# Enhancing Disaster Response with Satellite-Based Alerts and LPWAN Distress Signaling

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***Abstract*— Disasters and emergency events often cause severe disruption to conventional communication infrastructures such as cellular networks, landlines, and the internet, which frequently fail during critical response periods. This breakdown hampers information flow, delays rescue operations, and endangers lives. Ensuring resilient, always-available communication is therefore vital for effective disaster management and Public Protection and Disaster Relief (PPDR) operations.**

**This paper examines the integration of satellite communication with non-cellular Low Power Wide Area Networks (LPWAN) as a hybrid framework for emergency communication. While satellite systems provide wide-area, authority-to-public alert dissemination, LPWAN technologies such as Long Range Radio (LoRa) enable energy-efficient, long-range, and low-cost distress signaling. Used together, they create a complementary mechanism that supports both top-down alerts and bottom-up user distress reporting, thus addressing key PPDR communication gaps.**

**We propose a conceptual framework that leverages these complementary strengths to improve situational awareness, resilience, and coverage across disrupted environments. Beyond terrestrial settings, the framework is also discussed in the context of maritime use cases, such as ships and sea vessels, where the combined reach of satellite and LPWAN ensures uninterrupted alerting and reporting capabilities. By bridging these critical gaps, the framework advances ICT convergence to support next-generation PPDR communication and large-scale emergency response.**

***Keywords*— *Disaster management, Satellite communication, LPWAN, PPDR, Emergency communication, CAP***

## I. Introduction

Disasters, whether natural or human-induced, pose a severe threat to life, property, and infrastructure. According to the United Nations Office for Disaster Risk Reduction (UNDRR), between 2000 and 2019 there were 7,348 major disasters worldwide, which claimed 1.23 million lives, affected 4.2 billion people, and caused an estimated US$2.97 trillion in economic losses [1]. In this context, the timely dissemination of critical information, including early warnings [2] and distress signals, is essential for effective disaster response. Public Protection and Disaster Relief (PPDR) systems play a central role in this domain by ensuring resilient communication, interoperability across agencies, and continuous situational awareness [3].

Recent advancements in communication technologies present new opportunities to strengthen PPDR frameworks. Satellite communication offers wide coverage and robustness against terrestrial disruptions, making it a dependable channel for authority-to-public alert dissemination. In India, the Common Alerting Protocol (CAP)–based platform developed by Centre for Development of Telematics (C-DOT) enables multilingual, multi-hazard alerts to be broadcast via satellite systems such as Navigation with Indian Constellation (NavIC) and GPS-Aided Geo Augmented Navigation (GAGAN) [4, 16, 18], thus addressing digital divides in underserved regions [4]. Complementing this, LPWAN technologies like LoRa with their long-range, energy-efficient connectivity can function reliably in disrupted or bandwidth-constrained environments. These technologies are increasingly viewed as enablers for emergency communications, particularly where rapid, low-cost deployment is critical.

This paper proposes a hybrid communication framework combining satellite-based alerting with LPWAN-enabled distress signaling to support and extend the capabilities of PPDR systems. The proposed approach ensures both top-down dissemination of alerts and bottom-up transmission of distress data, creating a two-way resilient network. Its strength lies in extending coverage seamlessly across land and sea, making it applicable not only to rural and remote inland regions but also to maritime environments where ships and sea vessels often lack reliable links to responders. By enhancing inclusivity, robustness, and situational responsiveness, the framework aligns with global PPDR priorities and offers a scalable pathway for next-generation disaster communication systems. These motivations set the stage for examining the limitations of conventional infrastructures, which remain a key barrier to resilient emergency communication [8].

## II. Limitations of Conventional Communication Infrastructure

Despite their ubiquity, conventional infrastructures such as landlines, cellular networks, and internet services remain unreliable during disasters [5]. Natural hazards frequently damage towers, cables, and exchanges, while prolonged power outages further disable essential equipment. Even when physically intact, these systems often fail under sudden surges in traffic, leading to congestion, dropped calls, and delays in transmitting critical information. For instance, during the 2018 Kerala floods, hundreds of mobile towers and more than 100 telephone exchanges were rendered non-functional due to flood-induced power outages and infrastructure damage, causing widespread communication blackouts that severely hindered rescue coordination efforts [19]. Such failures directly undermine the effectiveness of PPDR operations, where timely communication is vital.

Technical and security-related disruptions add further fragility. Extreme weather may degrade system performance, while cyberattacks or deliberate sabotage can compromise service availability during emergencies. Moreover, rural, remote, and maritime regions often remain outside the coverage footprint of terrestrial networks, leaving populations completely cut off when disasters strike. As seen, in the 2011 Great East Japan Earthquake and Tsunami, approximately 1.9 million fixed-line services and 29,000 mobile base stations were disabled, compelling reliance on satellite phones in emergency zones where conventional systems had failed [20].

These limitations demonstrate that conventional systems alone cannot guarantee resilient communication for PPDR. Hence, scalable and independent alternatives—capable of functioning even when ground-based infrastructure is impaired—are essential to strengthen disaster response and ensure continuity of operations. Challenges of terrestrial communication infrastructure underscore the need for resilient, non-terrestrial solutions. In this regard, satellite based messaging services of NavIC and GAGAN provide the underlying communication backbone, which is leveraged by C-DOT's CAP-based early warning platform to implement large-scale disaster alert mechanisms, which are discussed in the next section.

## III. Satellite based Disaster alerting mechanisms in India

Given the vulnerabilities of conventional communication systems highlighted in Section II, resilient non-terrestrial channels are essential for effective disaster response. Satellite communication forms a key pillar in India's alerting architecture, providing wide-area coverage, reliability, and operational continuity in remote, rural, and infrastructure-deficient regions where terrestrial networks often fail [6]. While NavIC and GAGAN satellites primarily serve navigation and aviation purposes, their messaging capabilities have been extended to support disaster management. Effective nationwide dissemination, however, requires a coordinating platform — C-DOT's CAP-based early warning platform, which integrates satellite messaging services with other communication channels to ensure timely and targeted alerts.

### *A. Navigation with Indian Constellation - NavIC*

NavIC is an independent satellite constellation developed by Indian Space Research Organisation (ISRO) to deliver high-accuracy positioning and timing services across the Indian subcontinent and up to 1500 km beyond Indian borders. It operates in the L1 (1563.42–1587.42 MHz) and L5 (1164.45–1188.45 MHz) frequency bands, with the L5 band reserved for safety-of-life applications [7].

Beyond navigation, NavIC supports short message broadcasting via the L5 band. These messages disseminate alerts, forecasts, and directives during natural disasters such as cyclones, tsunamis, floods, and landslides [8]. This dual role—navigation plus emergency messaging—makes NavIC a critical component of national disaster resilience.

### *B. GPS-Aided Geo Augmented Navigation - GAGAN*

GAGAN, a Satellite-Based Augmentation System (SBAS) jointly developed by Airports Authority of India(AAI) and ISRO, enhances Global Navigation Satellite System(GNSS) performance by improving accuracy and integrity for civil aviation. Its functionality has been extended to disaster management through the GAGAN Message Service (GMS) [9].

GMS leverages spare SBAS bandwidth (notably message type 63) to broadcast short text alerts via GAGAN GEO satellites [17]. These alerts include early warnings for natural disasters, meteorological updates, oceanic alerts, and other safety-critical information. By enabling direct-to-user dissemination, GAGAN acts as a last-mile alerting channel for both aviation and non-aviation communities.

### *C. Synergy with C-DOT's CAP-Based Early Warning Platform*

The C-DOT`s early warning platform based on CAP protocol acts as the central hub for disaster alert dissemination in India, coordinating with NavIC and GAGAN to provide wide-area coverage and ensuring alerts are delivered reliably across multiple channels. The operational workflow is outlined as follows:

- Issuing Agency Generates Alert: Disaster management authorities in India generate CAP-compliant alerts describing the nature, severity, and geographic scope of the hazard.
- C-DOT CAP Platform Disseminates: Alerts are transmitted via multiple channels—SMS gateways, cell broadcast, mobile applications, social media, and specifically, NavIC/GAGAN messaging services [4,18].
- Satellite Uplink/Downlink: Ground stations forward the formatted disaster alert messages to NavIC/GAGAN satellites, which broadcast them across the coverage region.
- End-User Reception: Citizens with NavIC/GAGAN-enabled receivers (integrated with smartphones via Bluetooth and apps) receive the alerts in real time, displayed in a standardized format for clarity.
- Targeted dissemination: This framework ensures that alerts reach only those within threatened areas, thereby minimizing panic and confusion while enabling timely evacuation and response.

While satellite systems provide broad-area, reliable alert dissemination, enhancing end-to-end PPDR communication requires complementary ground-level technologies such as LPWAN for localized, low-power distress signaling, which is discussed in the next section.

## IV. Low Power Wide Area Network (LPWAN) Technologies based Distress signaling

Building on the wide-area dissemination achieved via NavIC/GAGAN–CAP channels, localized and energy-efficient communication is critical for two-way PPDR interactions. LPWAN technologies, such as LoRa, enable affected individuals to transmit distress signals directly to rescue teams and coordination centers, complementing satellite-based alerts and ensuring end-to-end situational awareness.

### A. LPWAN Communication

LPWAN is a wireless technology designed to interconnect battery-powered devices, over extended distances, making them ideal for emergency beacons and distress signaling. LPWANs offer broad coverage, very low energy consumption, and high network capacity [10, 11, 12].

LoRa WAN typically uses a star topology, where nodes communicate with gateways that relay data to a central server. However, this single-hop design has limitations, especially in remote or obstructed areas, and gateways represent a single point of failure that can disrupt network communication.

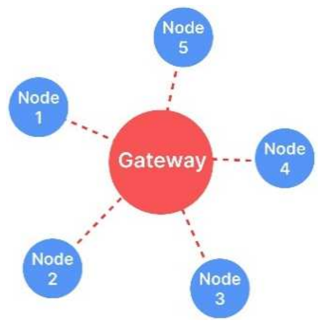


Fig. 1. Star Topology

On the other hand, a full mesh network ensures all nodes can communicate directly with any other node in the network [13]. This decentralized structure removes reliance on a central node, providing robust and reliable communication [14].

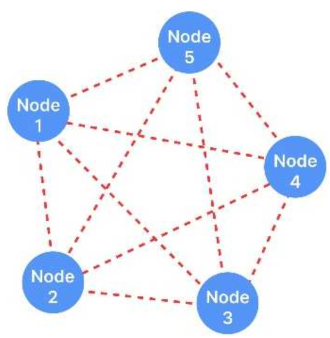


Fig. 2. Mesh Network topology

### B. Distress signaling over LoRa mesh

When an individual sends distress signal through their personal emergency devices, the signal hops through nearby LoRa nodes carried by other people until it reaches a rescue coordination center.

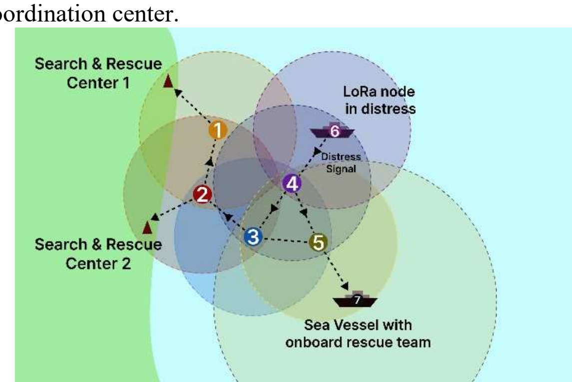


Fig. 3. Distress signaling over multiple hops in a LoRa mesh network

Emergency devices can continuously transmit location coordinates enabling rescuers and neighboring nodes to locate individuals. These devices can also transmit standardized emergency codes that identify specific type of distress. This allows rescue teams to prioritize responses and deploy appropriate resources.

### C. Emergency and Distress Communication in Maritime Environment

The hybrid approach proposed in this paper integrates satellite-based alert reception with LoRa mesh transceivers within a single maritime emergency device. The satellite component ensures wide-area coverage, while the mesh network addresses local gaps and enables nodes to relay alerts to neighboring units. Operational advantages include:

- Mesh relay overcoming coverage gaps to ensure no node remains uninformed.
- Self-organizing network maintaining connectivity even with moving nodes.
- LoRa coverage across extensive maritime regions, supporting ships and sea vessels. [21].

This hybrid framework ensures broad dissemination of satellite-based disaster alerts, while the LoRa mesh network relays messages to remaining nodes, analogous to its role in distress signaling, thereby sustaining resilient PPDR communication across land and maritime domains. By bridging large-scale satellite alerts with localized, low-power distress signaling, this approach sets the stage for a unified emergency communication system

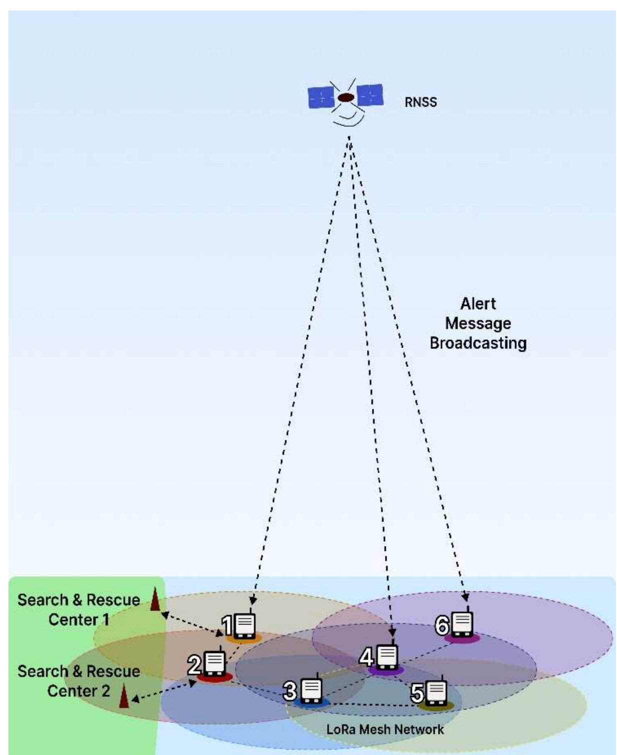


Fig. 4. Hybrid approach involving Satellite based disaster alerting and a LPWAN technology (LoRa) based Distress signaling in a mesh network

The hybrid deployment is illustrated in the figure, showing satellite broadcasting combined with a LoRa mesh network for reliable message dissemination. While Regional Navigation Satellite Systems (RNSS) satellites transmit alerts directly to ground nodes and search & rescue centers, some nodes may miss messages due to coverage gaps or obstructions. LoRa mesh enables received alerts to be relayed to neighboring nodes, ensuring comprehensive dissemination.

Key mechanisms include:

- Intelligent routing algorithms: Mesh networks automatically adjust communication paths when nodes fail or become inactive, maintaining reliability while minimizing routing overhead.
- Energy-aware routing: Moving nodes continuously adapt relay paths based on signal strength, extending network lifetime and ensuring distress signals reach coordination centers even under dynamic or disrupted conditions.

This framework ensures resilient, end-to-end disaster communication across land and sea, bridging wide-area satellite alerts with localized LPWAN relays. It also sets the stage for a unified hybrid communication model, which is further discussed in Section V.

## V. A Model for the Future

Building on the hybrid satellite–LPWAN framework discussed in Section IV, a comprehensive disaster communication model can leverage both broad-area satellite based disaster alerting and localized LoRa-based distress signaling to enhance PPDR effectiveness. C-DOT's Common Alerting Protocol based platform, integrated with NavIC and GAGAN, demonstrates a scalable framework for geo-targeted disaster alerts and multi-agency coordination. Its standardized messaging and regional coverage enable more efficient disaster response across India [18]. Satellite systems such as NavIC and GAGAN have proven effective for broadcasting emergency warnings, while their messaging capabilities can be leveraged for targeted public alerting in critical scenarios.

Future enhancements could integrate other RNSS as Satellite-Based Augmentation Systems (SBAS), allowing precise alerts to reach end-user devices within defined coverage areas. A promising extension is the convergence of satellite alerting with LoRa-based distress signaling in a single hardware unit. Such hybrid terminals allow individuals to both receive disaster alerts and transmit emergency signals when in distress or act as a relay for other nodes in distress. LoRa's long range, low power, and mesh networking complement satellite broadcasts to provide a robust, two-way communication system.

In regions with weak satellite connectivity, LoRa mesh networks relay distress messages across multiple hops to ground-based control centres without requiring user intervention [15]. This redundancy ensures reliable communication even for isolated communities. Deploying hybrid terminals capable of receiving satellite alerts and transmitting LoRa distress signals offers a cost-effective, resilient solution. When distributed to authorities, local leaders, and vulnerable households, these devices can enhance situational awareness and disaster preparedness across both land and maritime regions, strengthening overall PPDR capabilities.

## VI. Conclusion

Building on the hybrid satellite–LPWAN framework discussed in Section V, this paper demonstrates how integrating RNSS based disaster alerting with LoRa mesh networks can significantly enhance disaster communication across both land and maritime environments. This approach supplements Public Protection and Disaster Relief by providing robust, two-way communication channels: top-down satellite alerts for wide-area coverage and bottom-up LoRa-based distress signaling for local resilience. The combined system ensures that even remote or isolated populations—onshore and at sea—can receive timely warnings and transmit emergency signals during disasters.

The proposed hybrid device architecture offers a cost-effective, scalable solution for improving disaster preparedness and response coordination. Its practical implementation supports rapid dissemination of alerts, reliable distress signaling, and situational awareness across diverse terrains. Future work should focus on large-scale deployment, validation in varied geographic and maritime regions, and integration with international PPDR frameworks to enhance interoperability and operational efficiency.

### A. Way Forward

Enhancing disaster resilience requires continued development and deployment of integrated satellite-based alerting systems and LoRa mesh networks for localized distress signaling. Priority should be given to producing affordable, multi-functional transceiver terminals capable of receiving satellite alerts and transmitting LoRa distress signals, particularly in high-risk and resource-constrained regions. Collaboration among governments, international agencies, and research institutions is essential to fund deployments, ensure interoperability, and address system efficiency, resilience, privacy, and security. Community and first-responder training programs are equally crucial. By advancing these integrated solutions, disaster-prone regions can significantly reduce human and economic losses. Moreover, this hybrid framework ensures effective coverage across both land and maritime environments, enabling timely alerts and distress signaling for coastal communities, and sea vessels.

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