# IoT Enabled Intelligent Tracking System for Forest and Hilly Region

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## Abstract

Wireless communication networks in mountain and forest regions face serious degradation due to specific problems like attenuation, shadowing, and multipath fading because of dense trees and hilly topographic conditions. Traditional satellite communication assists in overcoming these disadvantages, but it remains costlier and power-intensive, and hence not suitable for remote IoT applications. This paper presents an IoT-based smart tracking system using LoRa (Long Range) communication technology, which serves as a cost-effective, energy-efficient, and long-range communication solution to overcome these specific drawbacks. The IoT-based tracking system utilizes GPS, a heart sensor, and an accelerometer, along with ESP32 and LoRa communication modules, to measure and implement self-communication without cellular services. The experimental analysis confirms that the designed LoRa-based network enables reliable connectivity with low power consumption and an extended range. This work establishes an effective and scientific basis for real-time surveillance, alert messages, and environmental monitoring in forest and hill regions.

**Keywords:** LoRa; Mesh Networks; Wide Area Tracking; Long Range Tracking; Internet of Things.

*Ruban Gladwin M.\*, Kasthuri N., Jenifer P., John Jebastin D., Muthu Krishnan M., Kaliarasan K.*

## 1. Introduction

The Internet of Things has numerous applications, including smart homes, transportation and logistics, agriculture, energy management, wearables and healthcare, security and surveillance, retail and marketing, and food safety/quality, etc. The 2020 prediction indicates that there will be 4.06 billion hectares of forest (31% of total land area), averaging 0.52 hectare per person. The forest distribution varies significantly both by geographic area and people around the globe. People located behind a mountain or in a forest face many difficulties and dangers from weather conditions, wildlife, communication failure, disorientation, lack of resources, time constraints, physical limitations, and mental health challenges caused by such a location. The nature of the landscape poses major challenges in finding and recovering lost people. IoT technology will highly improve and increase search and rescue operations in dense forests and mountainous regions. An effective tracking solution will require a special unit that can overcome the challenges of dense growth, uneven surfaces, and poor network connectivity. Key areas to consider in this system include full-spectrum satellite systems (examples: GPS with GLONASS or Galileo) which provide increased accuracy and reliability. Devices can be selected based on battery life, as it will be difficult to find a way to replace or recharge the batteries. Some devices can be charged using solar power and are also suitable for environmental use. The best outdoor devices will be able to withstand hot, cold, wet, and dry environments.

Another consideration when selecting outdoor mapping devices is the availability of offline sources. The best devices for outdoor mapping will allow users to store maps on the device and navigate through locations without requiring an internet connection. In areas with poor or minimal cellular coverage, devices with mesh networking capability allow communication with one another, expanding each other's coverage area. Additionally, devices that have SOS buttons or emergency capabilities are highly preferred to send a warning signal and location details to emergency authorities or designated contacts when evaluating devices for possible outdoor use. It is also useful to have the ability to record data on the device for tracking and analysis at specific times, even if the device is not connected to a network. Hence, there is an increasing need to develop a smart device to survive outdoor use, including accidents, shocks, and vibrations. Devices that use satellite or another long-range network to provide real-time monitoring of user location should be a first priority. This research study

focuses on developing such a system integrated with IoT to track users in forest and hilly regions.

## 2. Related works

The process of monitoring and protecting systems is rapidly changing with the implementation of the Internet of Things (IoT) into environmental and forest management systems across the world. Liao et al. [1] presents a conceptual framework for IoT to develop industrially and ultimately lead to the integration of analytics and detecting power. Singh et al. [2] provides an example of how Forest 4.0 can support this type of integration within the forestry industry as it relates to sustainable forest management through digitalization. Applications of IoT for early warning systems and prevention of natural disasters have received much attention, including systems for forest fire monitoring [4][5][10], weather forecasting [8] and landslide detection [7]. These research works highlight the real-time capability and flexibility of IoT networks along with their potential diversity. The findings of Marcu et al. [6] validated the effectiveness of the use of sensor networks in monitoring forests, while Pereira et al. [9] demonstrated the application of Radio Frequency Identification (RFID) technology for monitoring wildlife and increased RFID that includes IoT technology. The ability to communicate accurately across all elements using an IoT network remains critical, as demonstrated by Che Osman et al. [12]. Baldini et al. [11] surveyed wireless and Long-Range Wide Area Networks (LoRaWAN) technologies used for remote monitoring in poorly connected areas. The work of Georgiou and Raza [14], Lee and Ke [15] and Raza et al. [16] examined the scalability and performance of Low-Power Wide Area Networks (LPWANs) to demonstrate that LoRa is a low-cost, energy-efficient system suitable for large-scale deployments. Researchers such as Panicker et al. [13] and Shanmuga Sundaram et al. [17] have demonstrated that the versatility of LoRa Technology allows mesh networking-based approaches for wide-area tracking, simultaneously identifying research gaps in scalability and interference management. Recent advancements in the interconnection of Machine Learning and the Internet of Things (IoT) have also provided a framework for increased sustainable comprehension, demonstrated by the work of Sheng et al. [18], which also explains the integration of LoRa protocol with machine learning technologies and developed a smart waste management system that allows predictive analysis to autonomously control the environments.

In conclusion, it is clear that IoT and LoRa technology are changing the environmental space by tracking and monitoring factors from wildfires and animal migrations to their corresponding environments, and providing the tools to make smart decisions to implement sustainable practices for our planet.

Today, there are different systems used to monitor and track hilly and forested areas. Most of these systems use an extensive array of technological and analytical tools to address multiple global issues, including climate change, wildlife conservation, and continued deforestation efforts. Technologies such as satellite images, aerial images, and ground-based sensors provide valuable data for the health of forest ecosystems and also provide other key indicators for the overall health of the environment. This data is necessary for better-planned land use activities to protect forests.

Below mentioned are some of the existing systems that monitor and record data related to forests and mountain areas:

- **Satellite-Based Systems:** Global Forest Watch (GFW) uses satellite images to determine when a forest has been destroyed through degradation and deforestation. NASA's Landsat provides information on forest cover and the classification of how land is being used, as well as how the land is changing. ESA's Copernicus has satellites that provide information on natural disaster management, land use classification, and forest monitoring.

- **Ground-Based Systems:** Forest Monitoring Systems (FMS) monitor the environment, animals, and health of forests. FMS gather data from cameras, sensors, and drones. Acoustic Sensor Networks (ASN) gather data about animal populations and the sounds they make. Wireless Sensor Networks (WSN) collect and send data based on environmental conditions such as soil moisture, temperature, and humidity over a wireless network.

- **Drone-Based Systems:** Drones, or unmanned aerial vehicles connected with cameras and sensors, provide forest monitoring data by capturing aerial images of the forest. DJI's Forest Management Solution provides a variety of drone-based solutions for managing and monitoring forests, including airborne monitoring of forests and other similar capabilities.

- **Mobile and Web Applications:** Mobile applications like Forest Watcher log instances of deforestation and record any damage caused to forests. OpenForis serves as a web-based platform used to manage and monitor any type of forest. The Forest Inventory and Analysis (FIA) app collects forest monitoring data on mobile devices.

- **IoT-Based Systems:** The Forest monitoring solution from Sigfox collects data on a number of environmental factors, including temperature, moisture levels, and overall health of forest areas, using IoT sensors. LoRaWAN provides a low-power and wide-area network designed specifically for the purpose of monitoring forest areas. Additionally, Cisco's Connected Forest also provides IoT-based solutions for the management and monitoring of forest areas.

## 2.1 Government Initiatives

The Forest Survey of India (FSI) examines forest surveys using satellite images and physical investigation at regular intervals. Forest health, growth, and deforestation are monitored using data collected from the USDA Forest Inventory and Analysis (FIA) Program. The EU Forest Strategy aims to maintain and restore European forests through sustainable forest management methods.

## 2.2 Research Initiatives

NASA's Terrestrial Ecology Programme is analysing the effects of climate change on forest areas. The EU's Horizon 2020 Forest Monitoring Project is creating new, innovative ideas for the protection of forested areas. The Forest Monitoring Project involves collaboration between universities and research organisations to develop new monitoring tools and methodologies.

Figure 1 illustrates the tracking system for forest and hilly regions using related works, and Table 1 explains the comparison between communication protocols.
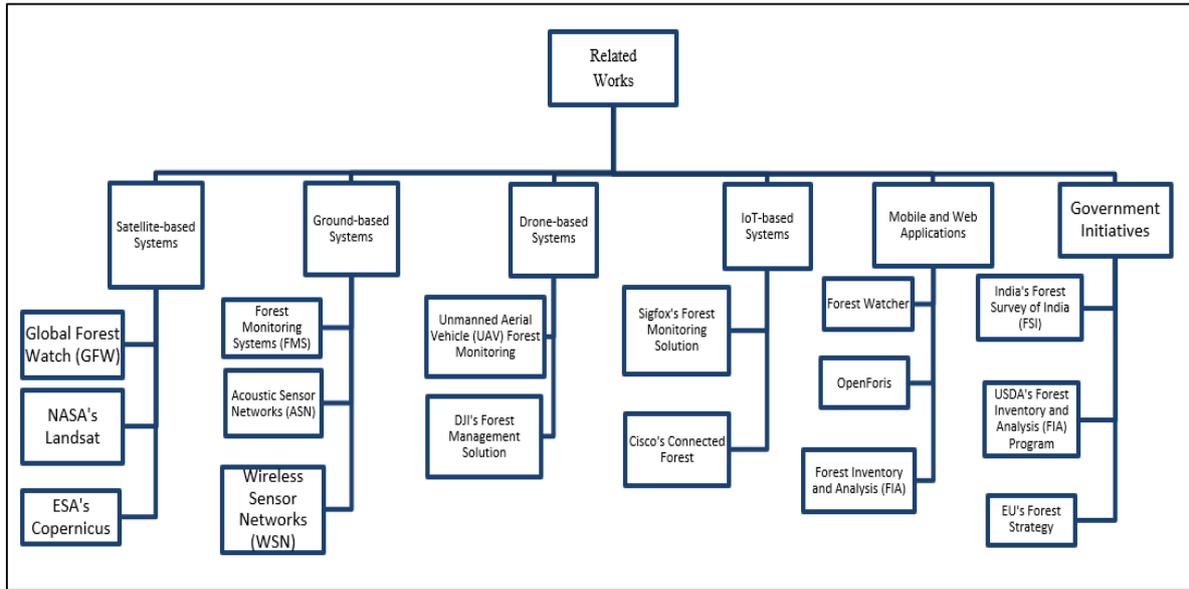
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**Figure 1.** Tracking System for Forest & Hilly Regions Related Works

**Table 1.** Comparison between Communication Protocol

| Feature | Bluetooth | Zigbee | Wi-Fi | LoRa |
|---|---|---|---|---|
| Range | Short (up to 100m) | Medium (up to 100m) | Medium (up to 100m indoors, longer outdoors) | Long (kilometers) |
| Data Rate | Medium | Low | High | Low |
| Power Consumption | Low (especially BLE) | Low | High | Very Low |
| Bandwidth | Medium | Low | High | Low |
| Latency | Low | Low | Low | High |
| Network Topology | Point-to-point, star | Mesh, star | Star | Star/Mesh (with gateways) |
| Use Cases | Audio streaming, file transfer, wearables, proximity sensing | Smart home devices, industrial automation | Internet access, high-bandwidth applications | IoT applications, long-range sensors, smart cities |
| Frequency Band | 2.4 GHz | 2.4 GHz | 2.4 GHz & 5 GHz | Sub-GHz (e.g., 868 MHz, 915 MHz) |

| Interference | Susceptible | Susceptible | Susceptible | Less susceptible |
|---|---|---|---|---|
| Cost | Low | Low | Medium | Low to Medium |
| Transmission Technique | Frequency Hopping Spread Spectrum | Direct Spread Spectrum Sequence | Orthogonal Frequency Division Multiplexing | Chirp Spread Spectrum |
| Max. end-devices | 255 (2 Billion in BLE) | More than 64000 | Depends on number of IP address | More than 5000 |

## 3. Previous Tracking Systems and Communication Protocols

GPS (Global Positioning System) utilizes signals sent from satellites to determine a user's location on Earth. GPS is exceptionally consistent because it allows users to accurately locate themselves within an approximate range of 3 feet under some situations. The failure to access these signals creates various challenges for individuals using GPS in remote areas of dense forest and steep hills. Terrain blocks and/or reflects many satellite signals, resulting in inaccurate GPS data or no GPS signal over the area. Another challenge is that the excessive use of battery power by GPS devices that continuously try to connect to satellite signals significantly decreases their battery life, limiting the time the tracking device can be utilized effectively. As a result, while GPS users experience better location accuracy in optimal conditions, they find their GPS devices ineffective in various situations.

Cellular (or mobile) networks provide a wide area of coverage but typically offer less coverage in remote areas because the necessary infrastructure to support cellular networks is located in populated areas; remote and highly populated forest and hillside regions lack the required cellular infrastructure. In combination with the expensive costs connected with data for continuous device tracking, this becomes a problem for users in remote areas. Additionally, the excessive use of battery power required to maintain a connection with cellular modems decreases the extended life of the battery in tracking devices.

Bluetooth is a low-energy, short-range wireless communication standard. The main limitation is its short range (around ten meters), limiting about 5% to 20% of normal daily

usage. These limitations make it insufficient for use in long-range applications, particularly in remote areas where tracking distances may exceed Bluetooth ranges.

Wi-Fi was developed to allow for high-speed data transfer rates (for example, 100 Mbps, etc.) between devices (for example, computers, tablets, smartphones, etc.) over short to medium range distances. While Wi-Fi has a larger physical range than Bluetooth, it is still not suitable to support large area tracking due to the requirement for the physical installation of infrastructure devices (or "access points") to provide a continuous connection. Therefore, Wi-Fi is suitable for short to medium range tracking applications, but in remote areas, Wi-Fi's infrastructure requirements can limit its utility in such locations.

Zigbee is a low-energy and low-data rate wireless communication protocol that allows for mesh networks or topologies. Connecting devices can provide better coverage compared to Bluetooth or Wi-Fi. However, the system must consist of numerous interconnected Zigbee-enabled devices to create a Zigbee network over a large area due to this requirement. When using a Zigbee system in large-scale applications, particularly in challenging terrain environments, significant installation and related costs are required. Therefore, Zigbee is more suitable than both Bluetooth and Wi-Fi for long range applications that require real-time monitoring of people or objects in and around remote areas.

## 4. Proposed System

The proposed model will use LoRa technology for long-range, low-power communications in remote and difficult-to-access locations. LoRa is a low-power, wide-area wireless technology that operates in an unauthorized area of the ISM frequency band. When using LoRa modules, data can be sent up to 10 km away from forest areas and other places with no cellular networks. This system has LoRa modules that will send data from devices placed in forests and hilly regions. The devices may be used to track things like people, wildlife, and devices. The sensed data that will be sent to the central server includes GPS coordinates and sensor data collected from the device. Once this data reaches the central server, it can be analyzed and provide real-time data to help in tracking and monitoring. Devices using small quantities of power indicate the device will survive longer than standard tracking devices; therefore, it will not need to be changed frequently. Overall, this system provides a highly reliable method of tracking and monitoring wildlife, personnel, and equipment in remote and

uninhabited locations, required to reduce the amount of resources. This system does not depend on base stations or communications infrastructure, but it is well-suited for locations with limited infrastructure. The long range, low power, and license-free features of LoRa make it an effective way to create strong and reliable IoT solutions in forested and hilly environments.

## 4.1 Propagation/Path Loss Modelling

When compared to the established propagation modelling standards (Okumura-Hata, COST-231, and ITU-R Veg) for measured RSSI values, the best interconnection between experimental data and the established modelling standards was provided in the ITU-R Model (lowest RMSE value). The log-normal shadow fading (standard deviation) was estimated at approximately 6.8 dB, with a path loss coefficient estimated between 3.4 and 3.9. The results within this study demonstrate that vegetation-specific models provide high performance compared to urban-based models in LoRa deployments within hilly terrains.

**Table 2.** Comparison of RMSE for All Models

| Path-Loss Model | Applicable Environment | Fitted Path-Loss Exponent (n) | Shadow Fading Std. Dev. ($\sigma$, dB) | RMSE (dB) |
|---|---|---|---|---|
| Okumura–Hata | Urban / Suburban | 2.9 | 9.6 | 11.4 |
| COST-231 | Suburban / Semi-Urban | 3.1 | 8.9 | 9.7 |
| ITU-R (Vegetation) | Forest / Hilly (NLOS) | 3.4 – 3.9 | 6.8 | 5.2 |

Table 2 shows the RMSE comparison of Path Loss Models for NLOS Forest and Hilly Terrain. Figure 2 represents the block diagram for the transmitter section of the proposed system, and Figure 3 represents the block diagram for the receiver section of the proposed work.
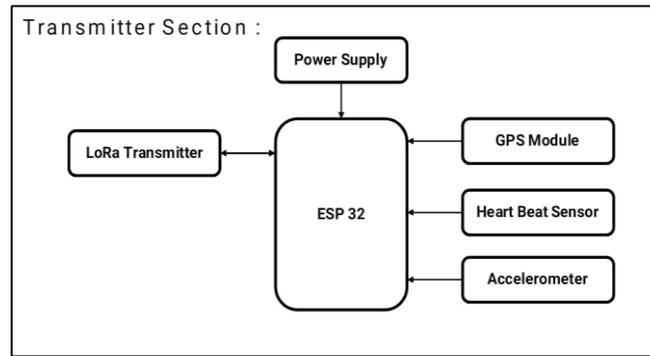
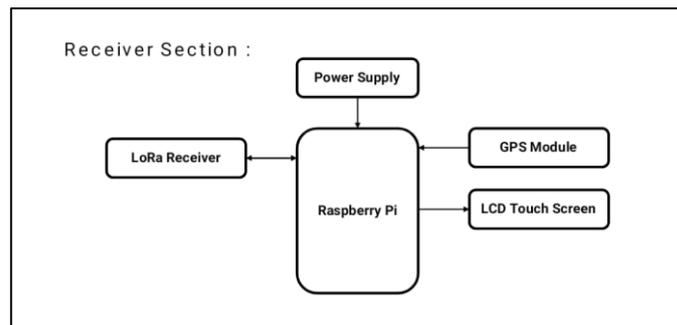**Figure 2.** Block Diagram for Transmitter Section of Proposed System



**Figure 3.** Block Diagram for Receiver Section of Our Proposed System

The following components are used at the transmitter side:

- A GPS module tracks the person's location.

- A heart beat sensor detects the heart rate of the individual.

- An accelerometer measures the changes in the individual's direction.

All three sensors (accelerometer, heartbeat sensor, and GPS module) connect and send data as inputs to an ESP32 microcontroller unit (MCU). ESP32 MCUs are used to design many Internet of Things (IoT)-based systems due to their built-in Wi-Fi and Bluetooth radio. ESP32 MCUs have been used to design different types of IoT applications, including environmental sensors and smart home devices.

Next, a LoRa transmitter is connected to the ESP32. LoRa is a type of long-range radio sensor commonly used to transmit IoT data.

At the receiver side:

- The LoRa receiver collects the data that was transmitted from the LoRa transmitter.

- The Raspberry Pi is connected to both the LoRa receiver and the GPS module.

- The Raspberry Pi is also connected to an LCD display shows the individual's location, heart rate and changed directions.

## 4.2 Signal loss in Forest and Hilly Terrains

The impact of the vegetation and terrain of forest and hilly regions on wireless signal transmission is significant. As part of the test process, LoRa Wireless Communication was tested in a variety of landscapes—e.g., hilly (sloping) and forested patches. The test results indicate that with heavy tree coverage, there was some packet loss; however, the Link Quality Index (LQI) maintained above 75% at a range of 8 km, demonstrating the high ability of LoRa to access and maintain the effects of the primary Wi-Fi, ZigBee, and GSM-based systems.

## 5. Results

The connection cost includes a 15 dB fade margin for regions limited by hills and deep shaded valleys. Nearly 3.2% of field testing produced transmissions that exceeded the fade margin, with these incidents frequently occurring in small valleys with heavy vegetation and rapid slope changes. The Adaptive Spreading Factor feature is used to reduce the length of these severe situations with minimal effects on the long-term performance and reliability of the overall system. The expected lifespan of a 3000 mAh 18650 lithium-ion cell battery is calculated based on several factors such as battery drain, temperature, cycle duty, and self-discharge. The estimated range of battery life will be approximately 9 to 11 months if the cycle time is below 1% and the frequency of sending a single packet every five minutes, using the coefficients produced at 25 °C battery life. When the storage temperatures of the 18650 battery are reduced (i.e., in the 0-5 °C temperature range), the duration of battery life usage decreases to approximately 6 to 7 months. This reduced timeframe is due to an additional reduction in the effective capacity of the battery and an increase in internal resistance as the distance increases (i.e., battery vs. electronics). Battery life prediction includes estimated losses related to the self-discharge of batteries (approximately 2% each month) and the degradation of the batteries over their lifetime.

Figure 4 provides an overview of both the transmitter and receiver sections used by the user. It shows how each of these components interacts and works together when connected. In addition, it provides an overview of the user interfaces with the transmitter and receiver components of the prototype to create and transmit messages (e.g., through a URL for location

information), and the receiver will display the messages received (e.g., location information). This figure also provides step-by-step instructions for operating the entire system during actual use cases. OFF Channel testing of a Packet Delivery Ratio (PDR) was conducted across forest areas with No Line of Sight (NLOS) from 2 to 8 kilometers. PDR remains high at 98.6% at 2 km, 96.1% at 5 km, and 92.4% at 8 km. Communication reliability was better even at long distances (i.e., forest with No Line of Sight (NLOS) conditions). As the travel distance increased, the speed of latency reached a maximum of approximately 410 ms at 2 km, an average of approximately 620 ms at 5 km, and a maximum of approximately 890 ms at an 8 km travel distance (95%). Results for PDR latency at 95% were recorded as improved distances traveled over NLOS increased in the same forested area (Table 2).
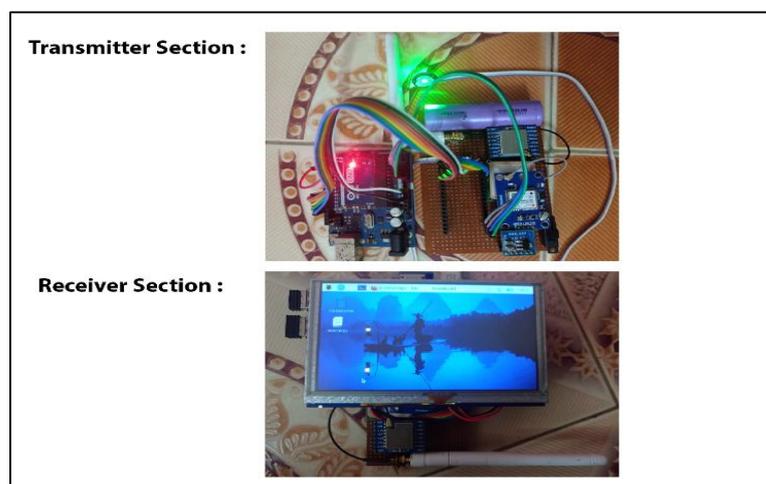


**Figure 4.** The Transmitter and Receiver Sections of the Developed Prototype

**Table 2.** Distance vs PDR vs 95th-Percentile Latency Values

| Distance (km) | Environment | PDR % | 95th-Percentile Latency (ms) |
|---|---|---|---|
| 0 | NLOS – Forest | 99.8 | 280 |
| 2 | NLOS – Forest | 98.6 | 410 |
| 5 | NLOS – Forest | 96.1 | 620 |
| 8 | NLOS – Forest | 92.4 | 890 |

The presented study analyzed the effect of rainfall and moisture in forests on the quality of both dry/wet tree conditions and the amount of rain across a variety of rainfall rates (2 - 10 mm/hr). The average SNR was reduced by 3 - 5 dB and the average PDR by 4 - 6% (over 5 km) with wet trees. Moderate rainfall (5 - 10 mm/hr) further reduced the SNR by up to 7 dB,

producing a 9% reduction in PDR (8 km). Histograms of SNR and PDR distributions showed a leftward shift after rain. This indicates increased variability in the wireless channel and an increased probability of packet loss during adverse weather conditions.

A mobile application has been created for the user's receiver section, allowing them to identify their position or the position monitored inside the forested area, hilly terrain, or any similar regions. The application presents the required data for efficient tracking and searching. Fig. 5 below illustrates the functionality of the application.
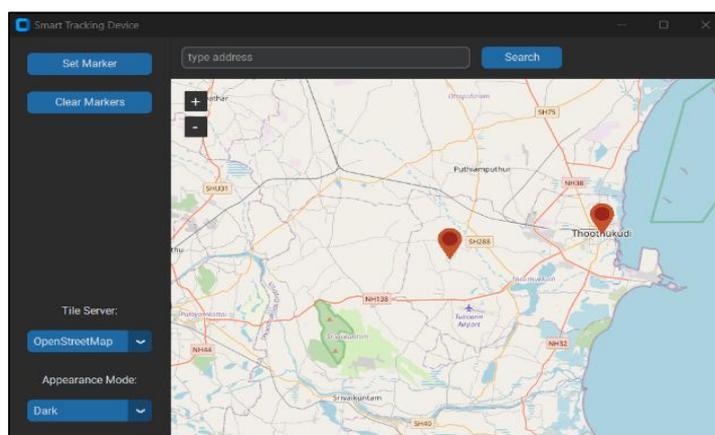


**Figure 5.** The App's Functionality

The LoRa-based transmitter module's power consumption is approximately 150 to 200 mW. The average current consumption during transmission is 40 to 50 mA, and while sleeping, it is 5 to 10 µA. Therefore, the batteries will last up to 2 to 3 months with a Li-ion 3000 mAh battery. Long-term use of devices requires minimal maintenance and battery changes because they consume minimal power to operate.

**Table 3.** Performance Comparison of the Proposed LoRa System

| Parameter | GPS-Based System | Zigbee System | Cellular Network | Proposed LoRa System |
|---|---|---|---|---|
| Communication Range | 2–5 km (line of sight) | < 500 m | Up to network coverage | 8–10 km |
| Power Consumption | High | Medium | High | Very Low (<200 mW) |
| Infrastructure Requirement | Satellite Link | Mesh Nodes | Cellular Tower | None (Peer-to-Peer) |

| Deployment Cost | High | Medium | High | Low |
|---|---|---|---|---|
| Data Transmission Rate | 10–20 kbps | 250 kbps | 1–5 Mbps | 0.3–50 kbps |
| Terrain Adaptability | Moderate | Low | Low | High (Forests & Hills) |
| Maintenance Complexity | High | Medium | High | Low |

Table 3 presents the comparison of LoRa system performance with other published systems as shown in [5], [7], [11], and [13]. The proposed LoRa system has demonstrated a significantly longer range than ZigBee technology and considerably lower energy consumption than NB-IoT based on testing. ZigBee technology had better performance (PDR) under 2 km, when the multi-hop distance limit reached caused the performance to decrease. NB-IoT has a very high PDR, and it consumes more power per delivered bit to maintain this level of performance as a result of the high overhead associated with network attachment and signaling. The proposed LoRa system maintained a PDR of over 90% at distances up to 8 km while requiring considerably less power per delivered bit. Thus, the proposed LoRa system is the best option for long-range battery-powered installations.

## 6. Limitation and Future scope

Heavy rain, dense vegetation, and steep slopes may interfere with the signal despite this system's high performance and power efficiency. The limited data rate is another constraint on the ability to send multimedia (video and images). There are various opportunities for improvement. Additional adaptive power control to optimize battery consumption based upon signals and terrain feedback can be added to the system to improve its capabilities. The system will allow for predictive connection control and dynamic network optimization using machine learning algorithms. Future work will support larger-scale deployments with less maintenance by utilizing edge-based data compression and LoRa nodes powered by solar panels. Additionally, by integrating with a cloud analytics platform provided by AWS IoT Core and Azure IoT Hub, forest officials and rescue teams could use dashboards to receive real-time updates.

## 7. Conclusion

This research study concludes that improving the system's functionality requires collaboration with industry experts to develop integrated solutions utilizing IoT and wireless technologies. Working with industry experts and research institutions will help improve communication and rescue technologies developed for use in forest and hilly environments, where a number of activities are remote and potentially dangerous. The ability to respond quickly to emergencies is crucial in these environments. The major objective of this system is to find and help people who are missing or injured in a short time, as rapid response is important to increase the survival rate for injured or missing people. This system also facilitates real-time tracking and communications, providing the ability to dispatch rescue teams quickly and improve search operations. The proposed system increases the safety of individuals working or recreating in these remote and risky areas, and its development and implementation represent a major advancement in protecting the well-being of people who work or live in hilly regions.

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