

# Self-Healing Decentralized Wireless Communication Network Using LoRa Mesh with GSM Backup

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**Abstract**— During the emergency cases like the occurrence of natural disasters or in the remote locations where the traditional networks usually become ineffective because of the overload, blackouts, or damages in the infrastructure, the communication plays a major role. The proposed paper presents a wireless communication system with decentralization and LoRa and GSM integration to provide the safety and continuity of the data transmission. It is supported by developing the system with the help of Arduino UNO, transmitter and receiver modules, which allow taking secure messages through Bluetooth, switching to the automatic mode when GSM and LoRa are used, and real-time tracking of the position. It allows communication over a long distance with limited power consumption and without the use of the internet. Emergency messages will automatically cause an instant audio message at the receiver end which provides quick response in emergency situations. The system is modularly designed, and therefore can be scaled easily and can be enhanced in future. It also makes sure that there is a minimum delay in communication which enhances the responsiveness of the entire system. The suggested solution gives greater credibility to communication even in unfavorable environmental circumstances. According to experimental findings, the proposed system is cost-effective, reliable and efficient in managing disasters and communicating remotely.

**Keywords**— *Wireless Mesh Network, GSM Communication, Community Networking, Emergency Communication, De-centralized Network, Rural Connectivity*

## I. INTRODUCTION

Rural and disaster prone regions are some areas that need to be able to communicate effectively in cases of disasters, emergency response, and sharing information. The conventional communication tools like cellular and internet-based tools are centralized infrastructure, which can easily breakdown when there is a natural disaster or in remote places and this results in tremendous communication failure [1], [2]. New development in the field of wireless technologies has made possible the decentralized and low-power communication systems that do not require any traditional infrastructure. WLAN is one of the technologies that have been widely researched in application in wireless sensor networks, ad-hoc networks, and mesh based systems [3], [4]. Nonetheless, the majority of these methods rely on the connectivity stability or are restricted to simulations, which are not as applicable to real-time cases of emergencies. New technologies such as the use of long-range

communication such as the LoRa have proven useful in transmitting low-power and long-range data. LoRa can be used in rural and disaster-prone areas because it has a large range and can resist interference [5], [6]. Nonetheless, the LoRa-based systems are limited in case there is a need to use fallback communication or external alert transmissions. To deal with this, hybrid communications systems have been considered that would help in the combination of both GSM and short-range wireless interfaces. GSM is an effective mechanism that ensures a fallback option whereas Bluetooth allows direct interaction with the user without the need to use internet [7]. Nevertheless, current systems do not imply on-the-fly hardware implementation, safe access, and inbuilt emergency notification. Also, data protection is a significant issue in decentralized systems due to the unauthorized access, which may cause critical failures. Even though secure authentication and access control has been researched upon [8], hardly is it applied to real-life hardware systems.

As a solution to these shortcomings, this paper suggests a decentralized communication system based on hardware that incorporates the LoRa, GSM, and Bluetooth technologies. The system allows transmission of real-time messages, emergency alerts and location tracking using GPS technology without the need of the internet connection. It is realized with the help of modules based on Arduino that provide a scalable, reliable, and cost effective solution to disasters management and remote communication.

## II. LITERATURE SURVEY

Modern information communication requires dependable wireless communication infrastructures and they are vital in the applications of the system in the area of public safety, rural connectivity and emergency response.

The family of IEEE 802 standards offers an overall architectural design of both local and metropolitan area network defining protocol layers, addressing schemes, and interoperability mechanisms of the wired and wireless communication systems [1], [2]. These are the basis of the majority of modern-day communication networks, though, they presuppose availability of stable infrastructure, uninterrupted power supply and centralized network management, which might not be possible when disasters happen or in isolated area.

Wireless local area networks (WLANs) have been extensively investigated to address the shortcomings of the

wired infrastructure. Selvakarhi et al. provided an instance of application of WLAN technology to replace the traditional field bus system in the industrial environment in which it is more flexible and less complex in term of maintenance [3]. On the same note, there has been a proposal of improvements in the WLAN applications [4]. Although these have been developed, WLAN-based systems have poor range of communication and are highly reliant on power and network connectivity which limits system application in emergent or rural scale.

The modeling of wireless propagation is important when it comes to reliability in communications. Han et al. suggested a model of cross scene wireless propagation to enhance prediction of signal strength in complicated scenarios like power systems [5]. Though the suggested model is more accurate in urban settings, it is based on the presence of environmental information and already existing infrastructure and cannot be used in the case of an emergency network that could be deployed quickly. Recent studies have given rise to more research on decentralized wireless sensor networks and mesh networks. Deep neural network-based localization of networks has been investigated to increase the positioning accuracy of a heterogeneous wireless sensor network without necessarily involving GPS [6]. The methods improve accuracy but add computational complexity and energy overhead. Secure wireless mesh networks have been of interest too with a proposal of a secure and energy saving over-the-air firmware update system, that integrates encryption, key pairing, and data integrity methods, made by Carnevale et al. [7]. Although security, scalability are also covered, the solution is not specifically tested within IoT settings but in general does not address emergency communication applications. Stability of routing in decentralized networks is a significant problem. A link prediction-based routing maintenance algorithm prediction algorithm was introduced by Cai et al. to maintain link failures in an urban transit scenario mobile ad-hoc network setting [8]. Such methods are effective in high-mobility settings, but are mostly simulation-based and have no hardware-level testing of emergency deployments.

The use of the Long-range communication technologies like LoRa and LPWAN has become a possibility of remote and low power communication. LoRa WAN gateway planning studies reveal that there are massive advantages to the probability of coverage and network efficiency in terms of smart city deployment [10]. Nevertheless, LoRa WAN structures are based on central gateways and the Internet backhaul that can break down in case of natural catastrophes or network overload. A number of publications in recent times have discussed infrastructure-less and emergency-based communication systems. Mesh networks based on LoRa are offered to off-grid emergency communications and allow devices to transmit data to each other without using cellular networks or internet connection [11]. There is also a study of hybrid emergency communication systems that integrate the concept of LPWAN and software-defined networking to improve their

reliability and fault tolerance [12], [13]. These strategies point to the possibilities of LPWAN technologies in emergency situations but tend to concentrate on particular locations, e.g., smart buildings or city infrastructures.

In-depth reports of LPWAN technologies comment on their appropriateness in the context of long-range, low-power communication and compare LoRa with other technologies like NB-IoT and Sigfox [14]. The concepts of infrastructure-less networking also highlight how disaster-resilient communication models should be decentralized in order to be rapidly deployed [15]. The LoRa WAN has been investigated to be integrated with mobile ad-hoc or mesh networks to enhance both coverage and routing flexibility [16], [17], but much of this research is theoretical, or even simulated.

Hybrid routing and fallback Routing and fallback technologies have also been employed in short-range mesh technology Bluetooth mesh networks have proven to have a better resilience by employing routing strategies that are context-aware [18]. Moreover, it has been suggested to use IoT-based public safety and emergency alert to help monitor the situation and dispense alerts in real-time [19]. Further comparative analyses between IEEE 802.15.6 and LoRa WAN help to substantiate the choice of LoRa to be used in long-range, low-power, and reliable communication systems [20].

Despite the existing significant progress in wireless mesh networks, the development of LPWAN technology, the majority of solutions are based on centralized infrastructure, internet connectivity, or simulations. There is little literature on an entirely hardwareized and decentralized solution that can combine long-range LoRa communication with GSM backup and real-time emergency notifications, which is what the proposed work is driven by in rural and disaster-prone areas.

### III. PROPOSED SOLUTION

The suggested system introduces a decentralized wireless communication system to be able to guarantee steady connectivity with the cases of emergency when the regular networks are unavailable. It combines both LoRa to provide long-range and low-power communications and GSM to ensure uninterrupted transmission. A secure Bluetooth interface is used to ensure message transfer between a mobile application is authentic, and real-time GPS allows better location awareness. The receiver unit shows messages and provides audio alerts in case of emergency conditions, and thus the system is appropriate in disaster-prone and isolated territories. More so, the system is built by a modular structure, which can be successfully upgraded by adding new sensors with the passage of time. It is made to consume low power and thus, it can be used in applications that require being carried around and are battery powered. The reliability is also augmented in the proposed solution because it offers a consistent performance even in difficult environmental conditions. Also, the system has a low communication delay

hence getting important information in case of an emergency is faster. It is meant to be user friendly and thus easy to use through easy mobile interf

### III. SYSTEM ARCHITECTURE

The general structure of the suggested system is depicted in Fig. 1 that is an integrated communication system with the modules interconnected to send and receive messages. The system aims at offering real-time emergency alerts and network independent, secure and decentralized communication.

The architecture is depicted in Fig. 1 as a centralized one, where the Arduino UNO is taken as the central control unit, and all other components are linked to it. The system incorporates the modules including LoRa transceiver, GSM module, GPS module, Bluetooth interface, LCD display and mode selection switch. The mode selection switch also executes the dynamic switching of the LoRa and GSM communication and at the same time, the LCD displays the mode of operation.

The Bluetooth module enables interaction between the user with the help of a mobile application (Serial Bluetooth Terminal). There is a password-based authentication system that provides security in accessing the system before transmission of messages. The GPS module constantly reports on real-time location, which is sent along with emergency messages.

The LoRa module on the receiving side intercepts data sent and sends it to the Arduino UNO which is linked to a PC terminal to display the messages. In emergency messages with preset keywords, an automatic audio alarm will be activated by a speaker, and the respective GPS coordinates will be presented on the terminal. Non emergency messages are also received and shown out without fail.

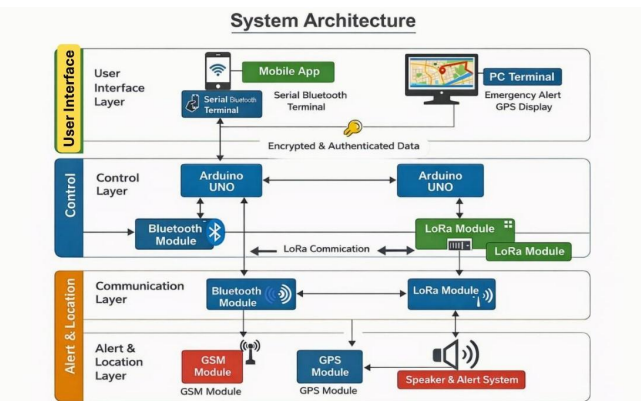


Figure 1: System Architecture

It is a system that can facilitate efficient communication using both LoRa and GSM to ensure the system runs continuously even in cases where there is no network connectivity. The integrated architecture is more efficient in communication and security as well as real-time responsive

and the system can be applied in a disaster prone as well as remote area environment.

### V. HARDWARE

The entire implementation of the proposed system is to use hardware in order to provide real time, and infrastructure independent communication. The entire hardware is separated into Transmitter Unit and Receiver Unit that are supposed to undertake certain tasks within the communication structure.

#### 1. Transmitter Unit

The transmitter is constructed with an Arduino UNO that is the main controller of all the peripherals. LoRa transceiver is a device involved in long-range wireless communication where internet and cellular facilities are not needed. To ensure long-range communication and backup, a GSM module is added so in case LoRa communication is not available, messages can also be sent. Real-time location information is obtained with the help of a GPS module, and its importance cannot be overestimated in the process of transmitting emergency messages. The Bluetooth module provides user interaction with a hardware such that a mobile device can communicate with the hardware via a serial Bluetooth terminal application. The 16x2 LCD display gives real-time updates on the status of the system like the mode of communication selected and the availability of network connection. The Arduino is linked to a mode selection switch which is used to switch between LoRa mode and GSM mode. Also, password-authentication system is applied when establishing Bluetooth connection to provide better security to the communication.

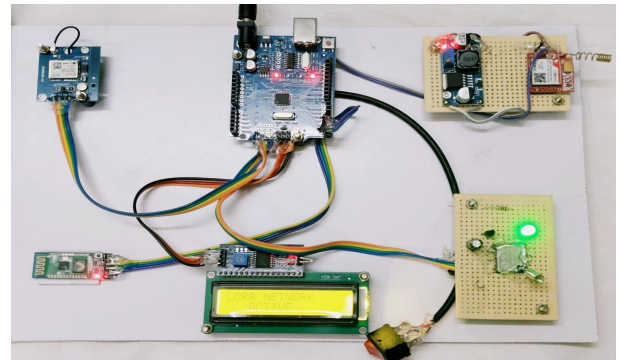


Figure 2: Transmitter

#### 2. Receiver Unit

Another processing unit used in the receiver unit is an Arduino UNO. Arduino is interfaced with a LoRa receiver module to receive a transmitted data sent by a transmitter. The information received is passed to a PC through serial communication where it is shown through a terminal application. In the case of the emergence of predetermined emergency commands like Emergency or Help, the system will automatically send an audio alarm and the emergency

message and live GPS position of the sender will be displayed on the PC terminal.

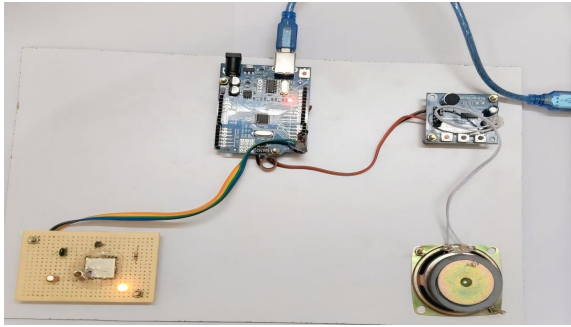


Figure 3: Receiver Unit

### 3. Power Supply

Both transmitting and receiving units are fed on regulated DC power departments to maintain a stable and reliable operation of all modules.

## VI. WORKING METHODOLOGY

The suggested system adheres to a hybrid and decentralized communication strategy that is to work in infrastructure- constrained and emergency situations. It describes the entire working methodology by describing the functional behavior of the transmitter and receiver units, mode selection, security mechanism as well as the emergency handling process.

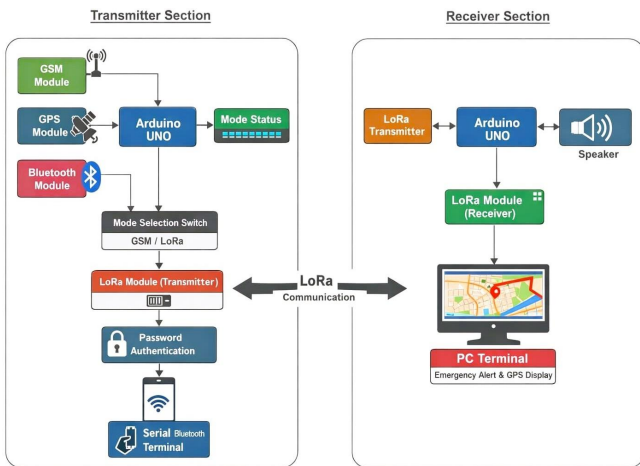


Figure 4: block diagram

### 1. System Initialization

Once power is applied to the hardware kit, the Arduino UNO will initialize all the peripheral modules and the LoRa transceiver, GSM module, GPS receiver, Bluetooth module, LCD display, and audio alert system will be activated. The system then does the initial check to ensure that there is proper connectivity between the modules. The LCD shows the current operational status and the mode of communication that is used to provide awareness to the user.

### 2. Mode Selection Mechanism

It has a hardware switch to choose the mode of communication desired. There are two operating modes supported by the system, they are:

a) LoRa Mode Offers long range and Network free communication.

b) GSM Mode is a backup cellular communication channel. The Arduino switches the corresponding communication module and deactivates the other inactive one depending on the switch position. The chosen mode and status of network availability is in a continuous display on LCD.

### 3. Bluetooth Secure Interface with Mobile Application

LoRa mode In LoRa mode, a secure connection is made between the transmitter unit and a mobile device using Bluetooth module. The authorization system is provided in the form of passwork to make sure that the system can be used exclusively by the authorized users. When a user has been successfully authenticated, he/she can send text messages with the help of a serial bluetooth terminal application. This interface enables communication without the need to have access to the internet, SIM cards the mobile network coverages.

### 4. Data transmission via LoRa

Authenticated message with the mobile application is read by the Arduino UNO and wirelessly transmitted with the help of the LoRa transceiver. LoRa communication is a low-power long-range data service that is applicable in rural and disaster- affected conditions. The received data packets are received at the receiver unit at the receiver end of the receiver module by the LoRa receiver.

### 5. Receiver Operation and Data Display

The LoRa module on the receiver node sends the data it receives to Arduino UNO. The received message is decrypted and a terminal application is used to receive it on a connected PC via serial communication. This arrangement enables real time reception of received messages without the need of extra display devices.

### 6. Mechanism of Emergency Alert and GPS Tracking

The system has standard emergency commands like the Emergency and Help. Whenever these commands are passed on:

1. The transmitter reads the real-time GPS location.
2. The messages are transmitted to the receiver where the audio is played out as an alert.

3. The receiver receives the emergency message and location information.
4. The emergency notification and live GPS coordinates is shown on the PC terminal.

This process allows quick situational awareness and instant response in an emergency situation.

## 7. GSM Backup Communication

When the LoRa communication is not available or it is disabled manually, the system goes to the GSM mode. Messages could be sent using the GSM module and it transmitted over the cellular network through which communication was not interrupted. This hybrid structure gives greater security to systems through redundancy in case of network failure or under extreme conditions.

## VII. RESULTS AND OUTPUT ANALYSIS

The decentralized wireless communication system was proposed and implemented successfully, through the implementation of a complete hardware prototype, which included transmitter and receiver units. The system was tested by varying operating conditions to establish consistent data flow, emergency notifications, and real time reporting of locations without internet connectivity and centralized network technologies.

### 1. Text Data Transmission

When the application is functioning normally, the transmitter unit creates a secure link with the mobile application via Bluetooth upon the authenticity of the password. When connected, people can send text-based messages of any size using the mobile application. These messages are encrypted and sent out via the LoRa module that is in long-range mode of communications.

The messages transmitted are properly received in the receiver side by the LoRa receiver module and are shown on the PC terminal application. This proves successful end-to-end transmission of data without need of SIM cards, mobile towers or internet services. The system showed reliable communication with a high range, which confirmed the efficiency of the wireless connection based on LoRa.

### 2. Audio alert and SOS indication

An emergency mechanism was established beforehand to increase the safety of the users when it comes to hard situations. In case the transmitter transmits pre-determined commands like Emergency or help, the receiver system will be activated automatically to emit an alarm. When these commands are detected, an audio alarm is sounded via the speaker that is attached to the receiver unit. At the same time, an alert message is shown on the PC terminal, which will guarantee instant awareness at the receiver end. This two-level mechanism of alarms is very effective in terms of

responding faster and making sure there is no negligence of emergency messages.

This dual-alert system ensures immediate attention and enables faster response, reducing the risk of missed emergency notifications.

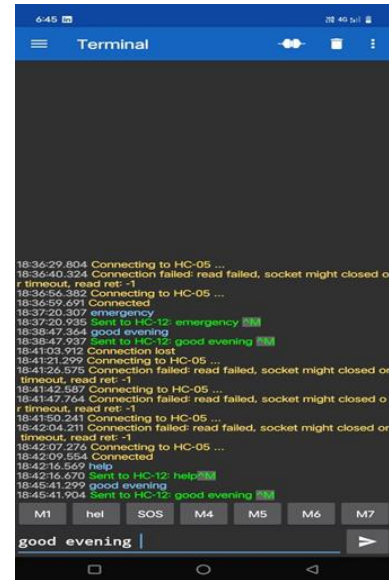


Figure 5: Serial Bluetooth Terminal mobile application used at the transmitter side for sending encrypted messages to the LoRa–GSM communication unit.

### 3. Real-Time GPS Location Display

The system incorporates a GPS device on the transmitting side to give real time tracking of the location. When relaying emergency messages, the geographical positions at that moment are recorded and added to the data being relayed out. The live GPS location is posted at the receiver side and the PC terminal presents the emergency alert.

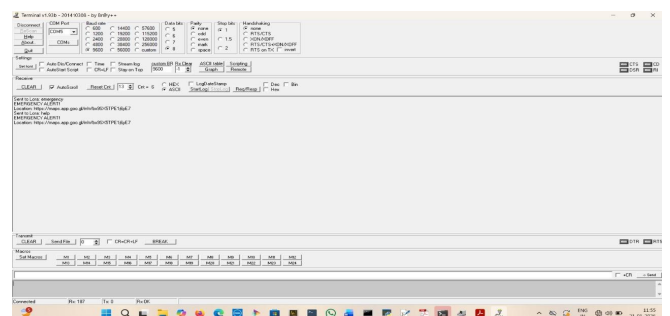


Figure 6: Emergency alert display with GPS coordinates.

This has allowed the feature to identify the location with precision, which is important as far as rescue missions and emergency response situations are concerned. GPS continuously provides correct positioning data which is up to date.

#### 4. Mode Selection and Network Reliability

To enable the modes of GSM and LoRa communication, a hardware switch was added, which would be chosen manually. The system will automatically switch to the LoRa mode when the GSM network is unavailable or has a low signal strength and it is signified on the LCD display as “LoRa Activated (LoRa Activated)”. It proves that the system can adjust to network conditions and preserve the continuity of communication.



Figure 7: LCD display indicating GSM network unavailability and system status before LoRa mode activation, LCD display showing LoRa mode activation

#### 5. System Validation

The experimental findings prove the validity of the proposed system in the achievement of secure, long range, and infrastructure-free communication. Transmission messages were received correctly without loss of data, and emergency alerts were triggered reliably. The successful implementation of the hardware confirms the feasibility of the suggested architecture for practical application.

#### VIII. CONCLUSION

The design and hardware implementation of a decentralized wireless communication system that combines LoRa-based long-range communication with GSM fallback to ensure reliable information exchange in rural areas and disaster-prone areas were presented in this paper. With the proposed system, there is no reliance on centralized infrastructure, internet connection, or availability of mobile networks, which keeps all users connected in case of any emergency.

The created prototype was able to demonstrate the ability to communicate text securely, generate predefined emergency alerts that trigger an audio signal, and transmit GPS position in real time with the help of a hardware-designed LoRa link. The mode selection mechanism offers seamless transition between GSM and LoRa operation based on network availability and enhances system adaptability as well as reliability.

The outcomes of the experiment prove that the system can send messages correctly over long distances.

without the SIM cards or mobile towers and internet services. The emergency alert system, in combination with the real-time location, is very effective in responding and rescuing. The components and hardware used are cheap and require low power, making the solution viable for large-scale implementation in resource-limited areas.

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