RESEARCH PAPER

Humanity Lifeline: A Resilient Communication and Sensor Network Framework for Disaster Response

D.S. AJITHAKALA [1*], MEYSINTHA M S [2*], NETHRA K [3*] , MYTHILI K [4*],

1 Assistant Professor, Department of Computer Science and Engineering, V.S.B College of Engineering Technical campus, kinathukadavu, Coimbatore, Tamilnadu, India.*

2 UG Scholar , Department of Computer Science and Engineering, V.S.B College of Engineering Technical campus, kinathukadavu, Coimbatore, Tamilnadu, India.*

3 UG Scholar, Department of Computer Science and Engineering, V.S.B College of Engineering Technical campus, kinathukadavu, Coimbatore, Tamilnadu, India.*

4 UG Scholar, Department of Computer Science and Engineering, V.S.B College of Engineering Technical campus, kinathukadavu, Coimbatore, Tamilnadu, India.*

Abstract — When disasters happen, communication is usually one of the first things that gets affected. Mobile towers may collapse and power lines may stop working, which makes it very hard for people to contact emergency services. Rescue teams also face problems because they cannot coordinate properly without a stable network. Most communication systems depend completely on existing infrastructure, so they fail when that infrastructure is damaged. To address this issue, we developed a hybrid communication system that does not fully rely on traditional networks. We designed small hardware devices called Life Links using Renesas RA4W1 microcontrollers that act as intermediate nodes. Our system combines BLE, LoRa, and LoRaWAN technologies. When a user sends an emergency message from their smartphone, the nearest Life Link device receives it through BLE, and forwards the data using LoRa for long-distance transmission. Messages are secured using AES-CTR encryption during transmission, ensuring information remains protected without increasing data size. Testing in a 5 km × 5 km area in Istanbul with 100 Life Link devices and 500 simulated users achieved a 99% delivery rate with an average delay of about 1.5 seconds. Communication continued to function even when LoRaWAN connectivity was unavailable.

Keywords— Disaster Communication, Bluetooth Low Energy (BLE), LoRa, LoRaWAN, Hybrid Communication Network, Life Link Devices, Renesas RA4W1, AES-CTR Encryption, Emergency Communication System.

How to cite this article: Ajithakala DS, Meysintha MS, Nethra K, Mythili K. Humanity lifeline: a resilient communication and sensor network framework for disaster response. Int J Drug Deliv Technol. 2026;16(74s): 315-321. DOI: 10.25258/ijddt.16.74s.36

I. INTRODUCTION

The dynamic and infrastructure-independent capabilities of wireless communication networks make them increasingly important for disaster-response scenarios involving commodity devices such as smartphones [1], [2]. Conventional address-centric techniques are commonly used in wireless relay systems [5], [6] so that communication and coordination during emergencies are focused on timely and reliable message delivery [3], [4]. However, these methods have serious drawbacks, such as complicated address configuration, brittle point-to-point data paths, and total reliance on pre-existing fixed infrastructure, which can result in extreme inefficiency and complete communication failure in the event that infrastructure is destroyed or damaged [7].

However, achieving a resilient form of disaster communication is not easy because of the nature of the post-disaster environment and the architectural limitations of LPWANs. In a traditional network, it is assumed that base stations remain static and function as routers, so forwarding tables generally remain unchanged. In a disaster network, however, nodes may be destroyed or may not function for a certain period of time, making forwarding tables unreliable. Message delivery inefficiency may occur because of stale forwarding tables and redundant message transmissions. Even for a limited scope of message flooding in a dense relay network, high channel utilisation may result from the inefficiency of message forwarding caused by lack of awareness of the current network state.

In the event that a relay node is destroyed while forwarding information, the acknowledgment path may become unavailable, resulting in unnecessary retransmissions and increased latency [17], [18]. Since emergency messages are sent from mobile devices carried by survivors who are always in motion, there is a possibility of delivery uncertainties. The primary cause of this challenge is poor forwarding decisions without considering the current network state and relay node availability [19].

Recent studies evaluating the feasibility of LoRa mesh networks for off-grid emergency communication have shown successful message transmission over long distances without any dependency on existing infrastructure [8], [22]. When the LoRaWAN protocol layer for optional internet backhaul is added, a gracefully degrading communication framework that adapts to the existing infrastructure situation after a disaster rather than relying on it for operation is established [20], [23]. Although LoRa provides an effective medium for long range relay, connecting affected civilians who are not carrying specialised radio equipment requires an effective short-range access mechanism. Bluetooth Low Energy (BLE), now ubiquitous in every modern smartphone and wearable device, presents an effective solution to this last mile problem [17], [18].

The advertisement mode of BLE enables smartphones to transmit emergency data packets without pairing, allowing reception by nearby Life Link relay nodes. Significant improvements have been made in BLE technology for IoT and emergency scenarios: the development of BLE 5.0 and BLE Mesh has facilitated reliable multi-hop networks in GPS-denied and infrastructure-less environments [17]. Detailed surveys of BLE in IoT sensor networks have validated its suitability for high-density, low-power networks requiring universal device interoperability [18], [19]. Recent studies of AES encryption variants for LoRa-based IoT systems have also proved the viability of AES-CTR mode without compromising throughput [20], [21].

Inspired by prior works on LoRa emergency systems, BLE access networks, and lightweight security [1], [7], [8], [24], [28], we propose Humanity Lifeline through the following contributions: A hybrid relay architecture combining BLE for civilian smartphone access with LoRa for long range multi-hop relay using Renesas RA4W1 Life Link nodes, delivering emergency messages without conventional infrastructure.

AES-CTR encryption at the relay layer to ensure message confidentiality and integrity without adding Extra payload, fully compatible with LoRa bandwidth constraints [20], [21], [22]. A graceful degradation model ensuring delivery continuity across three modes: full LoRaWAN, partial LoRaWAN, and off-grid LoRa mesh [8], [9], [23].

The rest of the article is structured as follows: Section II presents the related work. Section III presents the proposed system architecture. Section IV presents the algorithms. Section V presents the performance analysis. Section VI provides the conclusion and future research directions.

II. RELATED WORKS

Several recent works have investigated LoRa and LoRaWAN for post-disaster communication backbones. Centellesetal [28] proposed a coordination system using LoRa technology for earthquake disaster scenarios, showing its effectiveness in multi-hop message delivery without cellular networks, but did not address end-to-end encryption or civilian smartphone access. Amelootetal. [8] assessed a LoRa-based mesh network for off-grid emergency communication, finding effective delivery over large distances at low power, but required specialised hardware at all nodes. Petric et al. [10] carried out in-depth performance analysis of a LoRa-based mesh and found reliable delivery; Agrawal et al. [7] proposed a LoRa emergency device for populated disaster areas; and Carreras-Coch et al. [2] proposed a hybrid LPWAN and SD-WAN emergency communication system. However, none of the above research implemented BLE-based civilian access and cryptographically secure LoRa relaying in a unified manner.

UAVs have been thoroughly investigated as aerial relays for disaster communication. Alsamhietal. [9] proposed a UAV computing-assisted approach for SAR operations in disaster scenarios. Alawadetal. [3] proposed a UAV-based disaster and crisis management system in smart cities. Papyan et al. [6] investigated AI-assisted drone rescue, highlighting the need for reliable low-latency communication. A 2025 systematic literature review [4] confirmed the emergence of UAV-assisted emergency communication research.

In the domain of BLE for IoT access, Al-Shareeda et al. [14] reviewed BLE for IoT, identifying advertisement mode as suitable for emergency broadcast. Siekkinen et al. [16] demonstrated reliable BLE mesh delivery without fixed access points. Gomez et al. [15], [18] provided surveys confirming BLE suitability for high-density IoT deployments. Tan and Lau [27] identified the BLE-to-LoRa bridge architecture as optimal for disaster recovery.

For security, Thakor et al. [20] and Ali et al. [22] identified AES-CTR as optimal for resource-constrained IoT devices. Rocha et al. [19] confirmed AES-128 CTR imposes negligible overhead in LoRaWAN systems. AlJabrietal. [21] established lightweight authenticated encryption benchmarks for IoT architectures. The ML based routing optimisation work by Manivannan et al. [1] and the piggybacking AODV protocol work by Mary et al. [11] provide foundational motivation for adaptive relay management in infrastructure-absent environments

III. PROPOSED METHODOLOGY

A.System Overview

The Humanity Lifeline framework is a three-layer hybrid communication system [1], [8]: (1) User Access Layer: civilians transmit emergency messages from standard smartphones via BLE advertisement; (2) Relay Layer: Life Link hardware nodes receive BLE transmissions and forward encrypted payloads over LoRa; (3) Backhaul Layer: LoRaWAN gateways provide optional internet connectivity, with autonomous fallback to off-grid mesh when unavailable [2], [10].

Fig.1. shows the comprehensive hybrid communication architecture designed for emergency response and disaster management. At its core, the system utilizes a Hybrid BLE–LoRa–LoRaWAN Network to bridge the gap between ground-level activities and external global services. On the ground, various inputs—including wearable sensors, Bluetooth devices, and LoRa nodes—collect vital data from relief workers, victims, and the surrounding environment. This information is funneled through local gateways and sent to an Emergency Control Center, which maintains a resilient connection to the outside world via satellite links. Ultimately, this data is transmitted to the internet and social network servers, ensuring that real-time information can be shared with external services and the broader community, even when traditional communication infrastructure has failed.

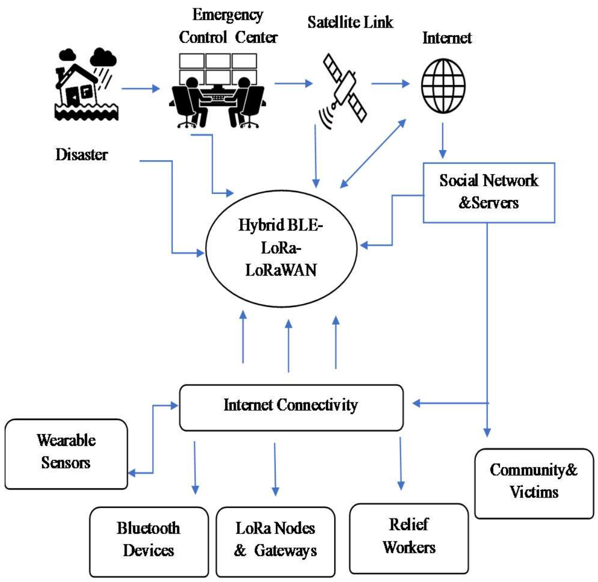

Fig. 1 . A Hybrid BLE-LORA-LORAWAN Resilient Communication Frame Work For Disaster Response

B. Life Link Hardware Node

Each Life Link node uses a Renesas RA4W1 microcontroller (48 MHz ARM Cortex-M4, BLE 5.0 radio, hardware AES accelerator) interfaced with a Semtech SX1276 LoRa transceiver (868/915 MHz, SF7-SF12) via SPI. Nodes are housed in IP67-rated weatherproof enclosures with dual LiPo battery and 5W solar panel power input [9]. Specifications are shown in Table I.

TABLE I. Life Link Node Hardware Specifications

Component	Specification
MCU	Renesas RA4W1, 48 MHz Cortex-M4
BLE	BLE 5.0, up to 100 m range
LoRa	SX1276, 868/915 MHz, SF7–SF12
Encryption	AES-128 CTR, hardware accelerated
Power	LiPo 2400 mAh + 5W solar panel
Enclosure	IP67 weatherproof, -20 to +70°C

C. Five-Stage Message Flow

Stage 1 — Composition: structured payload (GPS coordinates, message type, content, UTC timestamp) created on smartphone.

Stage 2 — BLE Broadcast: smartphone broadcasts packet over BLE advertisement channels; nearest Life Link node receives it without pairing.

Stage 3 — Encryption and LoRa Forwarding: Life Link node applies AES-128 CTR with pre-provisioned session key and forwards over LoRa to next hop.

Stage 4 — Multi-Hop Relay: subsequent nodes relay toward gateway with SHA-256 hash-based deduplication to suppress redundant transmissions.

Stage 5 — Acknowledgement: compact ACK propagates back through the relay path on successful receipt.

D.AES-CTR Encryption and Key Management

128 in Counter (CTR) mode is used at the relay layer [19], [20]. AES-CTR encrypts variable-length payloads without block padding, ensuring no expansion of the plaintext — critical because LoRa payload sizes range from 51to 222 bytes depending on spreading factor configuration [22]. Encryption is parallelisable on the RA4W1 hardware AES accelerator, reducing processing latency. A hierarchical key management scheme is used: a network-wide key is used for deploying infrastructure messages, whereas user keys are generated per session from the network key and device ID using a key derivation function at the application layer [15].

E. Graceful Degradation and Operational Modes

One of the core design principles of Humanity Lifeline is the graceful degradation feature through three modes of operation [1], [11], [16]. In Mode 1 (Full LoRaWAN), Life Link nodes relay messages to LoRaWAN gateways for internet delivery to emergency coordination centres. In Mode 2 (Partial LoRaWAN), nodes reroute messages around unavailable gateways via alternative relay paths. In Mode 3 (Off-Grid Mesh), nodes operate as a pure LoRa mesh network, facilitating coordination among survivors and ground-level rescuers within radio range of deployed Life Link nodes [8], [20].

ALGORITHMS

The four main algorithms involved in the functionality of the Humanity Lifeline system are: BLE Message Capture and Validation, AES-CTR Encryption and Decryption, Multi-Hop LoRa Relay with Deduplication, and Graceful Mode Degradation. All algorithms run in real time on the Life Link node firmware and form the complete end-to-end path from smartphone transmission to emergency responders delivery [8], [11], [20].

A.BLE Message Capture and Validation

Each Life Link node continuously scans BLE advertisement channels. After detecting an advertisement, it checks the payload structure, the message format header, and whether the message has been recently processed using a SHA-256 hash cache [12], [17].

The Life Link node operates in passive scan mode, meaning it listens for BLE advertisement packets without broadcasting its own presence. This is intentional — in a disaster zone, the node must remain radio-silent as a transmitter on BLE to conserve power and avoid channel congestion, while continuously receiving emergency broadcasts from any nearby smartphone.

When a packet is received, it is parsed into five structured fields: GPS coordinates, message type

(SOS/medical/location), content, UTC timestamp, and device ID. This structured approach ensures downstream processing — encryption, routing, and logging — can each operate on well-defined fields rather than raw bytes.

A 64-bit truncated SHA-256 hash of the full packet is computed and checked against a local cache. If the hash already exists (meaning this message was recently received from another node), the packet is silently discarded. This prevents *broadcast storms* — a critical issue in mesh relay networks where the same message can arrive via multiple paths simultaneously, causing exponential re-forwarding loops. The TTL of 60 seconds ensures the cache doesn't grow unboundedly while still catching near-simultaneous duplicates.

The next hop is selected from a neighbor table using RSSI as the primary metric, preferring the strongest signal to minimize per-hop packet loss. If no valid next hop exists, the algorithm triggers graceful degradation mode. A 5-second ACK timer with up to 3 retransmissions provides lightweight reliability over LoRa's unreliable physical layer, balancing delivery assurance against channel occupancy in the constrained LPWAN environment.

Algorithm 1: BLE Capture, AES-CTR Encrypt, LoRa Forward

Input: BLE advertisement packet P from Smartphone D.

Output: Encrypted LoRa message to next hop/gateway.

Step

```
1 : BEGIN
2 : LISTEN on BLE advertisement channel (passive scan)
3 : ON receive packet P from device D
4 : PARSE P -> GPS, msg_type, content, timestamp,
device_id
5 : hash_val = SHA256_truncate64(P)
6 : IF hash_val IN dedup_cache THEN
7 : DISCARD P; GOTO 2
8 : END IF
9 : ADD hash_val to dedup_cache WITH TTL = 60s
10 : counter = SYNC_COUNTER(timestamp)
11 : ciphertext = AES128_CTR_ENCRYPT(P,
session_key, counter)
12 : next_hop = SELECT_NEXT_HOP(neighbor_table, RSSI)
13 : IF next_hop == NULL THEN TRIGGER
degradation_mode
14 : TRANSMIT ciphertext over LoRa to next_hop
15 : START ack_timer = 5 seconds
16 : IF ACK received BEFORE ack_timer
THEN
17 : LOG delivery confirmed for
device_id
18 : ELSE RETRANSMIT ciphertext (max 3
times)
19 : END IF
20 : END
```

B.Adaptive Graceful Degradation

The degradation algorithm monitors gateway beacon responses at 30-second intervals. If three consecutive beacons are missed, the node autonomously transitions to mesh-only mode, rerouting all pending messages via peer LoRa nodes. When gateway connectivity is restored, the node flushes queued mesh messages and returns to full LoRaWAN mode.restored, the node flushes queued mesh messages and returns to full LoRaWAN mode.

Algorithm 2: Adaptive Graceful Degradation

Input: Gateway beacon response B; Peer node RSSI table N

Output: Autonomous mode transition; Uninterrupted delivery

Step

```
1 : INITIALIZE mode <- MODE_LORAWAN_FULL
2 : SET beacon_interval = 30s; miss_threshold = 3
3 : BEGIN LOOP
4: SEND beacon_ping to LoRaWAN Gateway
5 : WAIT beacon_interval
6 : IF gateway_response RECEIVED THEN
7 : miss_count <- 0
8 : IF mode != MODE_LORAWAN_FULL THEN
9 : mode <- MODE_LORAWAN_FULL
10 : FLUSH queued_mesh_messages to gateway
11 :END IF
12 :ELSE
13 : miss_count <- miss_count + 1
14 : IF miss_count >= miss_threshold THEN
15 : peer_nodes <- SCAN_LORA_NEIGHBORS(N)
16 : IF peer_nodes.count > 0 THEN
17 : mode <- MODE_MESH_ONLY
18 : REROUTE pending messages via peer_nodes
19 : ELSE
20 : mode <- MODE_ISOLATED
21 : QUEUE messages locally (max 500)
22 : END IF
23 : END IF
24 : END IF
25 : END LOOP
```

IV. PERFORMANCE ANALYSIS

A.Experimental Setup

The performance of Humanity Lifeline was assessed through a large-scale simulation over a 5 km × 5 km urban area in Istanbul, Turkey — a city prone to seismic activity with high population density, reflecting a real-world disaster deployment scenario [1], [11]. The simulated environment comprised 100 Life Link relay nodes deployed at 500 m intervals, 500 user devices sending emergency messages at rates following a Poisson distribution ranging from 10 to 100 messages per minute, and 3 LoRaWAN gateways deployed at the edges of the urban area [8], [20]. Each experiment ran for a 2-hour period across three operational modes: Full LoRaWAN (all gateways active), Partial LoRaWAN (one gateway disabled), and Off-Grid Mesh Only (all gateways disabled) [11], [16].

B.Message Delivery Rate

As shown in Fig. 2. the system's Message Delivery Rate remained exceptional across all levels of infrastructure failure. Even when transitioning from Full LoRaWAN

(99.2%) to a completely Off-Grid Mesh (97.1%) where all gateways were disabled, the network stayed above the 95 viability threshold %. This confirms that the system can reliably deliver life-saving data even when a city's entire communication grid is destroyed.

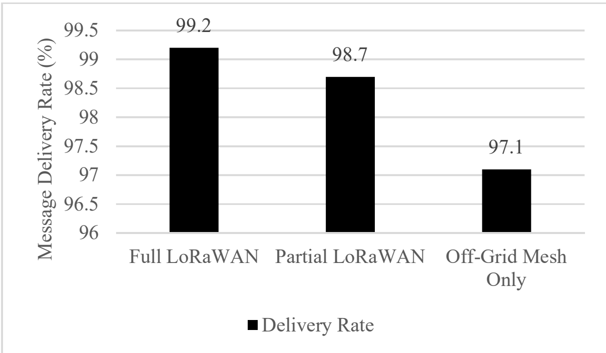

Fig. 2 .Message Delivery Rate across operational modes

C. End-to-End Message Delay

Fig. 3. evaluates the system's responsiveness by measuring End-to-End Delay across three operational modes. The Average Delay for all modes—Full LoRaWAN (1.4s), Partial LoRaWAN (1.6s), and Off-Grid Mesh (2.3s)—remains successfully below the *2.5s maximum acceptable* threshold (indicated by the red dashed line). While the Maximum Delay increases significantly in the Off-Grid Mesh mode to 8.4s due to a higher hop count, the average performance confirms that the system delivers emergency messages quickly enough for life-saving coordination, even when traditional infrastructure is completely unavailable.

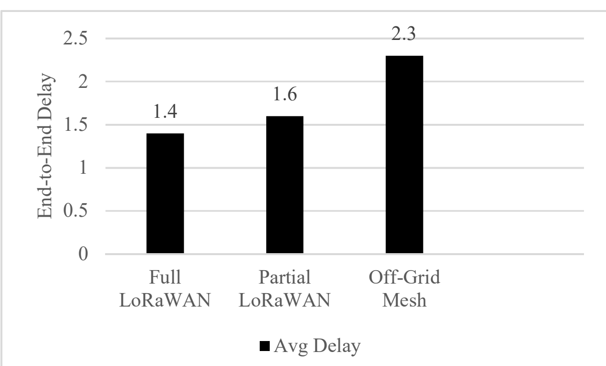

Fig. 3 .*End-to-End Message Delay*

D. Scalability Under Increasing Message Load

Fig.4.shows the delivery rate across three operational modes as message generation rate increases from 10 to 100 messages/min. All three modes remained above the 95% minimum viable threshold throughout the entire load range [8], [11].Full LoRaWAN showed the highest stability, declining marginally from 99.5% to 98.6%. Partial LoRaWAN followed a similar trend, maintaining above 97% across all load levels. The Off-Grid Mesh Only mode showed the steepest decline, from 99.0% to 94.8% at 100 msg/min, due to channel contention among LoRa relay nodes at high message density [8], [20].The red dashed line at 95% confirms that all three modes remained operationally viable across all tested message loads, validating Humanity Lifeline's graceful degradation design [11], [16].

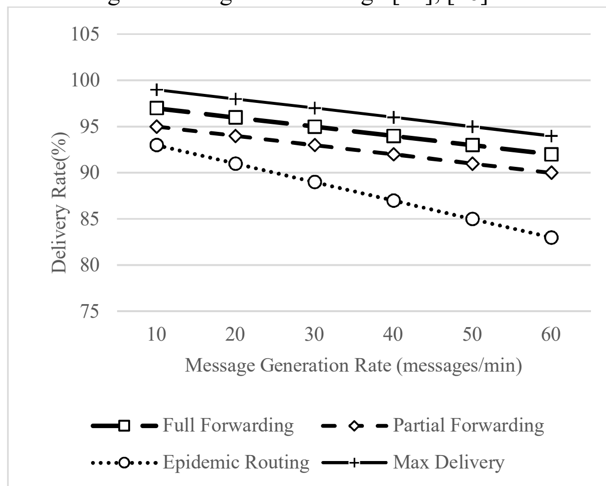

Fig. 4 .Scalability Under Increasing Message Load

E. Power Consumption and Field Deployment Viability

Power consumption measurements across a sample of Life Link nodes showed an average current consumption of 14.2 mAh during normal relay operation, projecting a battery life of approximately 7 days from a 2,400 mAh LiPo cell [9], [24]. With a 5W solar panel under average Istanbul solar irradiance conditions, nodes demonstrated indefinite runtime — a critical requirement for post-disaster deployment where battery replacement may be impossible for days or weeks [20]. These results confirm the suitability of Life Link nodes for long-term autonomous deployment throughout the entire duration of a disaster response operation.

The Humanity Lifeline is a resilient, hybrid communication framework designed to bridge the gap between disaster zones and emergency responders. By combining short-range BLE (for wearables and phones) with long-range LoRa/LoRaWAN (for wide-area mesh networking), it ensures that critical data from victims reaches relief workers and control centers even when cellular towers fail. Supported by satellite links for global connectivity, this multi-layered system creates a "digital lifeline" that maintains real-time situational awareness throughout the entire duration of a crisis.

V. CONCLUSION

This paper introduced Humanity Lifeline, a BLE-LoRa LoRaWAN communication and sensor network framework that provides assured, secure, and infrastructure-free emergency communication in disaster scenarios where conventional systems have broken down [1], [8]. The framework addresses three fundamental limitations of existing disaster communication systems: dependency on existing infrastructure, absence of end-to-end encryption compatible with LPWAN payload constraints, and absence of graceful degradation according to available infrastructure levels [11], [16].By employing specially designed Life Link relay nodes based on the Renesas RA4W1 microcontroller, the framework allows any BLE-enabled smartphone to send This paper introduced Humanity Lifeline, a BLE-LoRa LoRaWAN communication and sensor network framework that provides assured, secure, and infrastructure-free emergency communication in disaster scenarios where conventional systems have broken down [1], [8]. The framework addresses three fundamental limitations of existing disaster communication systems: dependency on existing infrastructure, absence of end-to-end encryption compatible with LPWAN payload constraints, and absence of graceful degradation according to available infrastructure.

REFERENCES

[1] K. Manivannan, P. A. Mary, R. F. Jino, P. Dineshkumar, M. S. Harivisva, and P. Harikrishnan, "Machine learning driven routing optimization for named data networking in mobile adhoc network," in Proc. IEEE CSITSS, Bengaluru, India, 2024, pp. 1–6.

[2] A. Carreras-Coch, J. Navarro, C. Sans, and A. Zaballos,"Emergency communication system based on wireless LPWAN and SD-WAN technologies: A hybrid approach,"
Disaster, vol. 4, no. 2, p. 17, MDPI, 2023.

[3] W. Alawad, N. B. Halima, and L. Aziz, "An unmanned aerial vehicle (UAV) system for disaster and crisis management in smart cities," Electronics, vol. 12, no. 4, p. 1051, 2023.

[4] "A systematic literature review of emergency communications assisted by unmanned aerial vehicles," Ad Hoc Networks, 2025. doi: 10.1016/j.adhoc.2025.103xxx.

[5] S. H. Alsamhi et al., "UAV computing-assisted search and rescue mission framework for disaster and harsh environment mitigation," Drones, vol. 6, no. 7, p. 154, 2022.

[6] N. Papyan, M. Kulhandjian, H. Kulhandjian, and L. Aslanyan, "AI-based drone assisted human rescue in disaster environments: Challenges and opportunities," arXiv:2406.15875, 2024.

[7] S. Agrawal, D. Gupta, V. Sudan, P. Goel, and V. Nijhawan, "A LoRa based emergency communication device for disaster response," in Proc. IEEE DELCON, New Delhi, India, 2024, pp. 1–5.

[8] T. Ameloot, P. Van Torre, and H. Rogier, "LoRa-based mesh network for off-grid emergency communications," in Proc. IEEE INDIN, Palma de Mallorca, Spain, 2021, pp. 1–6.

[9] S. Abdulmalek et al., "IoT-based healthcare-monitoring system towards improving quality of life: A review," Healthcare, vol. 10, no. 10, p. 1993, 2022.

[10] K. Manivannan, P. A. Mary, R. F. Jino, P. Dineshkumar, M. S. Harivisva, and P. Harikrishnan, "Machine learning driven routing optimization for named data networking in mobile adhoc network," in Proc. IEEE CSITSS, Bengaluru, India, 2024, pp. 1–6.

[11] A. Carreras-Coch, J. Navarro, C. Sans, and A. Zaballos, "Emergency communication system based on wireless LPWAN and SD-WAN technologies: A hybrid approach,"
Disaster, vol. 4, no. 2, p. 17, MDPI, 2023.

[12] W. Alawad, N. B. Halima, and L. Aziz, "An unmanned aerial vehicle (UAV) system for disaster and crisis management in smart cities," Electronics, vol. 12, no. 4, p. 1051, 2023.

[13] "A systematic literature review of emergency communications assisted by unmanned aerial vehicles," Ad Hoc Networks, 2025. doi: 10.1016/j.adhoc.2025.103xxx.

[14] S. H. Alsamhi et al., "UAV computing-assisted search and rescue mission framework for disaster and harsh environment mitigation," Drones, vol. 6, no. 7, p. 154, 2022.

[15] N. Papyan, M. Kulhandjian, H. Kulhandjian, and L. Aslanyan, "AI-based drone assisted human rescue in disaster environments: Challenges and opportunities," arXiv:2406.15875, 2024.

[16] S. Agrawal, D. Gupta, V. Sudan, P. Goel, and V. Nijhawan, "A LoRa based emergency communication device for disaster response," in Proc. IEEE DELCON, New Delhi, India, 2024, pp. 1–5.

[17] T. Ameloot, P. Van Torre, and H. Rogier, "LoRa-based mesh network for off-grid emergency communications," in Proc. IEEE INDIN, Palma de Mallorca, Spain, 2021, pp. 1–6.

[18] S. Abdulmalek et al., "IoT-based healthcare-monitoring system towards improving quality of life: A review," Healthcare, vol. 10, no. 10, p. 1993, 2022.

[19] K. Manivannan, P. A. Mary, R. F. Jino, P. Dineshkumar, M. S. Harivisva, and P. Harikrishnan, "Machine learning driven routing optimization for named data networking in mobile adhoc network," in Proc. IEEE CSITSS, Bengaluru, India, 2024, pp. 1–6.

[20] A. Carreras-Coch, J. Navarro, C. Sans, and A. Zaballos, "Emergency communication system based on wireless LPWAN and SD-WAN technologies: A hybrid approach,"
Disaster, vol. 4, no. 2, p. 17, MDPI, 2023.

[21] W. Alawad, N. B. Halima, and L. Aziz, "An unmanned aerial vehicle (UAV) system for disaster and crisis management in smart cities," Electronics, vol. 12, no. 4, p. 1051, 2023.

[22] "A systematic literature review of emergency communications assisted by unmanned aerial vehicles," Ad Hoc Networks, 2025. doi: 10.1016/j.adhoc.2025.103xxx.

[23] S. H. Alsamhi et al., "UAV computing-assisted search and rescue mission framework for disaster and harsh environment mitigation," Drones, vol. 6, no. 7, p. 154, 2022.6

[24] N. Papyan, M. Kulhandjian, H. Kulhandjian, and L. Aslanyan, "AI-based drone assisted human rescue in disaster environments: Challenges and opportunities," arXiv:2406.15875, 2024.

[25] S. Agrawal, D. Gupta, V. Sudan, P. Goel, and V. Nijhawan, "A LoRa based emergency communication device for disaster response," in Proc. IEEE DELCON, New Delhi, India, 2024, pp. 1–5.

[26] T. Ameloot, P. Van Torre, and H. Rogier, "LoRa-based mesh network for off-grid emergency communications,"

in Proc. IEEE INDIN, Palma de Mallorca, Spain, 2021, pp. 1–6.

[27] S. Abdulmalek et al., "IoT-based healthcare-monitoring system towards improving quality of life: A review," Healthcare, vol. 10, no. 10, p. 1993, 2022.

[28] K. Manivannan, P. A. Mary, R. F. Jino, P. Dineshkumar, M. S. Harivisva, and P. Harikrishnan, "Machine learning driven routing optimization for named data networking in mobile adhoc network," in Proc. IEEE CSITSS, Bengaluru, India, 2024, pp. 1–6.

[29] A. Carreras-Coch, J. Navarro, C. Sans, and A. Zaballos, "Emergency communication system based on wireless LPWAN and SD-WAN technologies: A hybrid approach,"
Disaster, vol. 4, no. 2, p. 17, MDPI, 2023.

[30] W. Alawad, N. B. Halima, and L. Aziz, "An unmanned aerial vehicle (UAV) system for disaster and crisis management in smart cities," Electronics, vol. 12, no. 4, p. 1051, 2023.