

A Survey on LoRa-Based Multi-Hop Communication Systems for Vehicular Accident Detection and Emergency Response

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Abstract—Road traffic accidents continue to be a major public safety concern, where the chances of survival depend heavily on how quickly emergency services are notified and deployed. Existing accident alert systems that rely on GSM or LTE connectivity often fail in remote and highway environments due to weak or inconsistent network coverage, leading to delayed rescue response. LoRa, a low-power wide-area communication technology, has emerged as a strong alternative due to its long-range, low-energy transmission capabilities that operate independently of cellular infrastructure. Current LoRa-based accident detection systems typically combine accelerometer-based impact sensing with GPS localization to generate emergency alerts; however, most implementations depend on single-hop transmission, resulting in limited communication range and reduced reliability in sparse vehicular environments. Recent studies have explored multi-hop LoRa communication, where vehicles or roadside modules relay messages over multiple nodes to extend network reach and improve alert delivery. While these approaches offer improved scalability and robustness, challenges remain in routing optimization, mobility handling, packet collision reduction, and temporal synchronization. This paper reviews existing single-hop and multi-hop LoRa-based vehicular accident alert architectures, evaluates their strengths and limitations, and outlines future research directions toward adaptive routing, hybrid LoRa-cloud coordination, and resilient communication frameworks for real-world intelligent transportation systems.

Index Terms—LoRa, Multi-hop Communication, Vehicular Accident Detection, Emergency Response Systems, Intelligent Transportation Systems, IoT, Wireless Sensor Networks, LP-WAN, Real-Time Communication.

I. INTRODUCTION

Road accidents remain one of the most critical global public safety concerns, contributing to a significant number of injuries and fatalities each year. The severity of post-accident outcomes largely depends on how quickly the incident is detected and emergency assistance is dispatched. Conventional accident alert systems rely on GSM, 3G/4G, or satellite-based communication networks, and therefore depend on stable connectivity. In rural and highway environments, where network coverage is weak or intermittent, such systems may fail to transmit alerts promptly, leading to life-threatening delays in emergency response [1], [2].

LoRa (Long Range) radio communication has gained considerable attention as an alternative due to its long-range transmission capability, low power consumption, and independence from cellular infrastructure [3]. Existing LoRa-based accident alerting platforms typically combine accelerometer-based impact detection, microcontroller-based event processing, and GPS-based localization to generate and transmit emergency notifications [1], [3]. However, many of these systems adopt single-hop LoRa communication, which limits the effective coverage area to the direct transmission radius of a single node. This limitation reduces message reliability in highway and remote environments where receivers or gateways may not be present [4].

To overcome this constraint, researchers have proposed multi-hop LoRa forwarding strategies, in which vehicles or roadside units act as relay nodes to propagate alerts across extended distances [8]. This cooperative communication enhances delivery reliability and enables alert propagation even in the absence of gateway coverage or Internet connectivity [9], [10]. Multi-hop LoRa networking is therefore especially relevant in intelligent transportation environments characterized by high mobility and decentralized topologies [8].

Despite these advancements, several challenges remain. These include packet collisions caused by competing transmissions, routing instability in highly mobile networks, synchronization overhead, and reduced forwarding reliability when relay density is low [9], [10]. Additionally, LoRa-based localization using Received Signal Strength Indicator (RSSI) remains insufficiently accurate for real-time vehicular emergency routing, making GPS the primary method for reliable positioning [5].

Therefore, the key research problem addressed in this survey is how multi-hop LoRa-based vehicular communication architectures can be designed to provide reliable, scalable, and infrastructure-independent accident alert dissemination in low-connectivity roadway environments.

Motivated by this problem, this survey reviews LoRa-based accident detection and emergency communication systems, emphasizes architectural design factors, and evaluates multi-hop forwarding approaches in vehicular networks. The review

highlights the limitations of single-hop and infrastructure-dependent systems, examines emerging decentralized routing strategies, and identifies future research directions involving hybrid LoRa–GSM architectures, adaptive multi-hop coordination, and intelligent vehicular communication models for enhanced real-time emergency response.

II. RELATED WORK

A. Overview of LoRa for Emergency Communication

LoRa has emerged as a low-power, long-range wireless communication technology suitable for environments with limited network infrastructure. Studies demonstrate that LoRa maintains signal reachability in rural and non-urban terrains while consuming significantly less power than GSM/LTE-based systems [1] [2]. These characteristics make LoRa suitable for emergency alert dissemination where continuous connectivity cannot be guaranteed [3] [4]. However, LoRa performance is closely influenced by environmental conditions, antenna orientation, and transmission distance, which affects reliability in moving vehicular networks [3].

B. LoRa-Based Accident Detection and Rescue Systems

Early accident-response systems integrated accelerometers for collision detection and GPS modules for location reporting. In [1], vehicle impact data is transmitted through LoRa directly to responders, reducing delays where cellular signals are weak. Similarly, [2] identifies the nearest medical center and communicates accident coordinates automatically. Outdoor emergency support for mountaineering in [3] verifies LoRa's ability to function in remote and high-altitude regions. However, these systems utilize single-hop LoRa, limiting communication to the immediate radio range of the sender. Consequently, such designs fail in highway environments where vehicles may be spaced far apart and no fixed receivers exist [1] [2].

C. Infrastructure-Dependent LoRaWAN and Smart IoT Safety Frameworks

To extend range, some systems rely on LoRaWAN gateways or cloud platforms. Vehicle tracking systems in [4] [5] support remote monitoring, but require pre-installed gateways, making them deployable mainly in urban regions. The emergency traffic clearance approach in [6] enables corridor creation for ambulances, but its operation depends entirely on LoRaWAN backhaul. Intelligent monitoring systems incorporating ML-based CCTV analytics or drone feedback [7] improve situational awareness, but require dense sensor deployment and stable network connectivity, making them unsuitable for rural highways.

D. Multi-Hop and Decentralized LoRa Communication Approaches

To remove dependence on gateways, multi-hop LoRa forwarding has been explored. The disaster response system in [8] enables node-to-node relaying to maintain communication when infrastructure is unavailable. A broader smart emergency framework in [9] shows that LoRa can support multi-domain

alerts. The dynamic multi-hop LoRa protocol introduced in [10] improves delivery reliability under node mobility.

However, vehicular environments introduce challenges that these works do not fully resolve, including:

High mobility, which changes network topology rapidly and breaks relay chains [10]

Low relay density, especially on highways, causing forwarding paths to collapse [8]

Packet collisions, due to simultaneous broadcast-based forwarding [9]

Unpredictable hop latency, leading to unreliable end-to-end delivery in real-time alerts [9] [10]

Thus, while multi-hop LoRa increases communication range, its reliability remains inconsistent under vehicular mobility and sparse deployment conditions.

E. Summary and Research Gap

Existing research demonstrates the suitability of LoRa for emergency communication; however, key issues remain:

- **Single-hop LoRa systems** fail to cover highway-scale distances due to limited link range [1] [2].
- **LoRaWAN-based solutions** depend on gateway availability, which is often absent in rural regions [4] [6].
- **Urban monitoring frameworks** rely on dense infrastructure and are impractical for remote deployment [7].
- **LoRa RSSI localization** lacks accuracy for fast-moving vehicular networks [5].
- **Existing multi-hop LoRa approaches** [8] [9], though promising, still face critical challenges: (i) rapid topology changes due to vehicle mobility, (ii) unreliable relay availability in low-density regions, and (iii) packet collision and delay accumulation over multiple hops.

Therefore, a key unresolved problem is the development of a reliable, scalable, and mobility-aware multi-hop LoRa communication framework that can operate effectively in highway and low-connectivity environments without relying on fixed infrastructure.

III. SYSTEM BACKGROUND

Vehicular accident detection and emergency alerting systems rely on two primary capabilities: (i) accurate sensing of collision or rollover events, and (ii) reliable communication of emergency alerts under varying network coverage conditions. Conventional GSM- and LTE-based telematics depend heavily on stable cellular connectivity, which is often inconsistent across highways, tunnels, and rural regions, leading to delayed rescue response [1], [2]. To address these connectivity constraints, LoRa (Long Range) has been examined for its low-power, long-distance communication characteristics and resilience in low-signal environments [3], [4].

A. LoRa Communication Model

LoRa networks operate either as peer-to-peer (P2P) links or within the LoRaWAN framework. While LoRaWAN enables large-scale network coordination, it depends on gateway availability, which is typically limited in distributed roadway

TABLE I
REPORTED THRESHOLD PARAMETERS IN VEHICULAR ACCIDENT DETECTION SYSTEMS

Parameter	Typical Threshold Range	Interpretation / Notes (Source)
Impact Acceleration (3-axis accelerometer)	3g–5g sustained peak	Indicates high-force collision event [1], [2].
Instantaneous Deceleration (GPS speed change)	Drop > 40 km/h within 1–2 s	Suggests sudden crash or severe abrupt stop [2], [4].
Rollover Tilt / Rotation (IMU)	Tilt > 45° or unstable orientation	Indicates vehicle overturning [1], [3].
Cabin Temperature / Flame Detection	Temperature rise > 60°C or flame trigger	Identifies post-impact fire hazard [3], [9].
Driver Response Timeout	No manual override within 10–20 s	Confirms emergency → triggers automatic alert [1], [2].
LoRa Multi-Hop Relay Depth	3–7 hops	Balances message reach vs. delay and collision probability [10].

environments [6]. Peer-to-peer LoRa communication supports direct messaging between nodes without fixed infrastructure [1]. To extend coverage beyond single-hop limitations, recent work adopts multi-hop relay forwarding, where intermediate nodes retransmit packets to reach distant receivers [8], [10].

B. Hybrid LoRa–Cellular Communication

Hybrid models use GSM/LTE when available and fall back to LoRa when cellular coverage is weak [3], [8]. Mobility-aware multi-hop LoRa routing further improves alert delivery under vehicular movement and intermittent connectivity [10].

C. Localization Mechanisms: GPS and RSSI

GPS provides primary location data during crash events [1], [2]. When GPS signals degrade in obstructed regions, coarse RSSI-based LoRa positioning serves as a fallback, though its accuracy decreases under high mobility [5].

D. Accelerometer-Based Collision Detection

A 3-axis accelerometer detects impact spikes or rollover patterns [1], [2]. Many systems cross-check acceleration data with GPS-derived speed change to filter false positives caused by braking or road irregularities [4].

E. Reported Threshold Parameters

Table I lists representative threshold values (impact, deceleration, tilt, temperature, relay depth) reported in vehicular accident-detection literature.

Summary: The communication models, sensing mechanisms, and threshold logic reviewed here establish the foundational principles required to evaluate single-hop and multi-hop LoRa emergency alert architectures in the following sections.

IV. SYSTEM ARCHITECTURE AND WORKING CONCEPT

This section provides a brief overview of earlier *single-hop* LoRa accident-alert systems and introduces the motivation for a hybrid multi-hop LoRa–GSM design.

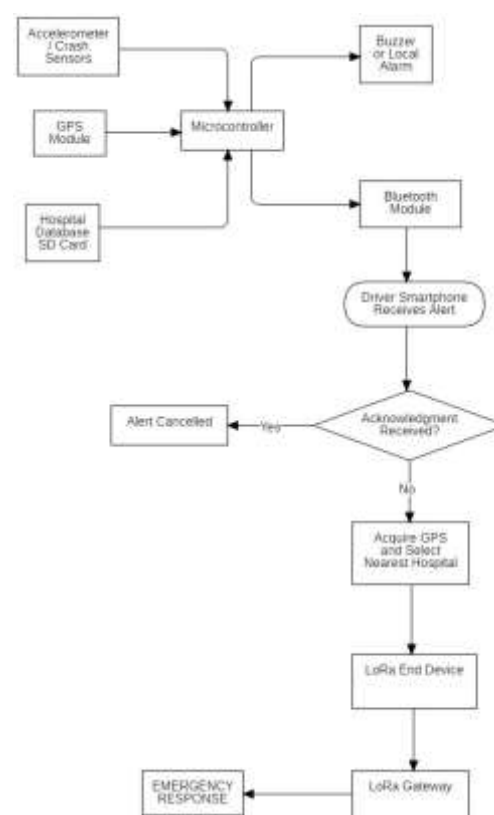


Fig. 1. Conceptual representation of a single-hop LoRa-based accident alert workflow, designed based on the approach presented in [2].

A. Existing LoRa-Based Accident Rescue Architecture

Early accident-alert systems used an onboard accelerometer to detect collision events and transmitted GPS coordinates to a monitoring unit through a *single LoRa hop* when GSM connectivity was unavailable [2]. Typical nodes combined a crash sensor, GPS receiver, microcontroller, LoRa transceiver, and a driver-acknowledgment interface to suppress false alarms [1]. As illustrated in Fig. 1, LoRa enables long-range, low-power communication in remote areas with minimal infrastructure [1], [4]. However, these designs succeeded only when a LoRa gateway or receiver was within direct radio range—an assumption that often failed on highways and low-density regions, resulting in missed alerts [2], [4]. This limitation established the need for multi-hop, relay-capable architectures.

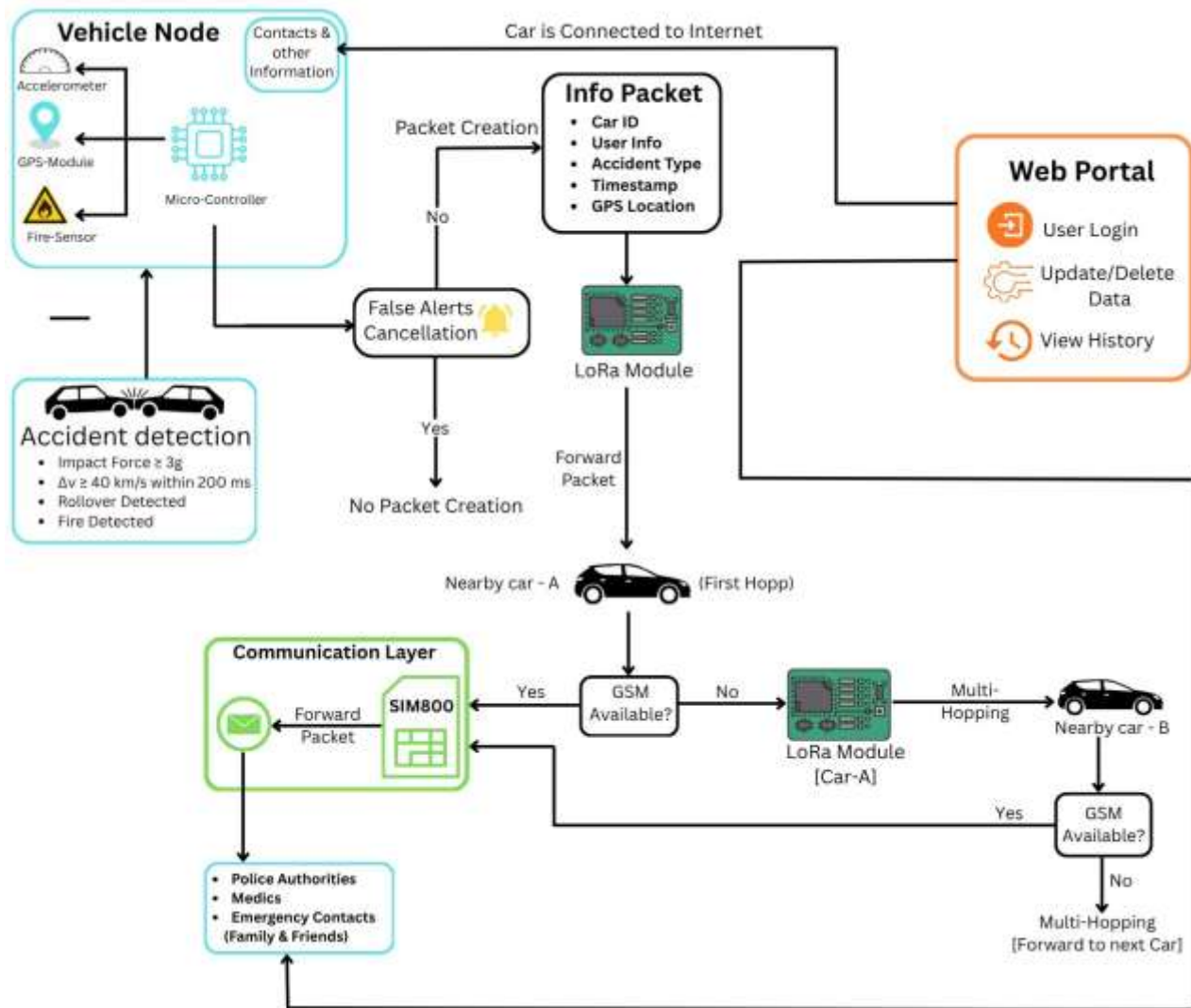


Fig. 2. Proposed hybrid multi-hop LoRa-GSM vehicular accident detection and emergency alerting architecture.

B. Proposed Hybrid LoRa-GSM Multi-Hop Architecture

The proposed architecture extends conventional accident-alert systems by combining on-vehicle sensing, context-aware packet creation, LoRa-based multi-hop relaying, and GSM/cloud delivery into a unified workflow. The complete system structure is illustrated in Fig. 2 and is placed at the top of the following page in accordance with IEEE float placement rules.

1) On-board sensing and event evaluation: Each vehicle node integrates an accelerometer, GPS module, flame/temperature sensor, and microcontroller. The accelerometer monitors impact force (e.g., $\geq 3g$), sudden velocity drop (e.g., $\Delta v > 40$ km/h), rollover conditions, and fire indicators. When a threshold is exceeded, the microcontroller validates the readings and raises an accident-detection flag. A false-alert cancellation interface enables the driver to dismiss non-critical

events.

2) Packet creation and metadata encapsulation: If the alert is not canceled, the system generates an information packet containing vehicle ID, user profile, accident type, GPS location, timestamp, and severity metadata [1], [3].

3) Adaptive routing using GSM and LoRa: Routing depends on connectivity:

- GSM available:** The packet is forwarded through the SIM800 module to cloud servers.
- GSM unavailable:** The packet is relayed through LoRa using a store-and-forward mechanism until a GSM-connected relay uploads the message [8], [10].

4) Cloud synchronization and portal access: Once received by the cloud server, the alert is logged and notifications are issued. The web portal supports incident visualization, record management, emergency contact handling, and access

to historical logs. Buffered packets are synchronized automatically when connectivity resumes [5].

C. Advantages of the Proposed Architecture

- **Extended communication reach:** Multi-hop LoRa enables coverage across remote segments without infrastructure.
- **Robust delivery under variable connectivity:** Opportunistic GSM ensures reliable cloud arrival.
- **Scalable behavior:** Vehicles form a natural, dynamic relay backbone.
- **Energy-efficient design:** LoRa supports ultra-low-power continuous operation.

The hybrid LoRa–GSM design therefore overcomes the geographic limitations of single-hop LoRa systems and the coverage dependency of GSM-only solutions.

V. KEY CHARACTERISTICS OF LoRa-BASED ACCIDENT RESPONSE SYSTEMS

LoRa is widely used in accident-response research due to its long-range operation, low energy cost, and ability to function without cellular infrastructure. Prior studies highlight the following core characteristics.

A. Low Power Consumption

LoRa transceivers operate at very low energy levels and can remain active for long durations, making them suitable for battery-driven vehicular safety units [1], [3]. Compared to GSM, LoRa significantly reduces transmission power requirements.

B. Long-Range Communication

Experimental deployments show that LoRa can operate across several kilometers in rural or open-road environments [1], [4]. This extended range is useful for accident alerts in areas where GSM coverage is weak or absent [2].

C. Independence from Cellular Infrastructure

LoRa peer-to-peer links do not rely on towers or gateways, allowing systems to function during GSM outages or in remote regions such as highways, tunnels, and hilly terrain [2], [3].

D. Cost-Effectiveness and Simple Integration

Low-cost LoRa modules (e.g., SX1278) and straightforward microcontroller interfaces make LoRa designs economically viable for large-scale deployment [2]. This simplicity reduces installation and maintenance overhead.

E. Suitability for Remote and Rural Areas

Studies confirm LoRa's stable performance in low-infrastructure areas, enabling reliable transmission where GSM systems often fail [3], [4]. This is particularly beneficial for long highway and freight routes [2].

F. Support for Multi-Hop Extensions

Although basic LoRa systems are single-hop, recent research demonstrates that multi-hop forwarding can expand communication coverage and maintain alert propagation in sparse networks [8]–[10].

G. Reliability Under Connectivity Variations

LoRa provides stable communication under variable channel conditions and is commonly used as a fallback when GSM connectivity becomes unreliable [3], [8]. Hybrid LoRa–GSM systems further improve end-to-end reliability [10].

VI. COMPARATIVE ANALYSIS

Existing accident-alert systems differ significantly in their sensing accuracy, communication strategy, and deployment feasibility. Early designs depend on single-hop LoRa combined with GPS localization [1], [2], offering long-range, low-power communication but failing whenever no receiver or gateway lies within direct transmission range. Studies show that this limitation becomes critical on highways and low-density corridors where vehicle spacing is large and gateway availability is unpredictable [2], [4]. Systems using LoRaWAN gateways or cellular networks further encounter performance bottlenecks in areas with sparse infrastructure or network congestion [6].

A second line of research improves accident detection through IMU-based impact analysis, tilt estimation, RSSI-assisted fallback localization, or machine-learning-based event classification [3], [5]. While these methods strengthen sensing accuracy, they still rely on single-path communication, making them vulnerable to connectivity loss. In practical deployments, sensing reliability alone cannot ensure timely emergency reporting unless supported by a robust communication pathway capable of bridging disconnected regions.

More resilient approaches explore multi-hop LoRa forwarding and distributed coordination for emergency situations [8], [10]. These studies demonstrate that cooperative relaying can extend LoRa coverage far beyond single-hop limits; however, most are evaluated in static or semi-static networks rather than vehicular environments, and they lack a GSM/cloud fallback mechanism. As a result, alert delivery still fails if no connected node or gateway is encountered during propagation.

These observations collectively show that neither LoRa-only nor GSM-only systems provide uninterrupted coverage. LoRa suffers during gateway absence, while GSM collapses during coverage drops. This motivates a combined architecture that integrates peer-to-peer multi-hop LoRa relaying with opportunistic GSM/cloud transmission, ensuring end-to-end packet delivery under varying real-world conditions. The following table (Table II) provides a structured, paper-wise comparison summarizing the key methods, contributions, limitations, and their relevance to the proposed hybrid LoRa–GSM framework.

Table II presents a consolidated comparison of all reviewed systems, summarizing key methods, contributions, limitations, and the relevance of each work to the hybrid multi-hop LoRa–GSM framework developed in this study.

TABLE II
COMPARATIVE ANALYSIS OF EXISTING ACCIDENT DETECTION AND EMERGENCY ALERTING SYSTEMS

Ref. No.	Topic / Method Used	Key Contributions	Limitations	Relevance to Proposed Hybrid System
[1]	LoRa-based accident alert system with GPS and ambulance routing	Demonstrates long-range LoRa alerts; supports hospital/ambulance notification	Single-hop only; no GSM fallback; unreliable in long highway segments	Shows LoRa feasibility; motivates need for multi-hop and redundancy
[2]	LoRa GPS accident-rescue design with Bluetooth driver acknowledgement	Driver confirmation model; nearest-hospital identification; LoRa coordinate transfer	Requires LoRa gateway; no cooperative relaying; Bluetooth adds dependency	Baseline "existing system" reference for comparison
[3]	LoRa-based mountaineering safety and IMU emergency alerts	Validates LoRa reliability in isolated zones; IMU-based detection	Not vehicular; no multi-hop; no GSM hybrid	Shows LoRa usefulness in low-coverage situations
[4]	LoRa-based vehicular tracking approach	Long-range tracking; low-power vehicle communication	No accident detection; no emergency workflow	Supports LoRa as communication layer in vehicle networks
[5]	RSSI-based LoRa localization for GPS-limited conditions	Provides backup localization when GPS fails	Low accuracy in moving vehicles; lacks alert workflow	Useful as auxiliary support for fallback positioning
[6]	LoRaWAN-based emergency vehicle signal clearance	Automates traffic signal priority using LoRaWAN gateways	Requires gateway infrastructure; not suitable for rural regions	Highlights need for gateway-independent peer-to-peer LoRa
[7]	Drone + ML accident detection with LoRa communication	Combines aerial sensing and ML for accident detection	High deployment cost; unsuitable for real-time ground reporting	Supports need for low-cost, ground-based embedded nodes
[8]	Multi-node LoRa coordination for disaster response	Shows cooperative multi-node message routing	Not designed for vehicular mobility; no GSM hybridization	Supports core idea of LoRa multi-hop relaying
[9]	IoT emergency response using cloud/mobile alerts	Cloud-based event reporting and notifications	Limited to WiFi/cellular; no long-range LoRa backup	Motivates LoRa fallback when GSM fails
[10]	Real-time multi-hop LoRa MAC for dynamic networks	Improves multi-hop reliability; reduces collisions	Protocol-only; no accident detection or GSM integration	Direct foundation for multi-hop routing in proposed design

VII. PROPOSED SYSTEM FRAMEWORK

This section presents the complete working model of the proposed vehicular accident-detection and emergency-alerting system. The framework integrates on-board sensing, threshold-based accident evaluation, user verification, LoRa-based multi-hop forwarding, GSM-assisted cloud uploading, and web-portal synchronisation. The overall process flow is illustrated in Fig. 3, and each stage of the workflow is described below.

A. Continuous Monitoring

The vehicle node continuously records sensor data required for detecting abnormal vehicular behaviour. This includes:

- 3-axis accelerometer readings,
- gyroscope angular velocity and tilt measurement,
- GPS speed and location,
- flame/temperature sensor readings,
- stored user and vehicle metadata.

This continuous monitoring ensures real-time awareness of vehicle behaviour under varying road and connectivity conditions [1], [3], [4].

B. Accident Detection Using Formula-Based Conditions

An accident is declared when **any** of the following mathematically defined conditions is satisfied. These thresholds reflect patterns commonly used in vehicular safety research and align with the sensing requirements of the proposed system [2], [4].

1) Sudden Velocity-Drop Condition:

$$\Delta V = |V_{t_0} - V_{t_0 + \Delta t}| \quad (1)$$

This represents the absolute drop in vehicle speed over a short time interval. A high value of ΔV indicates a sudden loss of speed commonly associated with collision events.

$$\Delta V \geq 40 \text{ km/h within } \Delta t = 200 \text{ ms} \quad (2)$$

This threshold identifies rapid deceleration patterns that cannot occur during normal braking.

$$a = \frac{\Delta V}{\Delta t} \geq 55.55 \text{ m/s}^2 \quad (3)$$

This computes the resulting deceleration. A value of 55.55 m/s^2 corresponds to extremely forceful impact conditions [2], [4].

2) Impact Force Threshold:

$$a_{\text{impact}} \geq 3g = 29.43 \text{ m/s}^2 \quad (4)$$

This condition captures high-magnitude acceleration spikes that typically occur during frontal or side collisions [1], [2].

3) Rollover Condition:

$$|\omega_{\text{roll}}| \geq 250^\circ/\text{s} \quad (5)$$

Angular velocity beyond this threshold indicates rapid rotational movement suggesting a roll event.

$$\vartheta_{\text{tilt}} \geq 60^\circ \quad (6)$$

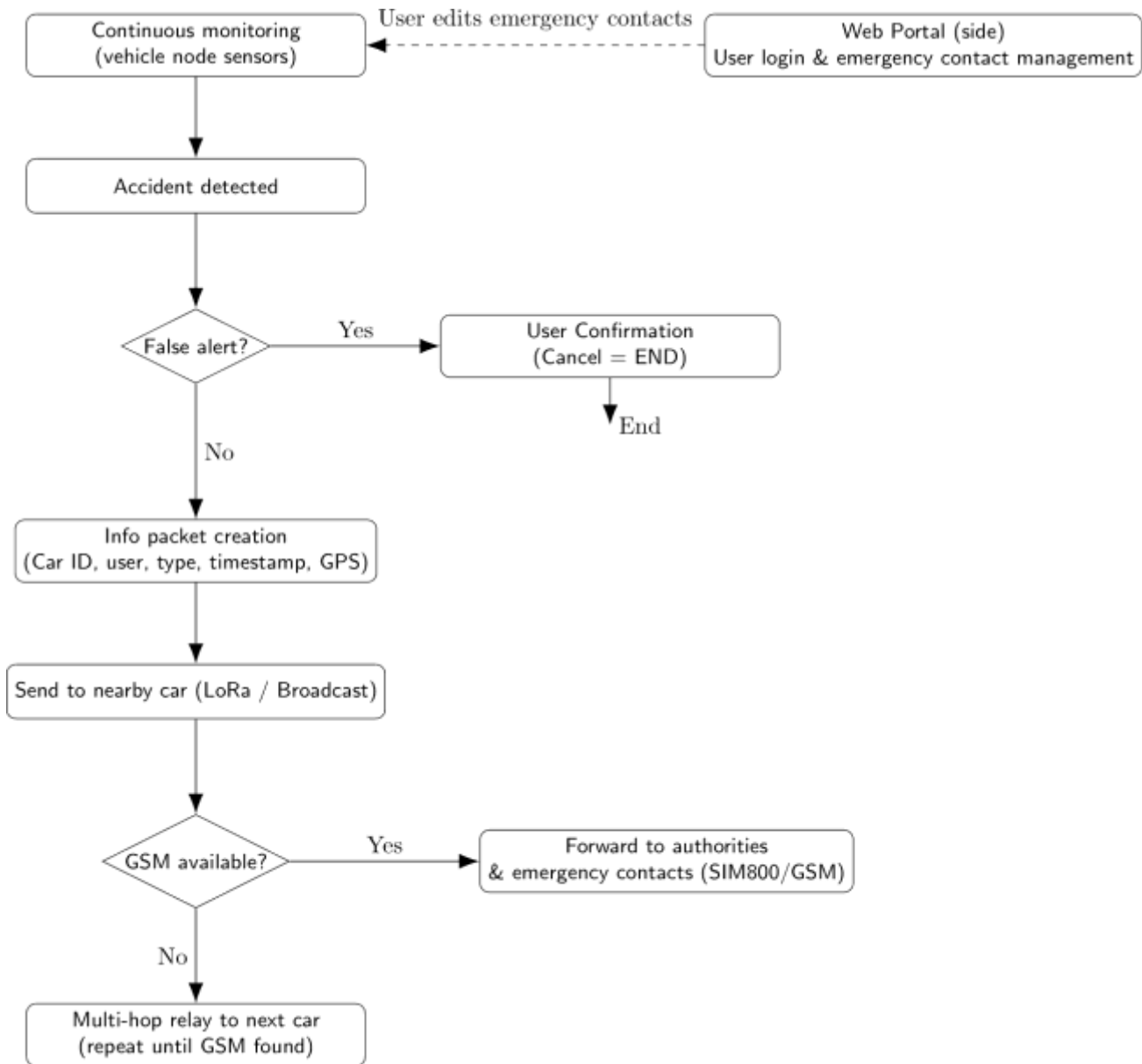


Fig. 3. Overall workflow of the proposed multi-hop LoRa-GSM accident-detection and emergency-alerting system.

A tilt angle above 60° confirms potential overturning of the vehicle [3], [4].

4) Fire Detection:

$$F_{\text{sensor}} = 1 \quad (7)$$

A binary flame-sensor output of 1 indicates the presence of fire.

$$I_{\text{flame}} \geq I_{\text{threshold}} \quad (8)$$

This intensity-based rule captures proportionate increases in fire or heat output [3].

Accident Trigger Rule:

$$\text{Accident} = \begin{cases} 1, & \text{if any of } C_1, C_2, C_3, C_4 \text{ is satisfied} \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

This final condition determines whether the event is classified as an accident based on sensor thresholds.

C. False-Alert Verification

Immediately after detection, the system prompts the driver with a cancellation option:

- If the driver confirms it is not an accident, the process terminates.
- If no response is received within a short timeout, the event is treated as valid.

This step prevents unnecessary emergency notifications and aligns with the decision stage shown in the workflow [2].

D. Information Packet Creation

After validation, the system generates a structured emergency packet containing:

- vehicle ID and user details,
- detected accident type,
- location (GPS),
- timestamp,
- severity indicators derived from sensor thresholds.

This packet forms the core message that travels across the LoRa–GSM communication chain [1], [3].

E. LoRa Transmission to Nearby Vehicles

If the originating vehicle lacks GSM connectivity, the alert packet is broadcast to nearby vehicles using LoRa peer-to-peer transmission. This ensures operability in remote or poorly connected highway segments [2], [4].

F. Connectivity Check and Multi-Hop Routing

Each receiving vehicle performs a connectivity check:

- **If GSM is available:** the relay uploads the alert via its SIM800 module to emergency contacts, hospitals, and authorities.
- **If GSM is not available:** the packet is forwarded via LoRa to the next nearest vehicle.

This store-and-forward behaviour repeats until a vehicle with GSM connectivity is reached, ensuring reliable end-to-end delivery even in sparse networks, consistent with multi-hop studies [8]–[10].

G. Cloud Uploading and Notification Delivery

Once GSM coverage becomes available at any relay node:

- the packet is uploaded to cloud servers,
- notifications are triggered for emergency contacts and medical responders,
- the data is logged in the system database.

This ensures that emergency alerts reach responders regardless of the initial vehicle's connectivity [9].

H. Web Portal Synchronisation

The web portal supports:

- user login,
- updating and managing emergency contacts,
- vehicle record modifications,
- viewing historical alerts.

These updates ensure that the emergency-information packet always contains the most recent data. The portal operates independently of the emergency-routing chain and does not affect multi-hop LoRa or GSM functionality [5].

and the requirement of a directly reachable receiver. Cellular-only methods also remain limited in regions with weak or inconsistent coverage.

Through comparative assessment, it became evident that no existing system provides continuous delivery under mobility, sparse connectivity, and infrastructure limitations. These gaps motivated the development of a hybrid multi-hop LoRa–GSM architecture that integrates threshold-based sensing, dynamic packet creation, peer-to-peer relaying, and opportunistic GSM/cloud transmission. The proposed workflow ensures that alerts propagate across vehicles until a connected node is reached, improving dependability in real-world deployment scenarios.

Overall, the findings indicate that combining LoRa's peer-to-peer resilience with GSM's wide-area reach enables a robust, scalable, and low-cost solution for vehicular emergency alerting. Such hybrid designs represent a practical direction for enhancing road-safety communication systems, especially in variable or low-connectivity environments.

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VIII. CONCLUSION

This survey reviewed existing accident detection and emergency alerting approaches across LoRa-based, cellular, and hybrid communication frameworks. The analysis showed that single-hop LoRa systems, despite their long-range and low-power benefits, fail to maintain reliability in highway and rural environments due to the absence of cooperative forwarding