

Design and Implementation of a Bidirectional Long-Range Communication System for Disaster Management Applications

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Abstract

In times of natural disasters like earthquakes, floods, landslides, and cyclones, the normal communication lines are frequently cut, thus reducing the ability of the affected people and the relief team to communicate vital information. Cellular networks and Internet-based communication systems could be compromised in the event of a loss of power, damage to infrastructure, or network congestion. Thus, it is necessary to have a communication system that will be dependable, low-power, and infrastructure-independent and can function during an emergency. This paper introduces the design and development of a bidirectional communication system for disaster management and emergency communication based on LoRa technology. The proposed system utilizes an ESP32 microcontroller as the brain and a LoRa transmitter-receiver module for long-range wireless data transfer. It features a built-in Neo-6M GPS module for real-time location and a keypad for setting and sending personalized messages. Transmitted and received messages, device status, and location information are displayed on an OLED display. Also, there is an SOS button provided for sending out alerts instantly and the user's location. The system is also solar-powered to eliminate reliance on traditional electrical systems in remote and disaster areas. The transmitted data (messages, GPS coordinates) is also uploaded to the cloud platform ThingSpeak if the internet connection is available, which allows data to be stored, displayed, and monitored remotely. The proposed system is a cost-effective, energy-efficient, and resilient communication system that can be used to support emergency response operations in challenging environments. The system integrates long-distance communication, location tracking, disaster emergency alert, and solar energy power support, allowing for better situational awareness, collaboration among users, and effective disaster response and recovery.

Keywords: LoRa, ESP32, disaster management, emergency communication, GPS tracking, IoT, solar power, ThingSpeak, long-range communication

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INTRODUCTION

Communication is key in disasters such as earthquakes, tsunamis, cyclones, and landslides. The same type of calamities can cause conventional communication systems, such as cell phone towers and Internet links, to fail. This can make communication challenging in such circumstances. Consequently, there is a growing need for low-power, long-range, network-independent communication systems [1–3].

Over the past few years, long-range (LoRa) communication technology has been in focus because of its long-range and low-power features, making it an ideal choice for the Internet of Things [4, 5]. This is different from other wireless

communication systems. It features an unlicensed radio frequency and chirp spread spectrum modulation, making it more resistant to interference and providing long-range communication of several kilometers [6, 7].

The performance of LoRa has been demonstrated in various applications, including dense urban areas, rural areas, and forest environments [8, 9], highlighting its versatility and adaptability. Additionally, owing to its versatility, LoRa is being utilized in various operations such as healthcare, surveillance, and service operations [3, 10, 11].

In this study, a bidirectional LoRa communication system for disaster response operations is introduced [2]. The system can enable real-time communication, tracking, and emergency alerts without the Internet. The proposed system can provide rapid and dependable communication during emergencies [3].

Proposed System

A bidirectional communication system using LoRa with the ability to communicate in case of disaster when normal communication is not possible. A peer-to-peer (P2P) communication system between two nodes that does not require an Internet connection or gateways is proposed. This system can be used for emergency communications or off-the-grid applications [8].

The core of the system is an ESP32 microcontroller that acts as a wireless communication node with a long-range LoRa module. LoRa communication is a perfect solution for such applications because it consumes low power and enables data transmission over several kilometers [4].

The system has a keypad for entering messages, allowing users to send user-defined text messages. It also features an SOS button for sending emergency messages at any time, enabling a quick reaction in case of an emergency [12]. It is also outfitted with a built-in Neo-6M GPS module to locate an individual in distress and send location details with messages. The system also uses a solar panel to power it, making it suitable for 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 off-grid locations. This is in line with the energy-efficient design of LoRa IoT devices [13].

The system is linked to ThingSpeak, and distance data can be visualized in the cloud using latitude and longitude data. This makes surveillance and monitoring easier, especially in search and rescue operations [10].

SYSTEM ARCHITECTURE

The designed system comprises two identical transceivers for bidirectional communication. There are four nodes with an ESP32 microcontroller and LoRa (SX1278) module, GPS (NEO 6M) module, keypad, OLED display, and SOS button. It is a peer-to-peer system in which no LoRaWAN gateways or Internet infrastructure are required [14].

The data flow starts with the user input via the keypad or by pressing the SOS button. The input is sent to the ESP32, which encodes the data in packets for transmission [9]. The data is then wirelessly transferred to the receiving node using the LoRa module. The receiver side consists of the LoRa module that receives the signal and the ESP32 that decodes the data and sends it to the OLED display. The block Diagram in Figure 1 shows the wireless communication system used in the model [15].

Simultaneously, the GPS module constantly sends latitude and longitude information, which is sent along with the messages. This allows the location of the sender to be tracked in real time. This has been proven in multiple studies in various environments for data transmission over long distances using LoRa [16].

It also integrates with data visualization and logging via ThingSpeak on the Internet, thereby allowing for the remote monitoring of data such as location and distance.

The system is bidirectional, which means that both nodes can send and receive messages, allowing for interactive and reliable communication [17].

WORKING OF THE SYSTEM

The system operates through two functional phases: transmission and reception, as shown in the system block diagram. Figure 2 shows the transmission process of the LoRa-based communication system.

On the transmitting side, a keypad was used for user input, and the GPS module continuously provided location data through latitude and longitude coordinates. The SOS button generates an emergency alert message that has been set up beforehand. The ESP32 microcontroller handles all incoming data, which is converted into data packets that are ready for transmission [18].

The LoRa module obtains the processed data required for its various signal processing functions. The baseband processor creates a digital signal that uses Chirp Spread Spectrum (CSS) technology for modulation. The modulation provides a longer communication distance while preventing interference [19]. 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 transmits to the surrounding area [5].

The receiving system operates through its antenna, which detects incoming data packets sent from the LoRa module on the transmitter side. Figure 3 shows the reception process of the LoRa-based communication system [20].

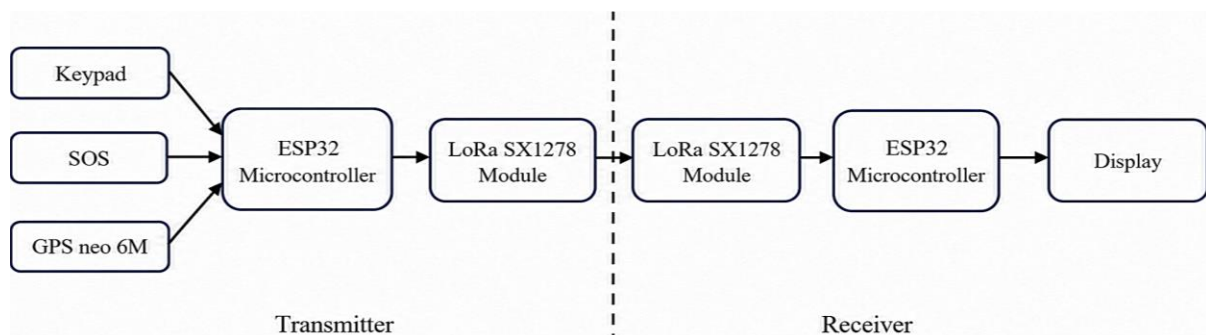


Figure 1. Block diagram of the process of the proposed system

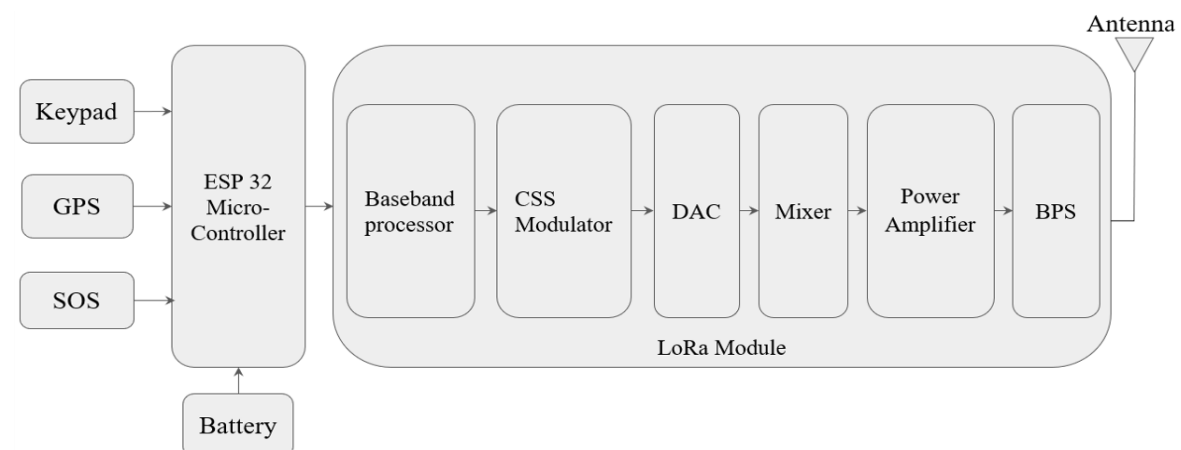


Figure 2. Transmission of the LoRa-based communication system.

Low-noise Amplifier (LNA) strengthens weak incoming signals. A bandpass filter (BPF) removes all frequency components that are not required. A mixer reduces the filtered signal to the 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 it. The baseband processor uses the data to send it to the ESP32 microcontroller. The ESP32 processes the received message, which is displayed on the OLED display with the associated GPS coordinates.

The system allows users to show local data while transmitting processed information to ThingSpeak to visualize distance and location data. This provision is allowed only when the Internet is available, as ThingSpeak requires Internet connectivity for cloud access.

RESULTS

The system was tested in various environments to evaluate its operational performance. The results showed that the surrounding physical terrain directly influenced the communication range. In urban environments containing dense obstacles, the reliable signal link reached up to 1 km, whereas open rural spaces allowed for significantly greater transmission distances. The given image shows the received output, as shown in Figure 4.

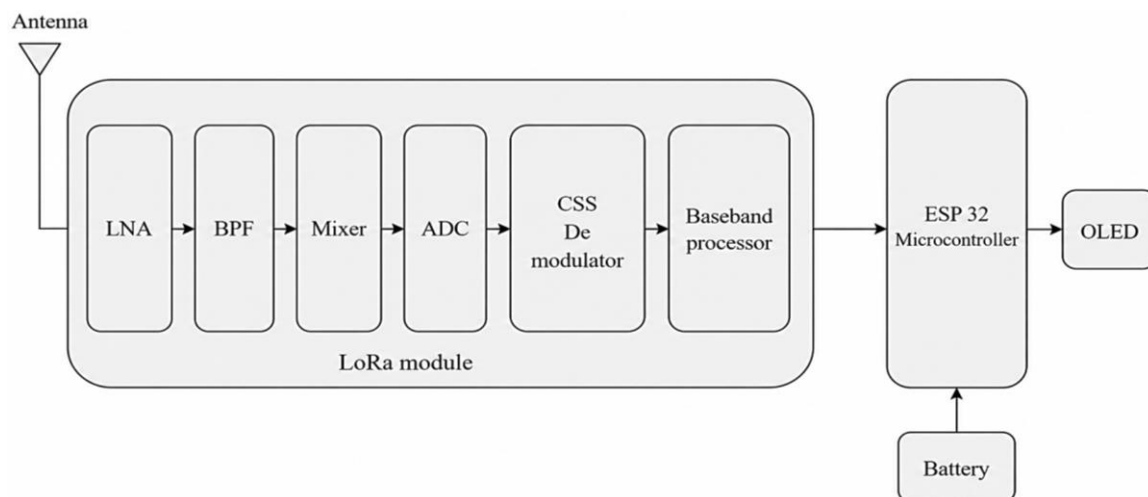


Figure 3. Reception of LoRa-based communication system.

Source: Authors' illustration.

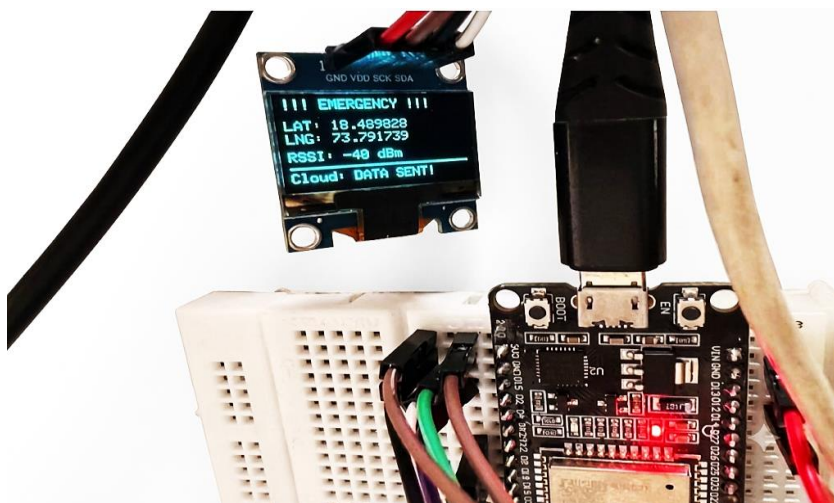


Figure 4. Transmitted location with coordinates and signal strength.

Source: Authors' illustration.

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

DISCUSSION

The variation in the communication range across deployment environments is attributed to multipath fading and structural attenuation. In urban settings, concrete walls and buildings introduce severe path loss and block the direct line-of-sight paths 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 demonstrated a viable architecture for emergency scenarios in which the 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.

DATA VISUALIZATION AND ANALYSIS

The proposed communication system based on LoRa was combined with a platform called ThingSpeak, which provides real-time visualization and monitoring of important communication parameters. The transmitted data (latitude, longitude, Received Signal Strength Indicator (RSSI), and distance between nodes) were uploaded to the cloud and analyzed using graphical representations, as shown in Figure 5, created by ThingSpeak.

Both the latitude and longitude plots showed that the communication node was stationary throughout the observation period. The acquisition and transmission of geographic coordinates were successful, which shows the successful integration of the GPS module Neo-6M into the LoRa communication system and confirms the reliability of location reporting.

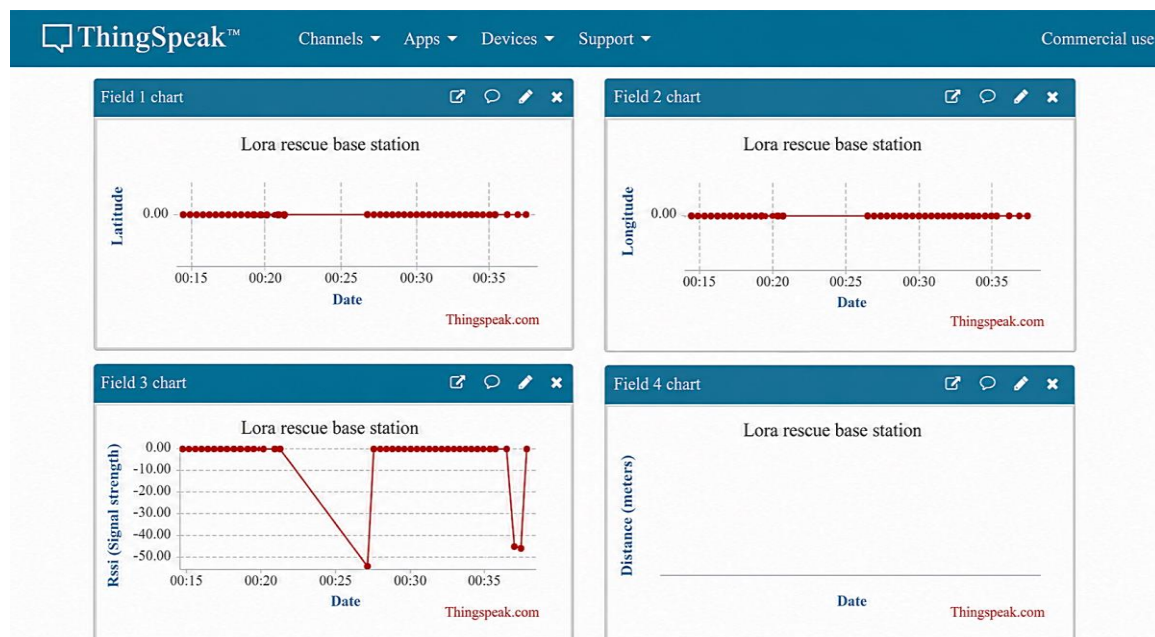


Figure 5. Graphical representation of the parameters.

Source: Authors' illustration

The RSSI graph depicts fluctuations in signal strength as a function of time, and the signal strength is typically stable and within the acceptable operating range of LoRa communication. A few points of RSSI decrease can be observed, but the signal returns to its normal value immediately, indicating that the communication line was stable during this experiment. Such variations are caused by the environment, antenna direction, and minor interference with wireless signal propagation.

For the distance graph, the difference was not significant and was relatively low throughout the test period. This was expected because both communication nodes were placed at a close distance during the experiment. Errors in the GPS measurements and variability in the satellite signals may have caused small differences.

Overall, the ThingSpeak visualization shows that the location and communication data were successfully sent to the cloud platform. The results prove the ability of the proposed system to successfully perform location tracking, signal strength analysis, and reliable real-time monitoring. This cloud-based visualization improves situational awareness and aids in making informed decisions during disaster management and emergency communication efforts.

Applications

LoRa communication does not require any existing networks, making it extremely convenient when all else fails. In disaster situations, such as landslides, floods, and earthquakes. Regular networks either fail or become overloaded, and teams are unable to coordinate. It operates in a low-power mode, extends the range of communication, and does not require a dependable outside infrastructure [4, 17]. Where conventional communication methods come to a halt, LoRa keeps people connected.

This can also be seen in rural or remote areas, where there is no or poor cell reception. In these locations, LoRa is the most appropriate solution for sending data over large distances without the need for Internet connectivity [13, 7].

It is used by defence organizations, especially in hard-to-reach areas such as urban areas or hilly terrain, where alternative networks are lacking. In remote areas, where no other communication can reach, LoRa is used by military teams as their only viable way to remain in contact [10].

As IoT continues to grow, numerous devices need to communicate with each other over long distances without using their energy resources.

Limitations

Although useful, the system faces specific limitations. Because LoRa operates at low data speeds, sending large messages takes longer [4]. Tasks requiring a fast data flow struggle to function well. High-bandwidth usage, such as video or audio transfer, often fails under these conditions.

Signals travel shorter distances when they are blocked by physical structures or natural features. Research indicates that urban clutter and tree cover weaken transmission quality [8, 18].

GPS units often work less precisely inside buildings or where satellites are difficult to reach. Wireless gadgets sharing similar frequencies may also disrupt signals [12].

One drawback lies in the lack of enhanced safeguards within the core setup, leaving it open to intrusion if the protections remain weak. Although functional by design, gaps in defense could allow entry to unintended users when configurations fall short.

Improving these limitations may lead to better performance and stronger reliability of the system.

Future Scope

In addition, some of the functionalities that have already been designed and developed should be included. One substitute is the implementation of a mesh network. In this arrangement, devices on the network can communicate with one another, thereby extending the range and reliability of the network. This can be achieved using a LoRaWAN network. It can have a mobile app, making it more convenient to use the system and allowing additional access to the system.

Encryption of transmitted data could also be implemented so that unauthorized individuals will not be able to see data as it travels. We could have a voice communication facility that can improve our ability to communicate when it is crucial. Another development to be implemented, and currently under investigation, is the application of satellite-assisted LoRa communication as a means of connectivity in areas that would otherwise be unattainable for using ground networks.

CONCLUSION

In this study, the design and implementation of a LoRa communication system for disaster management was investigated. It provides communication over long distances without any conventional network, which helps in emergencies.

The system has all the required components. The ESP32, LoRa module, GPS module, Keypad, OLED, and solar energy system make it a space-efficient, power-saving, portable communication system. The system effectively communicates over long distances at low power.

This system will help provide practical and low-cost communication for emergencies and can be implemented in any type of IoT device and real-life application.

Declaration of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript.

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