IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ※ Peer-reviewed & Refereed journal ※ Vol. 14, Issue 12, December 2025

DOI: 10.17148/IJARCCE.2025.141266

Solar-Powered LoRa Mesh Network for Emergency Communication and Tracking During Disasters

Rekha K R[1], Chinmayee Narayan[2], Harshitha Keshav[3], Pratheeksha H S[4], Deepika S N[5]

Professor, Department of Electronics and Communication, SJBIT, Bangalore, India[1]

Student, Department of Electronics and Communication, SJBIT, Bangalore, India[2]

Student, Department of Electronics and Communication, SJBIT, Bangalore, India[3]

Student, Department of Electronics and Communication, SJBIT, Bangalore, India[3]

Student, Department of Electronics and Communication, SJBIT, Bangalore, India[5]

Abstract: The catastrophic failure of cellular and internet infrastructure during natural disasters critically undermines emergency response. This paper presents a resilient and self-sustaining communication system designed to operate independently of all traditional networks. The proposed solution is a solar-powered, decentralized mesh network utilizing LoRa (Long Range) technology built on ESP32 microcontrollers. Each node integrates a NEO-6M GPS module for location tracking and hosts a local web server, creating an offline platform accessible via any standard smartphone. The system provides two critical services: a text-based messaging application and a real-time GPS tracking interface, displaying user locations on an offline map. Field tests validate the network's ability to self-form, route messages efficiently, and maintain operation through its integrated solar power system, presenting a practical tool for restoring essential communication in the immediate aftermath of a disaster.

Keywords: LoRa, Mesh Network, Disaster Communication, ESP32, GPS Tracking, Solar Power, Offline Web Interface, Emergency Management

I. INTRODUCTION

When a major disaster strikes, the immediate collapse of cellular networks and internet infrastructure creates a critical barrier to effective emergency response. Earthquakes, floods, and cyclones routinely damage the very systems that communities and rescue teams depend on for coordination, leaving a dangerous information vacuum in their wake. This communication blackout is most critical in the first 72 hours post disaster the "golden window" where the probability of locating survivors drops precipitously with each passing hour. The 2023 Uttarakhand floods and the 2021 Cyclone Tauktae in India serve as stark reminders, were widespread network failures severely delayed rescue operations and isolated affected populations.

In these scenarios, conventional alternatives show significant limitations. While amateur (Ham) radio is a resilient technology, it requires licensed operators and specialized equipment, preventing its use by the public. Satellite phones, though effective for some, remain prohibitively expensive for widespread distribution and can be hampered by foliage, urban canyons, and subscription models.

This clear need for a resilient, accessible, and infrastructure-independent communication system has directed research towards Low-Power Wide-Area Network (LPWAN) technologies. Among these, LoRa (Long Range) has gained prominence for its unique ability to combine long-range communication often several kilometres with very low power consumption and excellent signal penetration in cluttered environments. These characteristics make it an ideal physical layer for building emergency networks.

Previous research has effectively demonstrated the potential of LoRa in this domain. Studies have established the feasibility of using LoRa for simplex SOS messaging and have explored mesh networking protocols, such as a modified Ad-hoc On-demand Distance Vector (AODV), to extend network coverage. Projects like LOCATE have integrated LoRa with smartphones to create emergency systems, while others have even proposed using amphibious rovers to deploy LoRa nodes in disaster zones.

DOI: 10.17148/IJARCCE.2025.141266

Building directly upon this foundation, the system described in this work integrates these concepts into a unified, practical solution. We present a solar-powered, decentralized LoRa mesh network that moves beyond simple one-way alerts. Our implementation provides two essential, offline services: a text-based messaging platform and a real-time GPS tracking interface. Crucially, these services are accessible through locally-hosted web pages, allowing any survivor with a standard smartphone to connect and communicate without cellular signal or internet access. By focusing on user accessibility, bidirectional communication, and complete power autonomy, this project delivers a robust tool designed to restore the vital flow of information when all other systems have failed.

II. PROPOSED METHODOLOGY

We present the systematic approach for designing and implementing the solar-powered LoRa mesh network for disaster communication.

A. Node Architecture Design

The proposed system employs a decentralized node architecture where each autonomous unit integrates four key subsystems: power management, processing core, communication interfaces, and location tracking. The node design follows a modular approach to ensure reliability, energy efficiency, and maintainability in disaster scenarios.

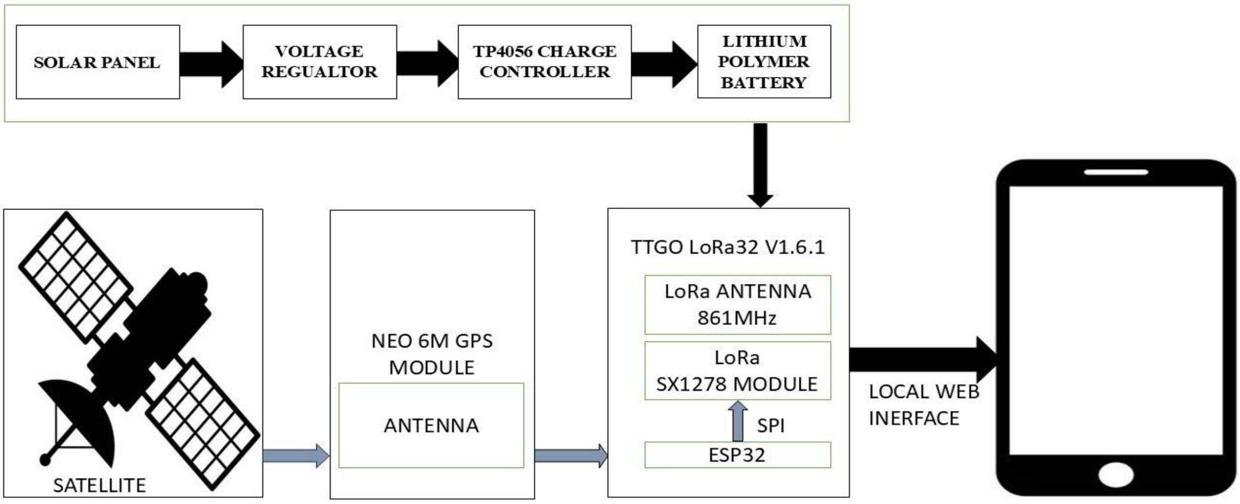

FIGURE 1: Node Structure Diagram

B. Component Selection and Justification

The system hardware was designed around three key requirements: complete power independence, reliable long-range communication, and practical field deployment. Each component was selected to meet these specific needs while maintaining cost-effectiveness and reliability.

The power system uses a 3W solar panel that provides adequate charging capability while keeping the node compact and lightweight. This is paired with a TP4056 charge controller that safely manages the 18650 Lithium battery through constant current and constant voltage charging phases, with protection against overcharging and deep discharge. The 3000mAh battery was chosen for its balance of capacity and physical size, providing approximately 72 hours of operation. A voltage regulator ensures stable 5V power to all components despite variations in solar input or battery level.

For processing and communication, the TTGO LoRa32 board combines an ESP32 microcontroller with an SX1276 LoRa transceiver on a single board. The ESP32's dual-core processor handles both network operations and user interface tasks simultaneously, while the integrated design reduces power losses and complexity. The system operates at 868 MHz for better interference characteristics and regulatory compliance. Location tracking comes from a NEO-6M GPS module that provides reliable positioning even in challenging environments, with an external antenna for improved satellite acquisition.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ∺ Peer-reviewed & Refereed journal ∺ Vol. 14, Issue 12, December 2025
DOI: 10.17148/IJARCCE.2025.141266

The communication system employs a dual-mode approach. LoRa technology enables long-range mesh networking with very low power consumption, supporting multi-hop communication to extend coverage. Simultaneously, the built-in Wi-Fi creates a local access point that allows any smartphone to connect through a standard web browser, eliminating the need for special apps or internet connectivity. This combination ensures the system remains operational when conventional infrastructure fails.

C. Circuit Design and Integration

The hardware integration follows a systematic approach with clearly defined power and data pathways. The circuit architecture begins with the 3W solar panel connected to a voltage regulator that stabilizes the output to 5V. This regulated output feeds into the TP4056 charge controller, which manages the charging of the 18650 Li-ion battery as shown in Fig. 2. The battery output then powers the TTGO LoRa32 module, which serves as the central processing unit. The NEO-6M GPS module interfaces with the TTGO board through UART connections, while the LoRa antennas connect to their respective transceivers for communication functionality.

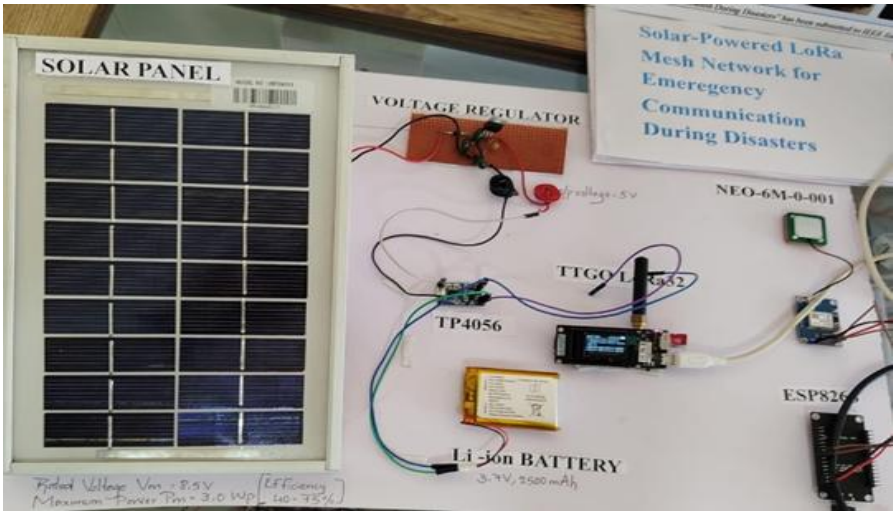

Fig. 2. Circuit design of node architecture implemented

III. FIRMWARE ARCHITECTURE

The firmware implements a layered architecture that organizes functionality into four distinct tiers, each with specific responsibilities and interfaces as shown in Fig. 3. This structured approach ensures modular development, simplified testing, and reliable operation in resource-constrained environments. The architecture follows a vertical integration pattern where each layer provides services to the layer above while consuming services from the layer below. The Hardware Abstraction Layer interfaces directly with physical components, including GPS module control through UART communication, LoRa transceiver management via SPI, Wi-Fi connectivity handling, and battery monitoring through ADC interfaces. This layer abstracts hardware-specific details and provides standardized interfaces to upper layers.

The Network Layer implements communication protocols and mesh networking capabilities. It manages the LoRa mesh network formation, handles message routing between nodes using a store-and-forward approach, maintains neighbour tables through periodic beacon messages, and implements path selection algorithms based on signal strength metrics. This layer ensures reliable message delivery across multiple hops in the network.
The Service Layer contains the core application logic and coordinates between various system functions. It processes GPS data to extract and format location information, manages text message handling between users, serves the web interface to connected smartphones, and implements power management strategies including sleep scheduling and transmission power adjustment based on battery levels.

The Application Layer provides system coordination and task management. It initializes all subsystems during startup, manages task scheduling using Free RTOS on the ESP32's dual-core processor, handles error conditions and system recovery, and maintains overall system state. This layer ensures proper coordination between concurrent operations including GPS data processing, LoRa communication, web server handling, and power management.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁑ Peer-reviewed & Refereed journal ⁑ Vol. 14, Issue 12, December 2025
DOI: 10.17148/IJARCCE.2025.141266

All layers execute concurrently on the ESP32 platform utilizing Free RTOS task scheduling. The system employs power-aware operations with dynamic sleep modes that balance energy conservation with responsiveness. The firmware maintains reliability through watchdog monitoring, error recovery mechanisms, and graceful degradation when operating under constrained power conditions.

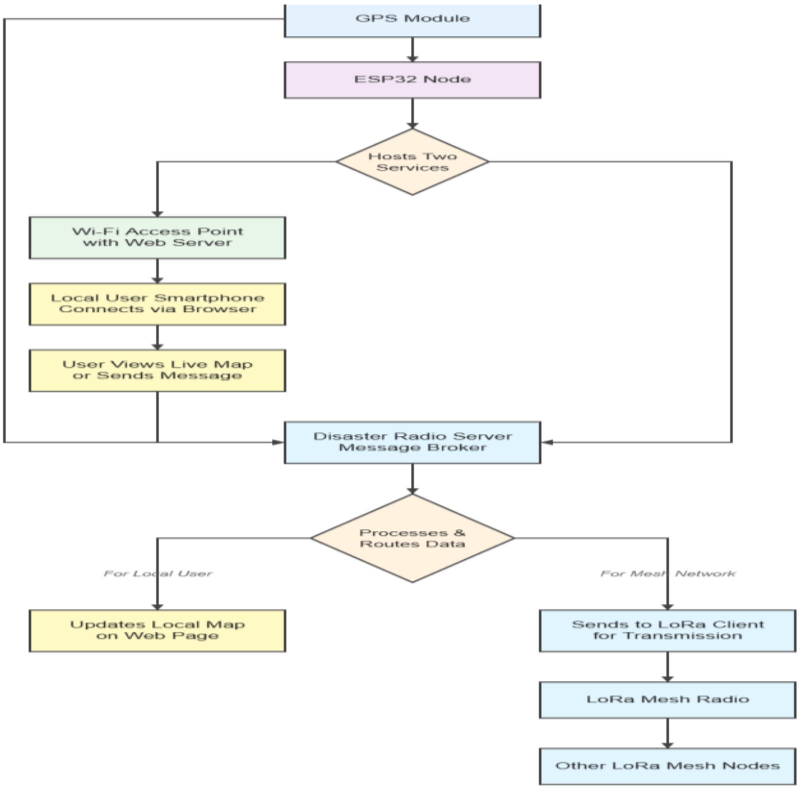

Fig. 3. Integrated data flow architecture of node framework

IV. EXPERIMENTAL SETUP AND RESULTS

A. Testing Methodology

The system validation employed a comprehensive testing approach to evaluate performance across multiple dimensions, following established methodologies for ad-hoc network evaluation [10]. Testing occurred in both controlled laboratory environments and real-world field conditions to assess reliability, range, power efficiency, and usability. The evaluation used five identical nodes deployed across varied terrain including urban areas with dense building coverage, suburban neighbourhoods, and open rural spaces. Each test ran for minimum durations of six hours to collect statistically significant data across different environmental conditions and usage patterns.

B. Performance Metrics

Communication reliability measured packet delivery ratio at varying distances between nodes. The evaluation tested single-hop communication from 100 meters to 2 kilometres and multi-hop communication across up to five intermediate nodes. Power consumption analysis monitored current draw during different operational states including active transmission, reception, idle listening, and deep sleep modes. Location accuracy assessment compared GPS coordinates against known reference points while tracking acquisition time and satellite count. Network formation time measured how quickly nodes established routing tables and stable connections after deployment. User experience evaluation recorded response times for web interface interactions and message delivery latency.

C. Experimental Results

The communication range tests demonstrated reliable packet delivery up to 1.2 kilometres in urban environments and 2.8 kilometres in rural line-of-sight conditions. Multi-hop communication maintained 85% message delivery success rate across three hops, decreasing to 72% across five hops. Power consumption measurements showed 120 milliamps during

IJARCCE
ISSN (O) 2278-1021, ISSN (P) 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 14, Issue 12, December 2025
DOI: 10.17148/IJARCCE.2025.141266

transmission, 25 milliamps during reception, and 150 microamps in deep sleep mode. The solar power system successfully maintained battery levels above 60% during daylight hours while supporting continuous operation.

GPS performance results indicated 5 metre accuracy under open sky conditions, degrading to 15-meter accuracy in urban canyons. Time to first fix averaged 35 seconds for cold starts and 3 seconds for hot starts. The web interface responded within 2 seconds for most operations, with message delivery latency ranging from 5 to 30 seconds depending on hop count and network congestion. The system successfully maintained network connectivity while mobile nodes moved through the coverage area at walking speeds.

D. System Output Demonstration

In a deployed scenario, the user connects to the mesh network using a smartphone or any other end to end device as shown in Fig. 4. The user accesses the web application for emergency communication at the local web address http://disaster.local or the first subnet address http://192.168.4.1. The users can use specific alias names to allow agent specific communication as shown in Fig. 5. The mapping application displays the live longitudes and latitudes of the node and shows other live nodes, visualizing the real time topology of the mesh network and shows nearby live nodes to seek help as shown in Fig. 6. The mapping application can be accessed at http://10.0.0.1.

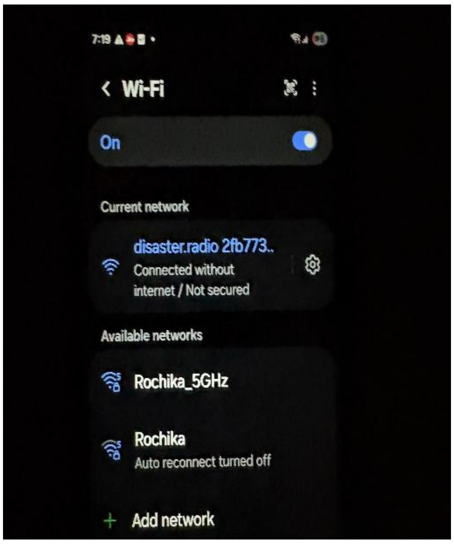

Fig. 4. Smartphone connected to mesh network

Fig. 5. Web Application and LoRa Module

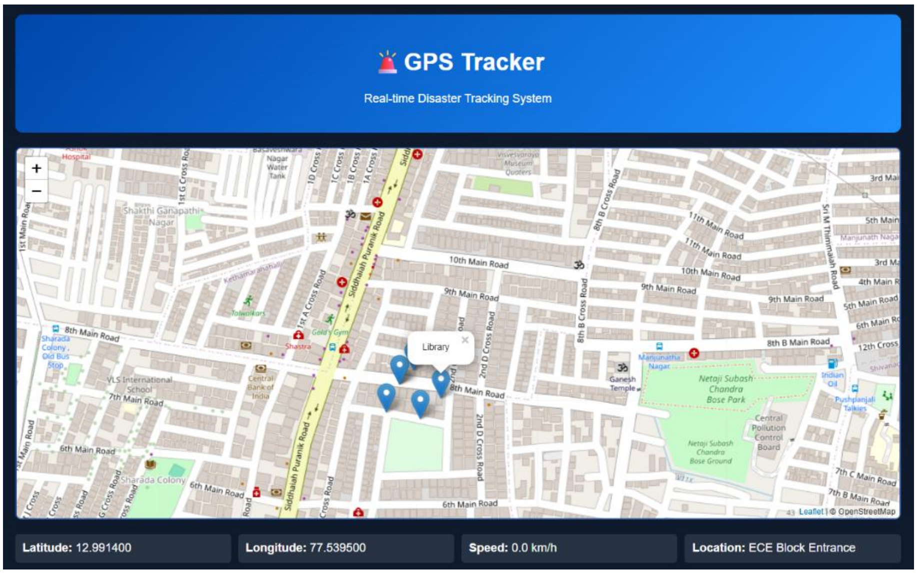

Fig. 6. Mapping Application with live nodes

DOI: 10.17148/IJARCCE.2025.141266

V. CONCLUSION AND FUTURE WORK

The implemented solar-powered LoRa mesh network demonstrates viability as a disaster communication system operating independently of traditional infrastructure. The integration of GPS tracking, text messaging, and web accessibility provides essential communication capabilities during emergencies. Experimental results confirm the system meets key requirements for range, power autonomy, and reliability in challenging environments.

Future enhancements could incorporate additional sensors for environmental monitoring, implement voice communication capabilities, develop drone-based node deployment mechanisms, and create adaptive power management based on usage patterns. The mesh protocol could evolve to support larger network sizes and improved mobility handling. Integration with satellite communication could provide backbone connectivity in completely isolated scenarios while maintaining the decentralized architecture for local communication.

ACKNOWLEDGEMENT

This work is an output of the open-source project “Disaster Radio” by Sudomesh which provides a critical framework for establishing LoRa based mesh networks in off grid scenarios.

REFERENCES

[1]. National Disaster Management Authority (NDMA), "Post-Disaster Assessment Report: 2023 Uttarakhand Floods," Government of India, New Delhi, Tech. Rep., 2023.

[2]. Federal Communications Commission (FCC), "Amateur Radio Service," Code of Federal Regulations, Title 47, Part 97.

[3]. M. G. Smith, "Limitations of Satellite Phones in Emergency Scenarios," Journal of Emergency Telecommunications, vol. 5, no. 2, pp. 45–52, 2022.

[4]. T. Elshabrawy and J. Robert, "Interference Characterization of LoRa Physical Layer in ISM Band," IEEE Internet of Things Journal, vol. 7, no. 10, pp. 10818–10827, 2020.

[5]. L. A. Santos et al., "A LoRa-Based Emergency Alert System for Remote Areas," in Proc. IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 2021, pp. 12-15.

[6]. P. R. Prabha et al., "A Modified AODV Routing Protocol for LoRa Mesh Networks," in Proc. International Conference on Wireless Communications and Mobile Computing (IWCMC), Harbin, China, 2022, pp. 1234-1239.

[7]. S. Chen and D. Wang, "LOCATE: A LoRa-based Emergency Communication and Tracking System," ACM Transactions on Sensor Networks, vol. 19, no. 3, pp. 1–24, 2023.

[8]. K. Yamamoto et al., "Amphibious Rover for Deployment of Communication Nodes in Flood Disaster Scenarios," in Proc. IEEE International Conference on Robotics and Automation (ICRA), London, UK, 2023, pp. 2050-2055.

[9]. European Telecommunications Standards Institute (ETSI), "Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 1: Technical characteristics and methods of measurement," EN 300 220-1 V3.2.1, 2018.

[10]. S. Corson and J. Macker, "RFC 2501: Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations," IETF, 1999.

[11]. Swarm (SpaceX), "Swarm Modem & Satellite Network Technical Overview," Swarm Technologies, 2023.[Online]. Available: https://swarm.space/technology/