 4 due to the many existing obstacles. When the test distance was shallow, namely 100 meters, the RSSI value was excellent and ideal. However, when entering 200 meters and beyond, it can be observed that RSSI spikes occur frequently but are erratic. This phenomenon is directly proportional to the influence of the packet loss value, so it can be concluded that in NLOS conditions, the signal power is affected by obstacles that can influence the size of the RSSI, thereby affecting the data transmission rate, such as packet loss and delay.

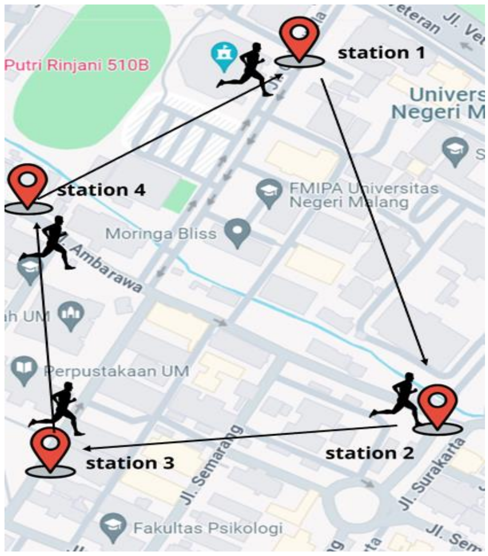


Figure 12. Selection of node positions in NLOS conditions

Table 3. The effect of distance on data transmission time

Distance (m)	Delay(s)				
	Station 1	Station 2	Station 3	Station 4	Average
50	5	5	5	6	5.25
100	6	7	6	6	6.25
200	8	9	9	9	8.75
300	9	12	9	9	9.75
400	12	10	9	9	10
500	13	13	13	13	13
600	13	14	13	13	13.25
700	14	15	13	14	14
800	15	15	13	15	14.5

Table 4. The effect of distance on the packet loss and RSSI values

Distance (m)	Amount of Data	Packet Loss (%)					RSSI (dBm)			
		Station 1	Station 2	Station 3	Station 4	Average	Station 1	Station 2	Station 3	Station 4
50	20	0	0	0	0	0	-32	-35	-38	-41
100	20	0	0	0	0	0	-58	-59	-54	-50
200	20	5	5	0	0	2.5	-68	-124	-65	-64
300	20	5	15	20	25	16.25	-120	-105	-192	-134
400	20	10	5	25	30	17.5	-121	-127	-132	-137
500	20	11	15	0	15	10.25	-125	-94	-95	-93
600	20	10	11	10	12	10.75	-106	-106	-107	-105
700	20	5	5	6	6	5.5	-116	-119	-118	-11
800	20	0	0	0	0	0	-120	-125	-119	-108

In the NLOS condition, there is uncertainty in the data results, such as during packet loss testing. When the test distance was low, namely 100 meters, the RSSI value was outstanding and ideal. However, when entering 200 meters and beyond, it can be observed that RSSI spikes occur frequently but are erratic. This phenomenon is directly proportional to the influence of the packet loss value, so it can be concluded that in NLOS conditions, the signal power is affected by obstacles that can influence the size of the RSSI, thereby affecting the data transmission rate, such as packet loss and delay.

4.4 The specific impact of obstacle types on signal performance by comparative tests LOS with NLOS

Comparative tests under LOS conditions would highlight the system's baseline performance and provide a direct contrast with NLOS scenarios. This would help quantify the extent of performance degradation due to specific obstacles and inform adjustments in node placement or communication protocols to minimize losses. For example, if testing reveals that dense vegetation causes a predictable 20% reduction in RSSI compared to LOS conditions, this information could guide node placement to optimize coverage.

Implementing signal optimization techniques, such as adjusting transmission power and spreading factor, directly impacts the system’s range and reliability. Increasing transmission power could strengthen signals over long distances but would require balancing energy consumption, especially in battery-powered devices. Adjusting the spreading factor increases communication range but could reduce data throughput, necessitating trade-offs depending on application requirements. Error correction methods, such as forward error correction (FEC), could mitigate the impact of data loss by enabling the receiver to reconstruct corrupted packets, improving reliability in high-loss areas.

Dynamic node placement strategies, such as deploying additional relay nodes in areas with high packet loss or weak RSSI, would enhance network robustness by providing alternative communication paths. For instance, placing a relay node in the mid-range of a high-loss zone (e.g., 300-400 meters) could reduce packet loss from 17.5% to near-zero levels while stabilizing delays. This approach ensures consistent data delivery and better overall system performance, particularly in environments with varying obstacle densities.

4.5 Discuss future directions and the implications

Based on the research results and discussions that have been described, the author can conclude the research that has been carried out. The use of LoRa in the GPS tracker system that has been created can function well. It can run automatically when sending data in coordinates and text to each device within a configured period, every 5 minutes.

The current system focuses on fundamental functionalities, such as location tracking and text communication, which are the core features for remote monitoring and essential information exchange. While these functions provide a solid foundation, there is significant potential to expand the system’s capabilities to increase its practicality and usability for diverse applications. One such extension could include the integration of SOS emergency alerts. A dedicated SOS button or gesture-based triggering mechanism could instantly send distress signals with location data to designated stations or emergency responders. This feature would be particularly beneficial in outdoor adventures, search-and-rescue operations, or disaster management, where timely alerts are critical for safety.

Another promising enhancement could involve weather data collection. The system could gather real-time environmental information and location data by integrating temperature, humidity, and atmospheric pressure sensors. This capability would make the system useful for agricultural monitoring, ecological studies, and outdoor activities. For instance, hikers or field researchers could benefit from localized weather updates to make informed decisions in remote areas where conventional weather forecasting might be unavailable.

These extensions could be implemented by leveraging the system’s existing LoRa communication and modular design. For instance, the SOS feature could utilize the LoRa mesh network to broadcast emergency messages to nearby nodes, ensuring redundancy and coverage even in poor network connectivity. Weather sensors, however, could seamlessly interface with the ESP32 microcontroller to transmit data periodically without overburdening the system’s processing or power resources. Moreover, pairing these features with the Bluetooth-connected smartphone application would enable users to configure alerts, access weather logs, and monitor emergency responses in a user-friendly manner.

Expanding the system with such functionalities would enhance its usability across various domains and improve its relevance for safety-critical and environmental applications. This would make the system more versatile and appealing to a broader user base while maintaining its low-power operation and long-range communication strengths.

5. CONCLUSIONS

Based on the research results and discussions, it can be concluded that implementing LoRa in the GPS tracker system has demonstrated reliable functionality. The system operates automatically to transmit coordinate data and text messages to interconnected devices at a configured interval of 5 minutes. Utilizing the LoRa mesh communication method, data is forwarded efficiently between nodes, ensuring the information is passed from the closest to the furthest nodes. To optimize network efficiency, the system avoids duplicate transmissions by preventing nodes from resending data that they have already received, thereby conserving bandwidth and reducing unnecessary network congestion.

The study also highlights the dependence of system performance on signal quality between devices, as reflected in key parameters such as RSSI, packet loss, and delay. In line-of-sight (LOS) conditions, the system exhibits stability up to a distance of 1 kilometer, while in non-line-of-sight (NLOS) conditions, the system remains stable up to 500 meters. Beyond these distances, significant signal degradation occurs, affecting data transmission reliability. This finding underscores the necessity of deploying additional nodes in challenging environments, such as mountainous regions, to enhance the network's reach and stability. By increasing the density of nodes in the mesh network, packet loss and delays can be minimized, ensuring consistent text data and GPS coordinates communication.

The conclusions could be broadened to include potential applications and future improvements to expand the practical significance of this research. For instance, this system is highly suitable for remote monitoring in challenging terrains, such as search-and-rescue operations, environmental monitoring, and adventure tracking. However, further enhancements could focus on integrating advanced features such as dynamic power adjustments for improved energy efficiency, SOS alert systems for emergencies, and environmental sensors for collecting additional data such as weather information. These developments would make the system more robust and versatile, catering to a broader range of applications.

Moreover, exploring alternative routing protocols within the mesh network, such as adaptive routing algorithms, could improve the system's performance in scenarios with high node density or significant environmental obstacles. Such improvements would ensure the system can scale efficiently while maintaining reliable communication, further enhancing its applicability in real-world conditions.

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REFERENCES

[1] Ghazali, M.H.M., Teoh, K., Rahiman, W. (2021). A systematic review of real-time deployments of UAV-based LoRa communication network. IEEE Access, 9: 124817-124830. https://doi.org/10.1109/ACCESS.2021.3110872

[2] Fargas, B.C., Petersen, M.N. (2017). GPS-free geolocation using LoRa in low-power WANs. In 2017 Global Internet of Things Summit (Giots), Geneva, Switzerland, pp. 1-6. https://doi.org/10.1109/GIOTS.2017.8016251

[3] Hashim, N., Idris, F., Ab Aziz, T.N.A.T., Johari, S.H., Nor, R.M., Ab Wahab, N. (2021). Location tracking using LoRa. International Journal of Electrical and Computer Engineering, 11(4): 3123-3128. https://doi.org/10.11591/ijece.v11i4.pp3123-3128

[4] Hadwen, T., Smallbon, V., Zhang, Q., D'Souza, M. (2017). Energy efficient LoRa GPS tracker for dementia patients. In 2017 39th Annual International Conference of The IEEE Engineering in Medicine and Biology Society (EMBC), Jeju, Korea (South), pp. 771-774. https://doi.org/10.1109/EMBC.2017.8036938

[5] Dwipayana, I.K.H., Santoso, I.H., Karna, N.B.A. (2021). Rancang bangun sistem tracking pendaki berbasis internet of things dengan modul lora. eProceedings of Engineering, 8(6): 11829-11838.

[6] Hasibuan, R.A., Tanjung, M.A.P. (2024). Rancang bangun sistem pelacak (GPS) untuk memonitoring pendaki gunung berbasis arduino. JATI (Jurnal Mahasiswa Teknik Informatika), 8(6): 11982-11991. https://doi.org/10.36040/jati.v8i6.11712

[7] Mackey, A., Spachos, P. (2019). LoRa-based localization system for emergency services in GPS-less environments. In IEEE INFOCOM 2019 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), Paris, France, pp. 939-944. https://doi.org/10.1109/INFCOMW.2019.8845189

[8] Sharma, D.R., Raghuwanshi, R.R., Chandak, T., Ramdasi, D. (2023). LoRa-based IoT system for emergency assistance and safety in mountaineering. International Journal of Safety & Security Engineering, 13(3): 491-500. https://doi.org/10.18280/ijsse.130311

[9] Bor, M., Roedig, U. (2017). LoRa transmission parameter selection. In 2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS), Ottawa, ON, Canada, pp. 27-34. https://doi.org/10.1109/DCOSS.2017.10

[10] Chitrakar, P., Biradavolu, Y., Yellampalli, S.S. (2021). GPS and LoRa module based safety alert system. In 2021 IEEE International Conference on RFID Technology and Applications (RFID-TA), Delhi, India, pp. 256-259. https://doi.org/10.1109/RFID-TA53372.2021.9617337

[11] Cattani, M., Boano, C.A., Römer, K. (2017). An experimental evaluation of the reliability of lora long-range low-power wireless communication. Journal of Sensor and Actuator Networks, 6(2): 7. https://doi.org/10.3390/jsan6020007

[12] Solé, J.M., Centelles, R.P., Freitag, F., Meseguer, R. (2022). Implementation of a LoRa mesh library. IEEE Access, 10: 113158-113171. https://doi.org/10.1109/ACCESS.2022.3217215

[13] Sallang, N.C.A., Islam, M.T., Islam, M.S., Arshad, H. (2021). A CNN-based smart waste management system using TensorFlow lite and LoRa-GPS shield in Internet of Things environment. IEEE Access, 9: 153560-153574. https://doi.org/10.1109/ACCESS.2021.3128314

[14] Ugarte, L.F., Garcia, M.C., Rocheti, E.O., Lacusta, E., Pereira, L.S., de Almeida, M.C. (2019). LoRa communication as a solution for real-time monitoring of IoT devices at UNICAMP. In 2019 International Conference on Smart Energy Systems and Technologies (SEST), Porto, Portugal, pp. 1-6. https://doi.org/10.1109/SEST.2019.8849100

[15] Ramly, R., Wahid, Y.A., Salleh, S.M., Zaaba, M.A.M. (2023). Location based tracking system for prison

transport using LoRa. In AIP Conference Proceedings. AIP Publishing, 2808(1). https://doi.org/10.1063/5.0133776
[16] Ben Temim, M.A., Ferré, G., Tajan, R. (2022). A new lora-like transceiver suited for LEO satellite communications. Sensors, 22(5): 1830. https://doi.org/10.3390/s22051830
[17] Di Renzone, G., Parrino, S., Peruzzi, G., Pozzebon, A., Vangelista, L. (2024). LoRaWAN for vehicular networking: Field tests for vehicle-to-Roadside communication. Sensors, 24(6): 1801. https://doi.org/10.3390/s24061801
[18] Lavric, A., Petrariu, A.I. (2018). LoRaWAN communication protocol: The new era of IoT. In 2018 International Conference on Development and Application Systems (DAS), Suceava, Romania, pp. 74-77. https://doi.org/10.1109/DAAS.2018.8396074
[19] Piyare, R., Murphy, A.L., Magno, M., Benini, L. (2018). On-demand LoRa: Asynchronous TDMA for energy efficient and low latency communication in IoT. Sensors, 18(11): 3718. https://doi.org/10.3390/s18113718
[20] Toro-Betancur, V., Premsankar, G., Slabicki, M., Di Francesco, M. (2021). Modeling communication reliability in LoRa networks with device-level accuracy. In IEEE INFOCOM 2021 IEEE Conference on Computer Communications, Vancouver, BC, Canada, pp. 1-10. https://doi.org/10.1109/INFOCOM42981.2021.9488783
[21] Devalal, S., Karthikeyan, A. (2018). LoRa technology-An overview. In 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, pp. 284-290. https://doi.org/10.1109/ICECA.2018.8474715
[22] Elijah, O., Rahman, T.A., Saharuddin, H.I., Khairodin, F.N. (2019). Factors that impact LoRa IoT communication technology. In 2019 IEEE 14th Malaysia International Conference on Communication (MICC), Selangor, Malaysia, pp. 112-117. https://doi.org/10.1109/MICC48337.2019.9037503
[23] Cass, S. (2024). It's Meshtastic!> LoRa-based tech brings mesh radio to makers. IEEE Spectrum, 61(6): 16-18. https://doi.org/10.1109/MSPEC.2024.10551793
[24] Janssen, T., BniLam, N., Aernouts, M., Berkvens, R., Weyn, M. (2020). LoRa 2.4GHz communication link and range. Sensors, 20(16): 4366. https://doi.org/10.3390/s20164366
[25] Rudeš, H., Kosović, I.N., Perković, T., Čagalj, M. (2018). Towards reliable iot: Testing lora communication. In 2018 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Croatia, pp. 1-3. https://doi.org/10.23919/SOFTCOM.2018.8555783
[26] Bouras, C., Gkamas, A., Salgado, S.A.K. (2021). Energy efficient mechanism for LoRa networks. Internet of Things, 13: 100360. https://doi.org/10.1016/j.iot.2021.100360
[27] Yahya, M.S., Soeung, S., Chinda, F.E., Musa, U., Yunusa, Z. (2024). Dual-band GPS/LoRa antenna for internet of thing applications. Bulletin of Electrical Engineering and Informatics, 13(2): 986-995. https://doi.org/10.11591/eei.v13i2.6428
[28] Baksi, A., Bhattacharjee, M., Ghosh, S., Bishnu, S.K., Chakraborty, A. (2020). Internet of Things (IOT) based ambulance tracking system using GPS and GSM modules. In 2020 4th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech), Kolkata, India, pp. 1-4. https://doi.org/10.1109/IEMENTech51367.2020.9270120
[29] Hattarge, S., Kekre, A., Kothari, A. (2018). LoRaWAN based GPS tracking of city-buses for smart public transport system. In 2018 First International Conference on Secure Cyber Computing and Communication (ICSCCC), Jalandhar, India, pp. 265-269. https://doi.org/10.1109/ICSCCC.2018.8703356
[30] Govindaraj, M., Arumugam, S. (2023). Enhancing IoT security with trust-Based mechanism for mitigating black hole attacks. International Journal of Safety & Security Engineering, 13(5). https://doi.org/10.18280/ijsse.130515
[31] Chen, W., He, C., Lu, J., Yan, K., Liu, J., Zhou, F., Xu, X., Hao, X. (2021). Research and design of distributed fire alarm system of indoor internet of things based on LoRa. Scientific Programming, 2021(1): 7462331. https://doi.org/10.1155/2021/7462331
[32] Sandoval, R.M., Garcia-Sanchez, A.J., Garcia-Haro, J. (2019). Optimizing and updating lora communication parameters: A machine learning approach. IEEE Transactions on Network and Service Management, 16(3): 884-895. https://doi.org/10.1109/TNSM.2019.2927759
[33] Misran, N., Islam, M.S., Beng, G.K., Amin, N., Islam, M.T. (2019). IoT based health monitoring system with LoRa communication technology. In 2019 International Conference on Electrical Engineering and Informatics (ICEEI), Bandung, Indonesia, pp. 514-517. https://doi.org/10.1109/ICEEI47359.2019.8988869
[34] Suryadevara, N.K., Dutta, A. (2021). Meshtastic infrastructure-less networks for reliable data transmission to augment internet of things applications. In International Conference on Wireless and Satellite Systems. Cham: Springer International Publishing. Springer, Cham, pp. 622-640. https://doi.org/10.1007/978-3-030-93398-2_55
[35] Reddy, S.K., Naik, A.S., Mandela, G.R. (2023). Development of a novel real-Time environmental parameters monitoring system based on the internet of things with lora modules in Underground Mines. Wireless Personal Communications, 133(3): 1517-1546. https://doi.org/10.1007/s11277-023-10827-0
[36] Turčinović, F., Vuković, J., Božo, S., Šišul, G. (2020). Analysis of LoRa parameters in real-world communication. In 2020 International Symposium ELMAR, Zadar, Croatia, pp. 87-90. https://doi.org/10.1109/ELMAR49956.2020.9219028
[37] Yao, F., Ding, Y., Hong, S., Yang, S.H. (2022). A survey on evolved LoRa-based communication technologies for emerging internet of things applications. International Journal of Network Dynamics and Intelligence, 1(1): 4-19. https://doi.org/10.53941/ijndi0101002
[38] Liaqat, R.M., Branch, P., But, J. (2022). LoRa based linear network applications, design considerations and open challenges: A review. In Proceedings of the 20th ACM Conference on Embedded Networked Sensor Systems, New York, NY, USA, pp. 913-917. https://doi.org/10.1145/3560905.3568111

[39] Azevedo, J.A., Mendonça, F. (2024). A critical review of the propagation models employed in LoRa Systems. Sensors, 24(12): 3877. https://doi.org/10.3390/s24123877
[40] Qi, P., Chiaro, D., Piccialli, F. (2024). Small models, big impact: A review on the power of lightweight Federated Learning. Future Generation Computer Systems, 162: 107484. https://doi.org/10.1016/j.future.2024.107484
[41] Zakaria, M.S.S.B., Salleh, S.B.M., Nasser, A.H.B.A., Zaaba, M.A.M., Ali, A.S. (2022r). LoRa network based wearable tracker-A preliminary work. In 2022 International Visualization, Informatics and Technology Conference (IVIT), Kuala Lumpur, Malaysia, pp. 9-16. https://doi.org/10.1109/IVIT55443.2022.10033340
[42] Fahmida, S., Modekurthy, V.P., Ismail, D., Jain, A., Saifullah, A. (2022). Real-Time communication over LoRa networks. In 2022 IEEE/ACM Seventh International Conference on Internet-of-Things Design and Implementation (IoTDI), Milano, Italy, pp. 14-27. https://doi.org/10.1109/IoTDI54339.2022.00019
[43] Freitag, F., Miquel Solé, J., Meseguer Pallarès, R. (2023). Position paper: LoRa mesh networks for enabling distributed intelligence on tiny IoT nodes. In Workshop Proceedings of the 19th International Conference on Intelligent Environments (IE2023), pp. 165-170. https://doi.org/10.3233/AISE230026
[44] Crisgar, P.V., Wijaya, P.R., Pakpahan, M.D., Syamsuddin, E.Y., Hasanuddin, M.O. (2021). GPS-based vehicle tracking and theft detection systems using Google Cloud IoT core & Firebase. In 2021 International Symposium on Electronics and Smart Devices (ISESD), Bandung, Indonesia, pp. 1-6. https://doi.org/10.1109/ISESD53023.2021.9501928
[45] Choi, W., Chang, Y.S., Jung, Y., Song, J. (2018). Low-Power LoRa signal-based outdoor positioning using fingerprint Algorithm. ISPRS International Journal of Geo-Information, 7(11): 440. https://doi.org/10.3390/ijgi7110440