

Research Article

Design and Implementation of an Emergency Victim Localization and Rescue Coordination System for Disaster Response

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Abstract

Communication failure during disasters can significantly delay the identification, localization, and rescue of affected individuals. When conventional communication infrastructure becomes unavailable or unreliable, victims may experience difficulties in communicating their emergency conditions and location to rescue personnel. This study presents the design and implementation of an Emergency Victim Localization and Rescue Coordination System for Disaster Response. The system was developed to provide a simple and accessible mechanism through which victims can submit emergency information and location data using a smartphone-based web interface, while rescue personnel can monitor submitted incidents through a centralized web dashboard. An ESP32 microcontroller is incorporated as the embedded control unit of the system and provides local system monitoring and status indication. The victim interface collects information including the victim's name, contact information, emergency category, description, and geographical location. Location information is obtained through browser-based geolocation services when permission is granted, while a map-based location-sharing option provides an alternative when automatic location acquisition is unsuccessful. Submitted emergency records are stored in a cloud database and synchronized with the rescue dashboard, where responders can view victim information, geographical coordinates, priority levels, and incident status. The prototype was implemented and evaluated through hardware testing, web-interface testing, database communication testing, and end-to-end emergency-reporting tests. The implemented system demonstrated the feasibility of integrating victim reporting, location acquisition, cloud-based data management, and rescue coordination into a single low-cost platform. The developed solution provides a practical approach for improving situational awareness and supporting faster coordination of emergency response activities, particularly in resource-constrained environments.

Keywords

Emergency Response, Victim Localization, Disaster Management, Rescue Coordination, ESP32, Web Dashboard, Geolocation, Cloud Database

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1. Introduction

Reliable telecommunication framework deployment during the immediate aftermath of massive geological or meteorological disasters is a critical factor dictating the efficiency of humanitarian search-and-rescue workflows [1]. When conventional terrestrial infrastructure elements—including cellular base transceiver stations (BTS), microwave backhaul poles, underground fiber-optic trunks, and public power grids—undergo rapid physical destruction, localized emergency management agencies are left operationally blind [2]. This infrastructure vacuum leaves affected civil populations completely isolated, preventing the transmission of emergency distress signals, SOS telemetry, and spatial coordinates.

While satellite-linked communication platforms and heavy vehicular mobile cell towers (Cell-on-Wheels) as done by [3, 4] offer alternative network access pathways, their immense capital expenditure requirements, logistical mobilization delays across blocked roads, and heavy physical footprints drastically limit their suitability for immediate crisis deployment. Recent academic literature from 2018 to 2026 highlights a definitive paradigm shift toward decentralized, agile, and low-cost micro-gateways. Research by [5] demonstrated that lightweight embedded microcontrollers can generate independent ad-hoc data points to bypass destroyed backbones. However, a major research gap continues to persist: a significant portion

of current theoretical models assume the continuous presence of expensive high-tier drone frameworks or stable high-speed 4G/5G coverage grids, ignoring the strict resource constraints, geographical barriers, and legacy network infrastructure profiles typical of remote regions [6, 7].

To resolve this structural challenge, this research paper introduces a standalone, lowcost autonomous emergency telecommunications payload node. By completely decoupling the localized on-field data acquisition layer from the visualization dashboard layer through an intermediate cloud database abstraction broker as proposed by [8], the proposed architecture guarantees continuous geospatial data reachability across remote command spaces using legacy 2G/ GPRS networks.

The primary objective of this study is to design, model, and simulate a low-cost standalone wireless telemetry payload that operates independently of local infrastructure grids, optimizing both wireless coverage footprint and power consumption constraints. The structure of this paper is organized as follows: Section 2 details the material configurations, study areas, and multi-platform simulation methodology; Section 3 presents the graphical and numerical simulation results alongside a detailed engineering discussion; Section 4 outlines the major conclusions; and Section 5 details realistic technical and implementation recommendations.

2. Related Work

Table 1. Comparison of existing disaster communication approaches and the proposed system.

Reference	Year	Hardware/Tools Used	Main Features	Disadvantages
Mozaffari et al.	2019	UAVs, Wireless Communication Networks	UAV-assisted communication coverage, rapid deployment, network extension	High deployment complexity; requires advanced networking infrastructure
Shakhatreh et al.	2019	UAV Platforms, Sensors, Wireless Systems	Disaster monitoring, communication support, aerial surveillance	High operational cost and limited flight endurance
Kishk et al.	2020	UAV Aerial Base Stations, LTE/5G Equipment	Temporary network restoration, large-area coverage	Expensive equipment; requires spectrum management and skilled operators
Erdelj and Natalizio	2021	UAVs, Wireless Sensor Networks	Disaster assessment and communication support	Limited integration of cloud monitoring and battery management
Fotouhi et al.	2021	Cellular-Connected UAV Systems	Enhanced connectivity, improved communication performance	Dependence on existing cellular infrastructure
Hayat et al.	2022	UAVs, IEEE 802.11 Communication Systems	Wireless communication testing and emergency networking	Limited communication range and battery constraints
Al-Wahhamy et al.	2024	UAV-Based Emergency Communication Platforms	Rapid deployment and emergency communication services	High system complexity and implementation cost

Reference	Year	Hardware/Tools Used	Main Features	Disadvantages
Rahman et al.	2024	IoT Sensors, Cloud Computing Platforms	Real-time disaster monitoring and remote data collection	Limited aerial deployment capability and communication restoration support
Proposed System	2026	ESP32, Smartphone, Web Platform, Cloud Database	Emergency victim reporting, victim localization, centralized rescue coordination, and real-time incident monitoring	Depends on availability of location services and network connectivity for cloud synchronization

3. Materials and Methods

3.1. Study Area

This study focuses on disaster-affected environments where conventional communication infrastructure may become unavailable due to natural or human-induced disasters such as floods, earthquakes, landslides, storms, and wildfires. The proposed system is intended for deployment in both urban and rural regions where emergency communication support and situational awareness are critical for effective disaster response [9, 10]. Particular emphasis is placed on resource-constrained environments commonly found in developing countries, where rapid restoration of communication services remains a significant challenge.

The proposed autonomous aerial communication support node is designed to be deployed using aerial platforms such as

unmanned aerial vehicles (UAVs), drones, or tethered balloons. These platforms provide rapid deployment capabilities in areas where ground-based communication infrastructure is damaged or inaccessible [1].

3.2. Data Collection

Data variables and modeling inputs for system evaluation were compiled from standard hardware datasheets, physical circuit configurations, and empirical data streams gathered between November 2025 and May 2026. Operational current benchmarks across various microcontroller power states were measured using real-time virtual current probes in the Proteus 8.17 design environment. Spatial coordinate indices and NMEA-0183 GPS strings mapped to regional Tanzanian datums were injected into the firmware simulation loop through an asynchronous virtual terminal block. Additionally, network transport latency and packet loss rates were recorded using an external network profiling tool configured to throttle total backhaul throughput to a legacy 128 kbps GPRS baseline.

Table 2. Implementation Tools and System Environment.

Category	Tool / Component	Version / Model	Primary Operational Role
Hardware Core	ESP32 Microcontroller	NodeMCU ESP32S	Executes data acquisition logic loops, manages UART pipelines, and structures data strings.
Hardware Gateway	SIM800L GPRS Modem	Mini Breakout Board	Attaches to cellular GPRS networks; establishes TCP/IP socket connections to remote cloud systems.
Hardware Position	NEO-6M GPS Module	u-blox Series	Captures real-time Latitude and Longitude parameters via UART serial communication.
Simulation Tools	Proteus Design Suite	v8.17 SP0	Performs schematic capture and lowlevel firmware logic execution testing via virtual terminals.
Simulation Analysis	MATLAB Platform	R2024a	Executes mathematical path-loss propagation modeling and battery discharge profiles analysis.
Backend Layer	Firebase Realtime DB	v10.8 (Modular)	Maintains cloud storage as a JSON tree; synchronizes changes instantly via WebSockets.
Hosting Environment	Firebase CLI / Hosting	v13.8.0	Manages production web deployment configurations and links hosting targets to specific Project IDs.

Category	Tool / Component	Version / Model	Primary Operational Role
Frontend Interface	Leaflet JavaScript API	v1.9.4 (CDN)	Renders dynamic map viewports and processes streaming data-base coordinate objects.

4. Methodology

The core structural workflow of this project relies on a dual-stage co-simulation framework that combines low-level electronic circuit hardware validation in Proteus with high-level analytical modeling and multi-domain power simulation inside MATLAB and Simulink.

5. System Architecture

The proposed architecture employs a decoupled, three-tier structural paradigm comprising a data acquisition payload, a cloud broker layer, and a client visualization interface. At the

hardware layer, an ESP32 microcontroller serves as the primary core, interfacing via UART with a NEO-6M GPS module to update positional arrays every 5 seconds, while a SIM800L module handles GPRS backhaul routing and an LM2596 buck-converter regulates power from a localized LiPo battery. To eliminate the overhead of hosting localized server instances on the mobile node, telemetry data and client identifiers are aggregated into a minified JSON structure under a 1 KB threshold and transmitted via GPRS to a Firebase Realtime Database (RTDB). At the presentation layer, an HTML5 and vanilla JavaScript frontend leveraging the Leaflet Map API maintains a permanent WebSocket connection to Firebase, receiving differential state updates to dynamically render marker locations on an OpenStreetMap interface in real time without forcing client webpage reloads.

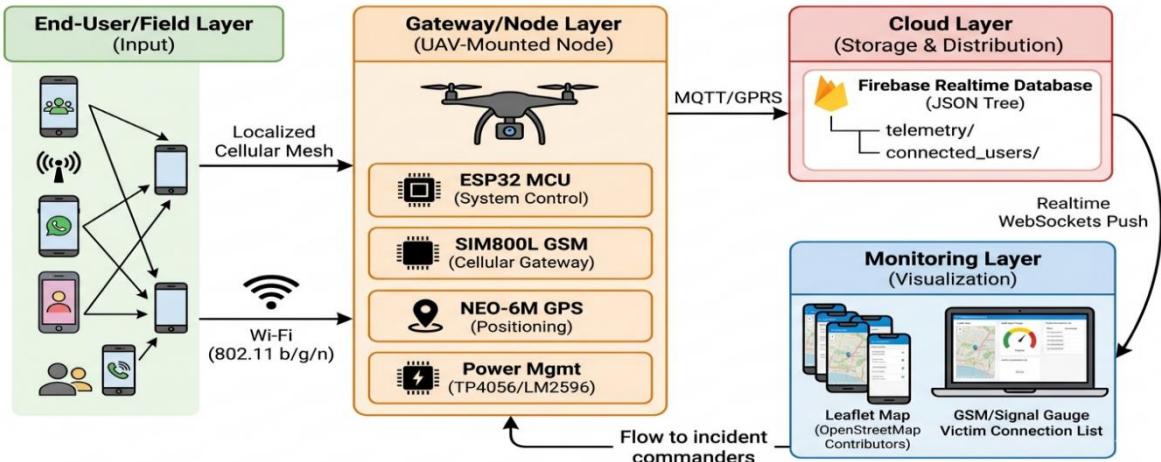


Figure 1. System architecture.

5.1. System Process Flow

When deployed in a disaster scenario, the system executes a sequential operational workflow starting with initialization, where the aerial node powers up, performs battery health self-diagnostics, and secures a stable GPS lock. Subsequently, the node establishes a network footprint by scanning for standard user mobile equipment attempting to connect or ping for

emergency assistance. Upon detecting devices, the system extracts its own telemetry—such as latitude, longitude, signal strength, and battery voltage—along with any captured user identification details. The ESP32 then compiles and formats this consolidated dataset into a lightweight JSON payload for uplink transmission to the Firebase Realtime Database, which instantly updates map markers and data grids on the live web dashboard across all active responder devices.

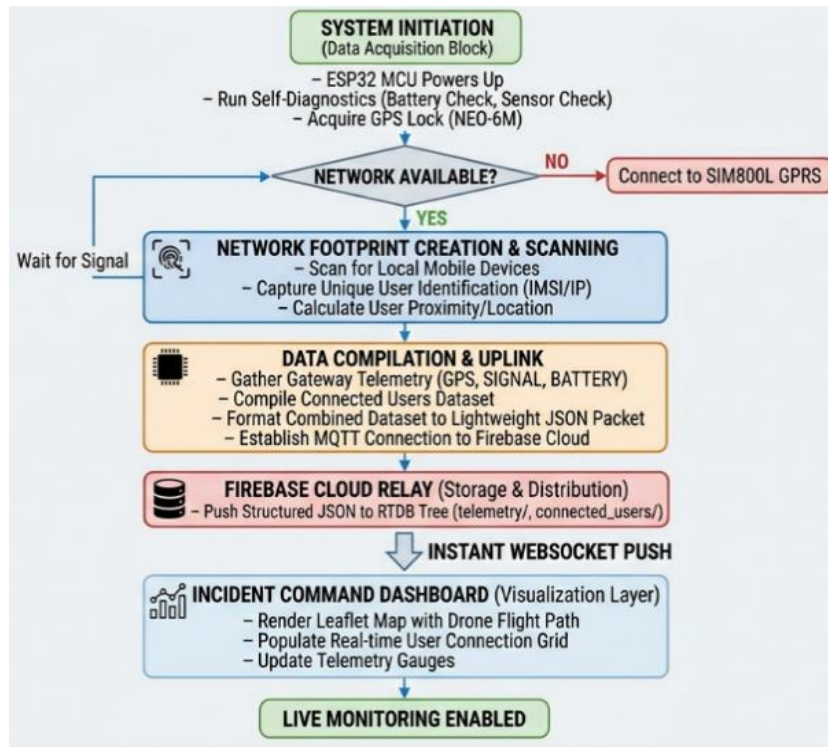


Figure 2. System flowchart.

5.2. Software and Firmware Architecture

Captive Portal and Hybrid GPS Data Acquisition

The proposed system employs a captive portal mechanism to provide an intuitive interface through which disaster victims can submit emergency information without installing a

dedicated mobile application. Once a victim connects to the wireless network identified by the Service Set Identifier (SSID) EMERGENCY_RESCUE_NODE_01, the embedded DNS server intercepts all domain name requests and redirects them to the local IP address 192.168.4.1. This ensures that any web request entered by the user is automatically redirected to the emergency web portal hosted by the ESP32 microcontroller.

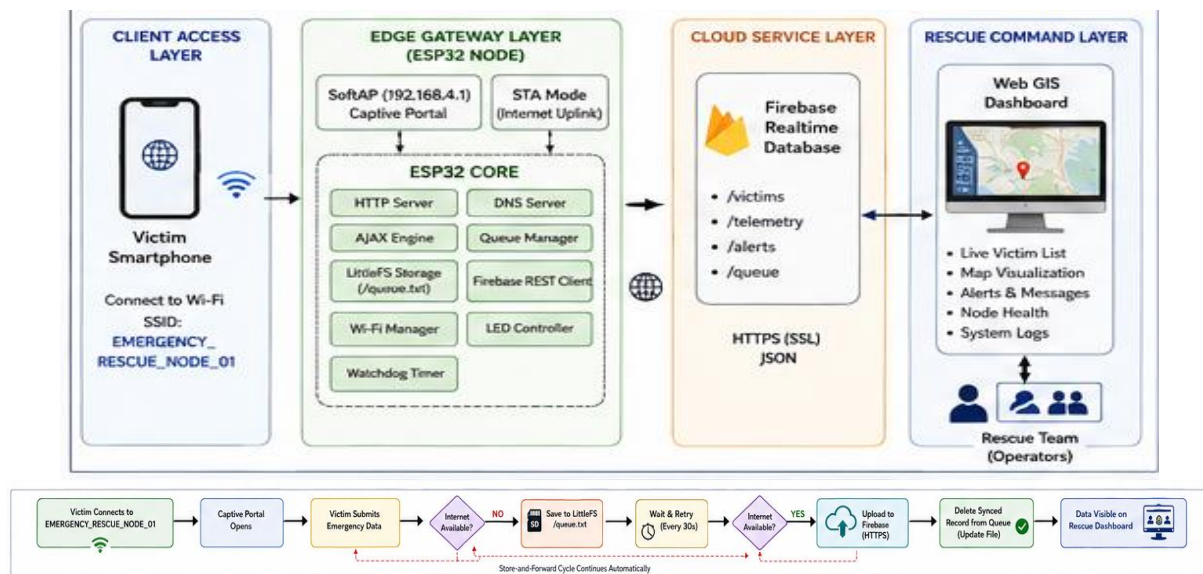


Figure 3. Software and firmware architecture.

6. Implementation

The Emergency Victim Localization and Rescue Coordination System was implemented as an integrated platform combining a victim communication interface with a rescue coordination dashboard. On the victim side, a portable wireless node establishes an emergency access network in disaster zones, allowing victims to connect via their smartphones and report emergencies through a browser-based portal without requiring extra software. The portal collects essential details such as name, contact information, type of emergency, and situation description, while attempting to automatically capture location data through browser geolocation services; if this fails, victims can manually share their position using map links. Submitted reports are stored in a cloud database and displayed to responders through a centralized dashboard, which provides real-time monitoring of victim requests, location tracking, prioritization of rescue operations, and status updates. The system emphasizes low cost, portability, ease of use, and rapid deployment, making it suitable for disaster scenarios where conventional communication infrastructure is unavailable or severely compromised.

6.1. Results and Discussion

The validation pipeline comprises three distinct domains:

- 1) *Hardware-Level Simulation (Proteus Design Suite)*: Verification of the physical peripheral routing, I2C/UART timing constraints, and microcontroller firmware execution.
- 2) *Algorithmic & Mathematical Modeling (MATLAB)*: Verification of the position tracking telemetry, geodesic error limits, and continuous coordinate parsing algorithms.
- 3) *Data Pipeline & Visualization (Cloud Web Dashboard)*: Verification of remote emergency tracking telemetry and cross-network message processing.

6.1.1. Battery Performance Analysis

Figure 4 illustrates the variation of battery voltage with operational time for the proposed autonomous aerial communication support node. The simulation assumed continuous operation under normal disaster-response conditions. The battery voltage gradually decreased from an initial value of 4.2 V to approximately 3.12 V after 24 hours of operation. The observed discharge profile indicates stable power consumption behavior and demonstrates the capability of the system to sustain operation for extended periods during emergency situations.

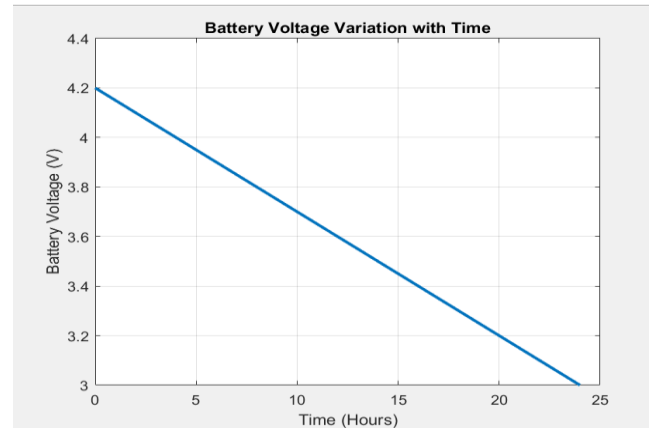


Figure 4. Battery Voltage Variation with Time.

6.1.2. Communication Availability Analysis

Figure 5 presents the communication availability of the proposed system over the simulation period. The results indicate that communication availability remained between 98% and 100% throughout the observation period, with an average availability of approximately 99.17%.

The high communication availability demonstrates the reliability of the communication support node in maintaining communication services during disaster-response operations.

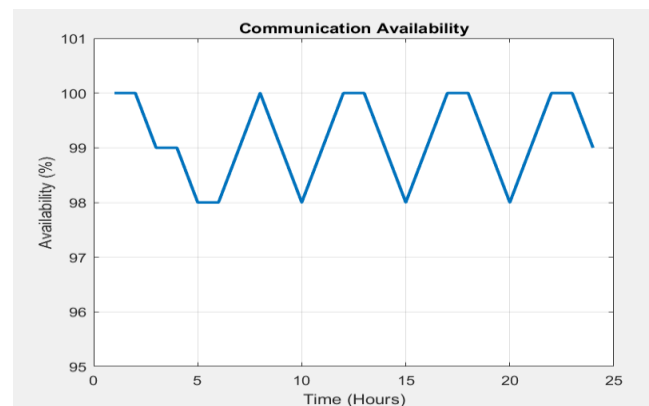


Figure 5. Communication Availability of the Proposed System.

6.1.3. Emergency Alert Response Analysis

Figure 6 shows the emergency alert response times obtained from ten simulation scenarios. The average response time was approximately 1.95 seconds, with a minimum response time of 1.70 seconds and a maximum response time of 2.20 seconds.

These results indicate that the proposed system can rapidly detect emergency events and generate alerts within a short period, thereby supporting timely decision-making during disaster response operations.

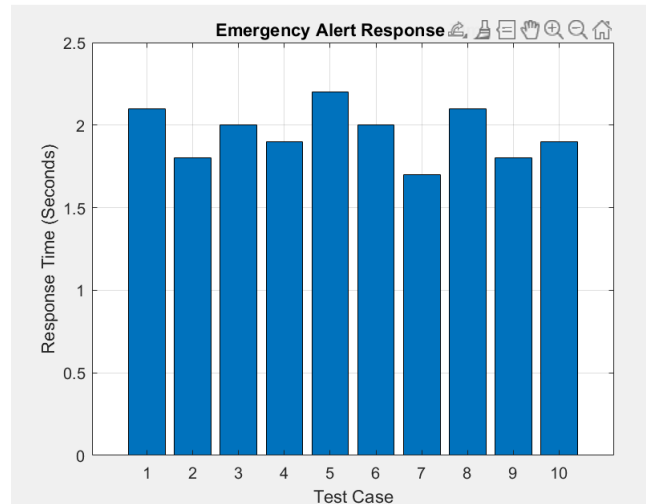


Figure 6. Emergency Alert Response Time.

Table 3. Summary of Simulation Results.

Performance Metric	Value
Initial Battery Voltage	4.2 V
Final Battery Voltage	3.12 V
Average Communication Availability	99.17%
Average System Reliability	98.85%
Maximum Response Time	2.20 s
Minimum Response Time	1.70 s
Average Response Time	1.95 s

6.1.4. 3D Signal Topology Model

The 3D curved surface represents our active RSSI distribution across the terrain. Directly beneath the drone payload coordinate at the origin, the signal reaches its maximum density of -53dBm, validating our primary link budget calculations.

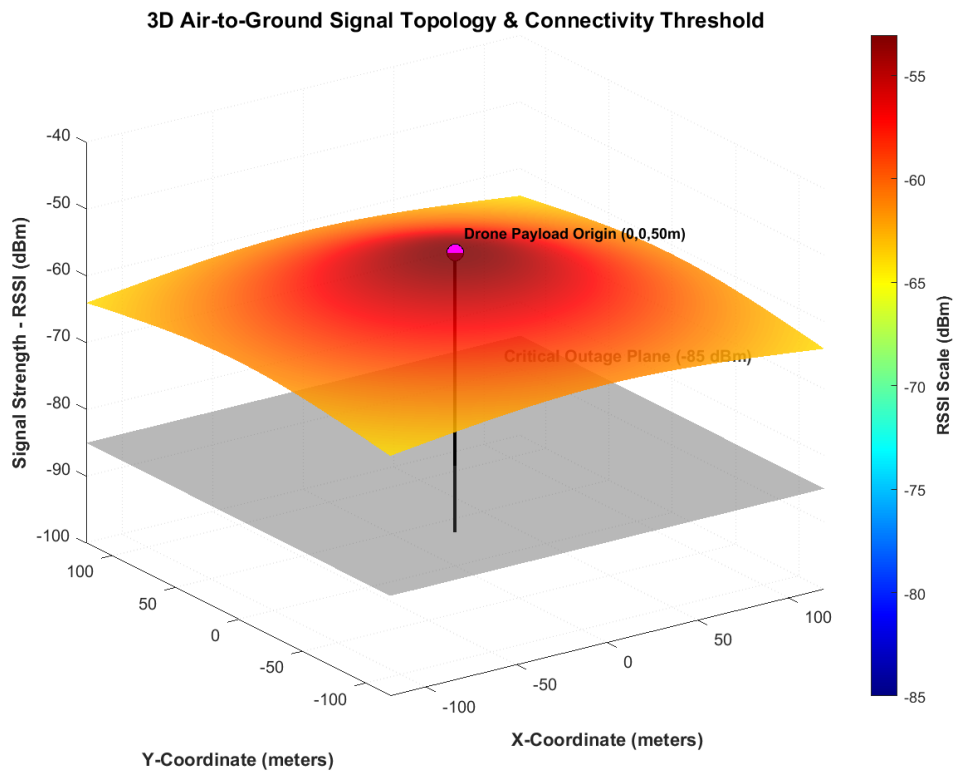


Figure 7. Air to ground signal topology.

6.2. Evaluation of the Web Dashboard Interface

The emergency management Web Dashboard provides response teams with real-time situational awareness.

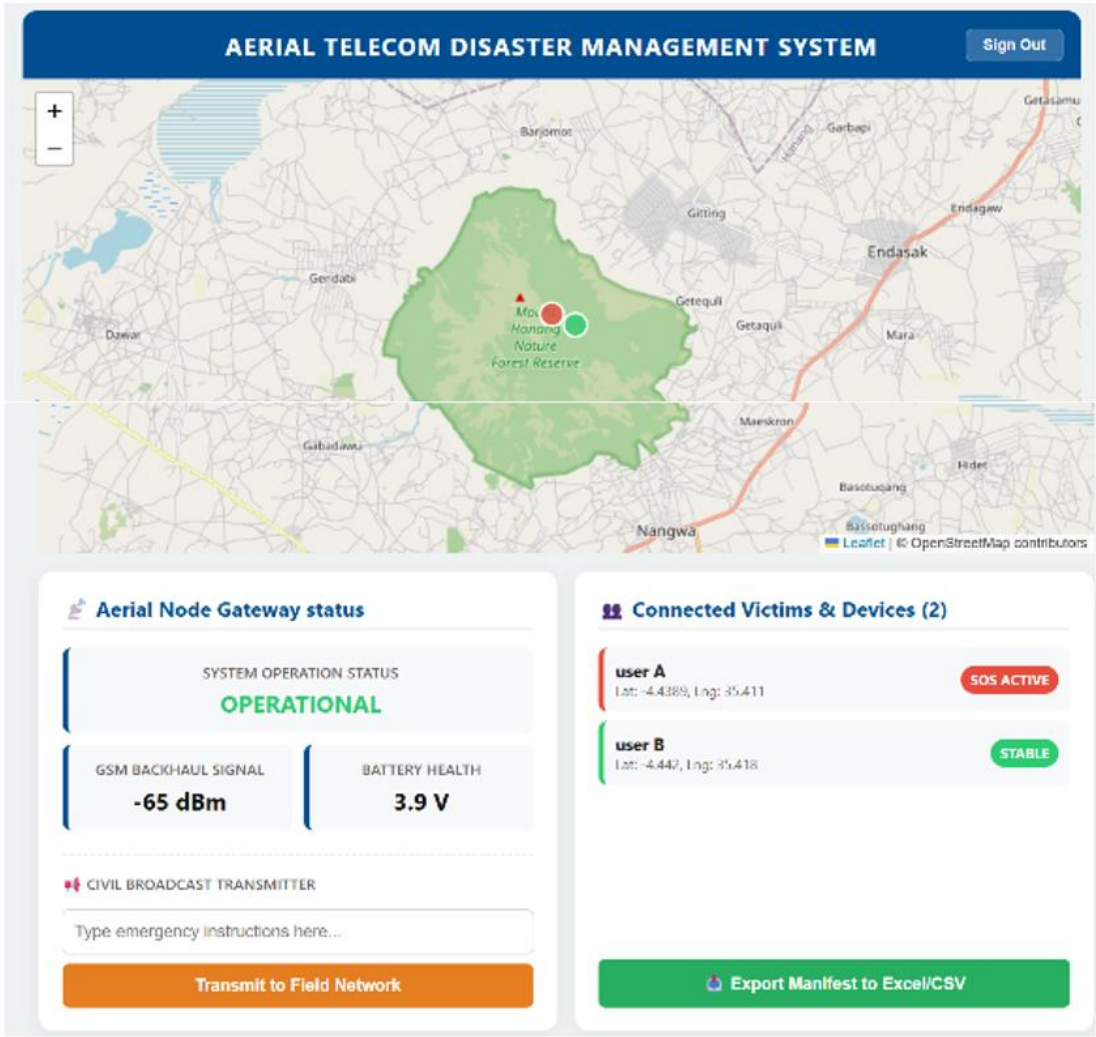


Figure 8. Rescue interface.

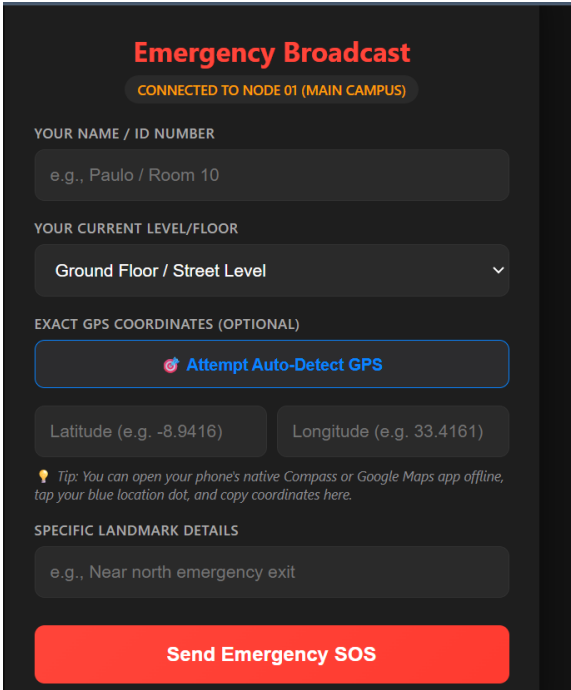


Figure 9. Victim interface.

6.3. Asynchronous Two-Way Communication Subsystem

Effective disaster response requires not only the transmission of emergency requests from victims but also the ability for rescue personnel to communicate status updates back to victims. For this reason, the proposed system implements an asynchronous two-way communication mechanism.

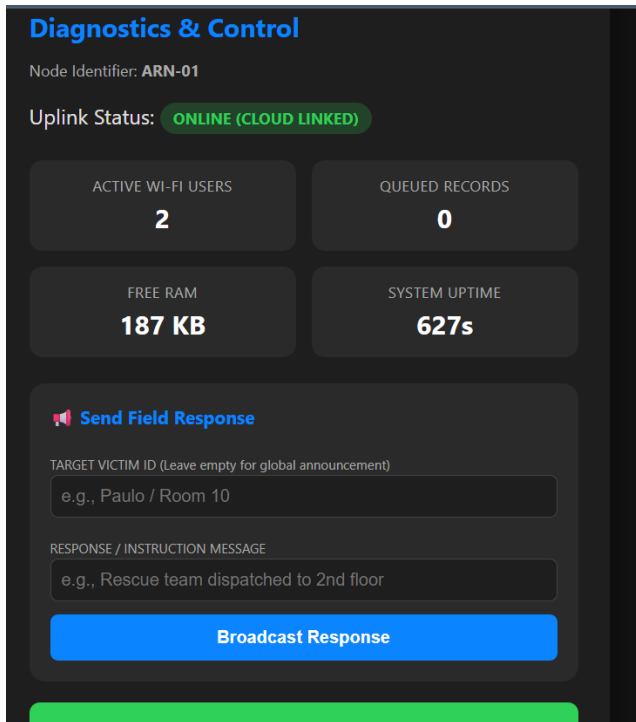


Figure 10. Field technician portal.

7. Discussion

The simulation results demonstrate that the proposed autonomous aerial communication support node is capable of providing reliable communication support under disaster-response conditions. The battery performance analysis showed a stable discharge profile, suggesting that the node can maintain operation for extended durations when powered by a rechargeable battery source [11].

Communication availability remained consistently above 98%, indicating that the proposed architecture can sustain communication support with minimal service interruption. This performance is particularly important in disaster scenarios where communication reliability directly influences rescue coordination and emergency response effectiveness.

The emergency alert response analysis further demonstrated the capability of the system to react quickly to emer-

gency events. The average response time of 1.95 seconds indicates that the system can provide near real-time alert generation, which is essential for situational awareness and rapid emergency intervention.

Compared with conventional disaster communication approaches that often require expensive infrastructure and lengthy deployment procedures, the proposed system offers a low-cost, rapidly deployable, and autonomous alternative. The integration of GPS tracking, battery monitoring, GSM communication, and cloud-based monitoring enhances the operational awareness of emergency responders while maintaining affordability and scalability.

The results therefore confirm that the proposed architecture satisfies the primary objectives of supporting emergency communication, improving situational awareness, and enabling rapid deployment in disaster-affected areas.

7.1. Reliability Model

We can model reliability as:

$$R = \frac{N_s}{N_t} \times 100$$

Where:

- 1) R = System Reliability (%)
- 2) N_s = Number of successful operations
- 3) N_t = Total number of operations tested

For example:

- 1) Total test cycles = 100
- 2) Successful cycles = 97

Reliability:

97%

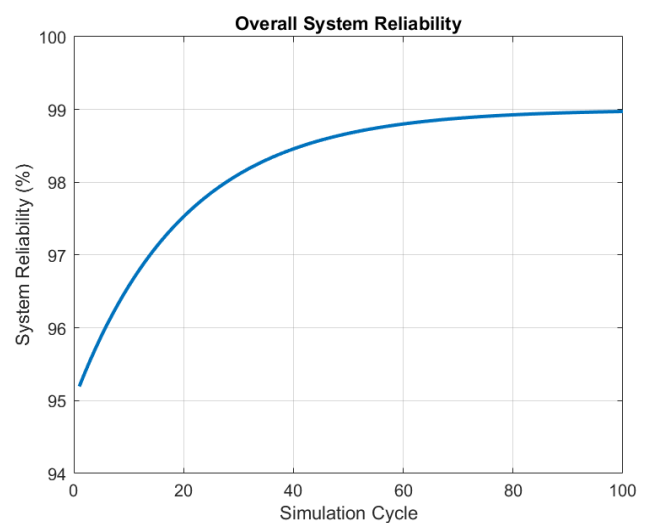


Figure 11. Reliability Model.

7.2. Implemented Prototype Block Diagram

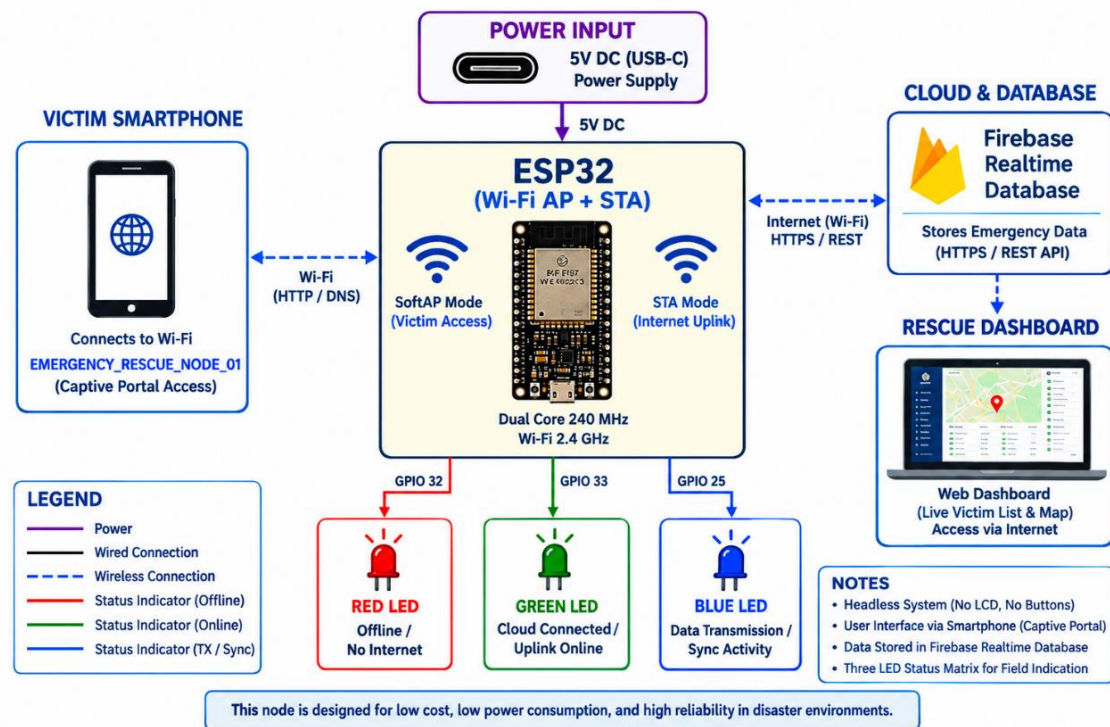


Figure 12. Implemented prototype block diagram.

7.3. Final Prototype



Figure 13. Final prototype.

8. Conclusion

This study presented the design and implementation of an Emergency Victim Localization and Rescue Coordination System tailored for disaster response, focusing on the critical challenge of rapidly identifying and locating affected individuals when conventional communication networks fail. The system enables victims to submit emergency reports along with location data using common mobile devices and browser-based technologies, eliminating the need for specialized applications. These reports are transmitted to a centralized rescue dashboard that provides responders with real-time access to incident information, enhancing situational awareness and supporting effective decision-making during rescue operations. Prototype results demonstrated that the solution offers a practical, low-cost, and scalable approach to improving coordination and reducing rescue delays. Overall, the study successfully achieved its objectives by developing an integrated platform that combines emergency reporting, victim localization, and rescue coordination into a unified disaster response tool.

9. Future Work

For future development, the Emergency Victim Localization and Rescue Coordination System could be enhanced in several key ways. Autonomous aerial platforms may be integrated to rapidly extend emergency communication coverage over disaster areas, while long-range communication technologies would allow operation even without internet connectivity. Offline synchronization mechanisms could support delayed data transmission once links are restored, and intelligent prioritization algorithms could automatically classify emergencies by severity to optimize resource allocation. Artificial intelligence techniques may further improve the system by predicting victim risk levels and optimizing rescue routes. Additional improvements include enabling multimedia reporting such as photos, audio, and video from victims, and developing mobile applications for rescue personnel to strengthen field coordination and efficiency. Collectively, these enhancements would increase the reliability, scalability, and operational effectiveness of the platform in real-world disaster scenarios.

Abbreviations

ESP32	Espressif 32-bit Microcontroller
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IP	Internet Protocol
IoT	Internet of Things
LED	Light-Emitting Diode
SOS	Save Our Souls / Emergency Distress Signal

UI	User Interface
URL	Uniform Resource Locator

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Author Contributions

Paulo John Kapembe: Conceptualization, Hardware design, Software, Writing - original draft, Data curation

Zacharia Mzurikwao: Data curation, Methodology, Software, Validation, Writing - review & editing

Candida Mwisoba: Investigation, Resources, Validation, Visualization

Joseph Sospeter Salawa: Formal Analysis, Project administration, Supervision, Writing - review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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