

Long-Range Emergency Communication Using LoRa Technology for Disaster Management

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Abstract - During disaster situations, traditional communications like cell phones can be inoperable or disconnected, making information sharing and emergency coordination difficult. The Long Range (LoRa) technology is an effective alternative due to its long-range capability, low power consumption and no dependence of the internet. In this study, a bidirectional communication system using LoRa is designed for disaster management applications. The main components of the proposed system include an ESP32 microcontroller as the central processing unit, a LoRa wireless communications module, a keypad for user input, and an OLED display for visualizing the data. Also, an SOS push button has been built in for easy emergency warning transmission. The device is powered by a solar energy system for uninterrupted operation in remote and disaster-affected areas. The ThingSpeak platform is a single repository and visualization system for collecting and interpreting data sent over the internet.

Key Words: LoRa, Disaster Management, ESP32, Emergency Communication, GPS Tracking, IoT, ThingSpeak, Solar Power, Bidirectional Communication, Wireless Sensor Networks.

1. INTRODUCTION

Communication is a vital component during disaster situations like earthquake, tsunami, cyclone and landslide. But these kinds of disasters often damage or disrupt traditional communication systems, such as cell phones and the Internet, making it very difficult to communicate and coordinate information. This has created a need for communication systems that can work without relying on the existing network infrastructure, that are low power and have a long range.

Recently, the technology of wireless communication with low power and long-distance has become popular, namely the technology of Long Range (LoRa) [5,18] which is suitable for Internet of Things (IoT) applications. LoRa is different from traditional wireless communication technologies, using Chirp Spread Spectrum (CSS) modulation and frequency bands in the unlicensed radio frequency spectrum. These features make it more resistant to interference and provide for good communication over distances of several kilometers [6,25].

The performance of LoRa has been assessed in a variety of environments such as urban areas, rural areas and forests and has been proven to be flexible, robust and adaptive in different operating conditions [4,12]. Moreover, LoRa technology has been successfully integrated in various application fields, including healthcare monitoring, surveillance systems, environmental monitoring, and public service operations, showcasing its versatility and effectiveness [3,9,11].

In this paper, a bidirectional communication system using LoRa for disaster response and emergency management is proposed. The proposed system enables the exchange of

messages, tracking position and sending of emergency messages without the need for Internet connection. It combines LoRa communication, GPS positioning and emergency notification capabilities to offer reliable, energy-efficient, and swift communication assistance in critical disaster scenarios.

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2. LITERATURE REVIEW

The performance and applicability of LoRa technology have been researched in various environments. Murata et al. [1] did a simulation study of LoRa communication in a rural megacity in Japan and showed its potential for wide area communication coverage while requiring little infrastructure. Villarim et al. [4] also evaluated LoRa communication in urban and forest settings, and found that LoRa can provide long-range communication, but physical obstructions and vegetation can have an impact on LoRa performance. The same conclusion, that is, the impact of the environment on LoRa communication, was noted in the applications of wildlife monitoring [12].

The technical aspects of LoRa communication have also been thoroughly researched. Springer et al. [6] explained the Chirp Spread Spectrum (CSS) modulation technique which is used to achieve robust long-range communication. Centenaro et al. [23] noted the increasing importance of LoRa in the field of Internet of Things (IoT) and smart city, as it is a low-power consumption technology that allows for long range communication.

There are some studies that have analyzed the drawbacks and issues of LoRaWAN networks. Adelantado et al. [5] found constraints of data rates, scalability, and duty-cycle limitations. The state, challenges and future of LoRaWAN deployments were also discussed in detail in the comprehensive review done by Rahman et al. [16] and the study presented in [17]. In the past few years, research has been conducted on ways to improve transmission in terrestrial and satellite aided communication systems [19,21].

LoRa has been proven to be used in many IoT applications. Misran et al. [3] proposed a health monitoring system that was able to transmit data over long distances with the LoRa communication method with high reliability. During the COVID-19 pandemic, Rawat et al. [8] pointed out that LoRa-IoT networks are crucial for remote monitoring and communication. Other potential applications include child tracking using GPS/Lora technology [11], messaging system without internet connection [15], wireless embedded

communication system [22], environmental sensing networks [20] and monitoring of electrical systems on ships [18].

The performance of LoRa under challenging communication conditions has also been investigated. Kucherov et al. [7] investigated signal detection under the interference environment, and Babayigit and Dogan [14] introduced the urban building density and its effect on the LoRa communication performance. A further study by Michaelis et al. [9] also showed that LoRaWAN was suitable for mission critical communication scenarios in military communication experiments.

Despite the extensive research of LoRa and LoRaWAN technologies, most of the available solutions rely on the LoRaWAN gateway-based infrastructure and connection to Internet. Few studies have been conducted on standalone bidirectional LoRa communication systems that enable emergency messages, GPS-based location tracking, and SOS messages to be sent during disasters. To this end, this work introduces a self-sustained LoRa based disaster communication system that can work without relying on the conventional communication infrastructure and can provide reliable communication and disaster response functions.

3. PROPOSED SYSTEM

The system is a bidirectional LoRa communication system that can be used in disaster situations where regular communication methods fail. This proposed system is a peer-to-peer (P2P) communication system between two nodes that does not require an internet connection or gateways. This system is suitable for emergency or off-the-grid communications.

The system is based on an ESP32 microcontroller that communicates with a LoRa module for long-distance communication. LoRa communication is well-suited for this type of application as it offers low power consumption and can send data over multiple kilometres [5, 25].

The system has a keypad to enter messages, allowing users to send user-defined text messages. It includes an SOS button for immediate emergency messages, allowing for a fast response in case of emergencies. It has a Neo-6M GPS module is integrated to acquire location information, which is sent with the messages to help in tracking down person in distress. The system uses a solar panel to power it, making it suitable for regions with off-grid locations. [11].

An OLED screen is used to show messages, coordinates and status information on the trans receiver. The proposed system is powered by a solar panel and can be used in areas with an off-grid locations. This is in line with the energy-efficient design of LoRa IoT devices [8].

The system is connected to ThingSpeak for cloud-based visualization of latitude, longitude and distance information. This makes surveillance and monitoring easier, especially in the case of search and rescue.

4. SYSTEM ARCHITECTURE

The architecture of the proposed system consists of two identical transreceivers for bidirectional communication. Each node includes an ESP32 microcontroller, LoRa (SX1278) module, GPS (NEO 6M) module, keypad, OLED display, and SOS button. The system operates in a peer-to-peer manner, eliminating the need for LoRaWAN gateways or internet infrastructure.

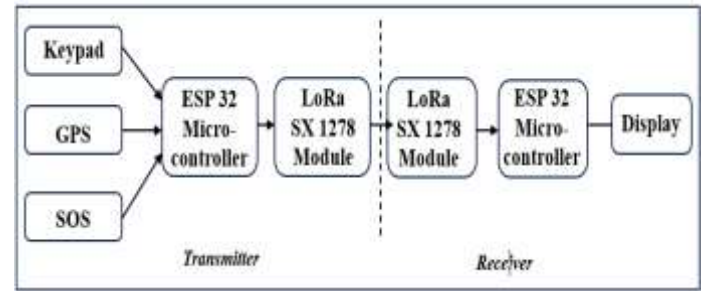


Fig -1: Block Diagram

As shown in figure 1, the data flow begins with user input through the keypad or activation of the SOS button. The ESP32 processes the input and encodes it into data packets for transmission. The LoRa module then transmits the data wirelessly to the receiving node. At the receiver side, the LoRa module captures the signal, and the ESP32 decodes and displays the message on the OLED display.

Simultaneously, the GPS module continuously provides latitude and longitude data, which is transmitted along with messages. This enables real-time tracking of the sender's location. The use of LoRa for such long-range data transmission has been validated in multiple studies across different environments.

The system supports data logging and visualization through ThingSpeak whenever internet gets available, where parameters such as location and distance can be monitored remotely.

The bidirectional nature of the system ensures that both nodes can send and receive messages, making communication interactive and reliable.

5. WORKING OF THE SYSTEM

The system operates through two functional phases which consist of transmission and reception as shown in the system block diagrams.

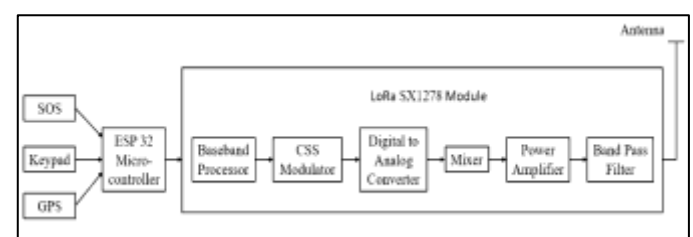


Fig -2: Transmission of LoRa Based Communication System

As shown in figure 2, on the transmitting side, a keypad is used for user input while the GPS module continuously provides location data through latitude and longitude coordinates. The SOS button generates an emergency alert message which has been set up beforehand. The ESP32 microcontroller handles all incoming data which it turns into a data packet that is ready for transmission.

The LoRa module obtains processed data which it requires for its various signal processing functions. The baseband processor creates a digital signal which uses Chirp Spread Spectrum (CSS) technology to undergo modulation. The modulation provides longer communication distance while preventing interferences. The Digital-to-Analog Converter transforms the modulated signal into an analog signal which the mixer then uses to boost the signal to its intended

frequency. The power amplifier enhances the signal strength which the antenna then transmits to the surrounding area.

The receiving system operates through its antenna which detects incoming data packets send from the LoRa module from the transmitter side.

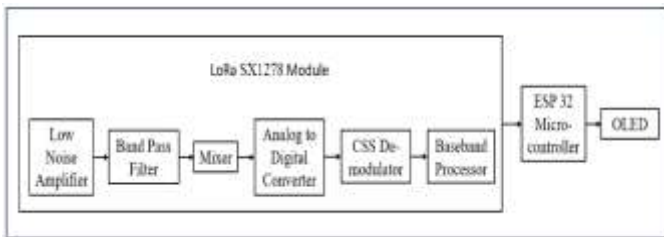


Fig -3: Reception of LoRa Based Communication System

As shown in figure 3, noise Amplifier (LNA) which strengthens weak incoming signals. A Band Pass Filter (BPF) removes all frequency components which are not required. A mixer reduces the filtered signal to baseband which the system processes into digital data through an Analog-to-Digital Converter (ADC).

The CSS demodulator extracts the original data from the received signal by demodulating the digital signal. Baseband processor uses the data to send it to the ESP32 microcontroller. The ESP32 processes the received message which it displays on the OLED display with the associated GPS coordinates.

The system allows users to show local data while they transmit processed information to ThingSpeak for visualizing distance and location data. This provision is allowed only when internet is available as ThingSpeak requires internet connectivity for cloud access.

6. RESULTS

The system was tested across various environments to evaluate its operational performance. The results showed that surrounding physical terrain directly influenced the communication range. In urban environments containing dense obstacles, the reliable signal link reached up to 1 kilometer, whereas open rural spaces allowed for significantly greater transmission distances.



Fig -4: Transmitted location with coordinates and signal strength

Throughout the field trials, the system maintained steady, bidirectional peer-to-peer communication. The integrated Neo-6M GPS module successfully provided accurate positioning data, enabling users to transmit local

coordinates alongside text messages and automated SOS alerts. When a local internet gateway became available, these metrics were uploaded to the cloud-based ThingSpeak platform, allowing users to track real-time coordinates and monitor distances between active nodes.

7. DISCUSSION

The variation in communication range across deployment environments is attributed to multi-path fading and structural attenuation. In urban settings, concrete walls and buildings introduce severe path loss and block the direct line-of-sight path required for optimal propagation. Although LoRa utilizes Chirp Spread Spectrum (CSS) modulation to achieve high noise immunity and robust performance, physical barriers still limit the absolute link budget.

The successful synchronization with ThingSpeak demonstrates a viable architecture for emergency scenarios where traditional cellular infrastructure fails. By relying on low-power, off-grid hardware, the system ensures persistent tactical communication during disaster management operations, while utilizing secondary internet networks to log long-term situational data.

8. DATA VISUALIZATION AND ANALYSIS

The proposed LoRa-based communication system integrates ThingSpeak for real-time data visualization and performance monitoring. The transmitted parameters, including latitude, longitude, received signal strength, and distance between nodes, were analysed using graphical representations obtained from the ThingSpeak platform.



Fig -5: Graphical Representation of the Parameters

The latitude and longitude graphs, as shown in figure 5, indicate that the system initially records near-zero or constant values, followed by a sudden increase once the GPS module acquires a satellite lock. This behaviour is typical of GPS-based systems, where an initialization delay occurs before accurate positioning data is obtained. The successful transmission of these parameters confirms the proper integration of the Neo-6M GPS module with the LoRa communication system.

The RSSI graph shows values ranging approximately between -65 dBm and -40 dBm, indicating a stable communication link between the transmitting and receiving nodes. The gradual improvement in signal strength suggests reduced interference or improved alignment during operation.

The distance graph, derived from GPS coordinates, shows relatively stable values with minor fluctuations over time. These variations can be attributed to inherent GPS

inaccuracies and environmental factors affecting signal reception.

Overall, the ThingSpeak analysis confirms that the system is capable of reliable real-time data transmission, effective signal monitoring, and dynamic distance estimation. The integration of cloud-based visualisation enhances system usability and provides valuable insights for monitoring and decision-making in disaster management scenarios.

9. APPLICATIONS

In emergency and disaster situations, LoRa communication systems are very useful because they do not rely on traditional network infrastructure. In times of crises like earthquake, flood, landslide and cyclone, the conventional communication systems may fail or turn too busy to coordinate the rescue operations and the impacted population. LoRa is a reliable solution for maintaining communication during such critical situations, due to its low power consumption, long communication range and infrastructure-independent operation [5,23]. In the event of conventional communication systems failing, LoRa-based systems can still provide a means for information to be exchanged and emergency coordination to be maintained.

LoRa technology is also well suited in rural and remote areas where the cellular coverage is weak or nonexistent. It can also be used to communicate and monitor in geographically isolated areas, where internet connection is not available, which makes it a valuable tool for such applications [8,20].

Furthermore, defense and security applications have investigated the potential of LoRa communication in difficult application conditions such as urban areas, mountainous regions, and remote areas where traditional communication networks are less reliable. Research has shown LoRa's ability to provide reliable communication in critical scenarios, improving operational efficiency under challenging environments [9].

In addition to applications in disaster management and disaster defence, LoRa has become one of the most important technologies powering the Internet of Things (IoT). It operates at low power and has a long range of communication which makes it ideal for environmental monitoring, healthcare systems, smart agriculture, industrial automation and asset tracking. With the ongoing growth of IoT ecosystems, LoRa is likely to become a key component in facilitating efficient and sustainable communication between interdependent devices across vast distances.

10. LIMITATIONS

Although the proposed LoRa based communication system has its merits, some limitations are found. The low data transmission rate is one of the main limitations of LoRa technology, making it difficult to efficiently transmit large volumes of data. As a result, applications that need to communicate at high speeds or transmit multimedia data (including audio and video streams) may suffer from decreased performance or become impractical [5].

The communication range of LoRa can also be affected by environmental conditions. Radio signals can be attenuated and transmission may not be reliable due to physical obstructions such as buildings, hills and dense vegetation. Urban areas and forest areas have been shown in previous

studies to have a significant effect on signal propagation and communication quality [4,16].

The other is with GPS location tracking. GPS accuracy could be reduced in an indoor environment or when the satellite signal is weak, which may lead to less accurate location data. Moreover, other wireless devices that work on the same frequency range as the communication devices can affect the performance of communication and signal reliability [7].

Another issue with LoRa communication systems is security. The system that is proposed is reliable in terms of communication functionality, but the lack of proper security settings could lead to network breaches and possible cyber risks. For this reason, effective authentication, encryption and access control are critical to increase system security.

In conclusion, while LoRa technology shows great promise for disaster management and emergency response applications, there are still several limitations that need to be addressed in the future through technological advancements and optimized system design.

11. FUTURE SCOPE

The future scope and enhancements: Future scope and enhancements:

There are some improvements that could be made to the proposed communication system using LoRa. The implementation of a LoRa mesh network can be used to increase the range of communication and provide network reliability by using nodes to relay messages between each other. A mobile app would offer a better way to manage messaging, location and emergency alerts.

Improved security can be achieved by using encryption and authentication methods to prevent unauthorized access to transmitted information. Furthermore, voice communication features can be integrated, which can enhance communication during emergencies.

Another interesting improvement is satellite assisted LoRa communication, where communication can be provided in remote, inaccessible regions where terrestrial communication infrastructure is not available [19]. These enhancements can lead to greater scalability, security, and reliability of the system for future disaster management use.

12. CONCLUSION

In this paper, the design and development of a LoRa communication system for disaster management application has been introduced. The proposed system can be used for long-range communication, and it can be used in the situation that the cellular and internet are not available, which is a time to emergency.

The system is made up of an ESP32 microcontroller, LoRa module, GPS module, keypad, OLED display, and solar power source, making it a portable, low-power, and inexpensive communication system. Experimental implementation showed that the communication had a high reliability over long distances and low consumption.

The proposed system provides a practical and cost-effective solution for emergency communication and has the potential to be applied to different IoT and real-world applications. It is useful for emergency response and management due to its applications in communication, tracking and alerting capabilities.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Electronics and Telecommunication, RMD Sinhgad School Of Engineering, Warje, Pune for providing support and guidance for this review work.

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