

Hybrid IoT Enabled Accident Reporting with Cloud Communication and Failover for Emergency Response

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Publication Date: 2026/05/11

Abstract: This study presents a hybrid IoT enabled accident reporting system designed to improve the continuity and responsiveness of emergency communication in low coverage environments. The study addresses the weaknesses of conventional reporting methods and single network IoT architectures by combining sensing, communication, cloud, and application layers in one event driven framework. The system was implemented in Node RED with Firebase Realtime Database, FlowFuse Dashboard, and Node RED World Map. Accident events were generated periodically and routed through a primary cellular path with satellite failover when the primary path was unavailable. In the observed run, six alerts were generated and all were delivered, with five transmitted through the cellular path and one through satellite failover. The observed delivery success rate was one hundred percent, while the weighted average delay was one point six five seconds. The results show that the proposed hybrid architecture improves accident reporting reliability and provides a practical basis for resilient emergency monitoring systems.

Keywords: IoT; Accident Reporting; Failover Communication; Emergency Response; Cloud Monitoring; Node RED.

How to Cite: Princewill Odinaka Onyema; Fatima Umar Zambuk; Badamasi Imam Ya'u; Sabiratu Aliyu; Faith Ckukwu (2026) Hybrid IoT Enabled Accident Reporting with Cloud Communication and Failover for Emergency Response.

International Journal of Innovative Science and Research Technology, 11(4), 4025-4029.

<https://doi.org/10.38124/ijisrt/26apr262>

I. INTRODUCTION

Accident reporting remains a major challenge in emergency response because conventional methods are often slow, inaccurate, and dependent on manual notification. The study argues that delayed reporting, poor situational awareness, and unreliable communication in low coverage environments continue to worsen emergency outcomes [1], [2]. IoT based approaches improve this situation by enabling automatic sensing, location tracking, and immediate event transmission to responders [2], [3].

The problem becomes more critical in environments where a single communication channel can fail. Existing high-performance frameworks such as 5G based emergency response models offer low latency and intelligent processing, but they depend on infrastructure that is often unavailable in many developing and remote settings [1]. Related studies reviewed in the study also show that many IoT accident systems rely on only one network path and therefore remain vulnerable to data loss during connectivity failure [4]-[7].

To address this gap, the study proposes a hybrid accident reporting architecture that combines primary GPRS communication with satellite failover, cloud synchronization, and live visualization. The strongest publishable contribution of the study is therefore the integrated framework and its simulation-based evaluation of continuity, latency, and visualization behavior under failover conditions [1], [4], [5], [8].

II. RELATED WORK AND RESEARCH GAP

The study situates the work against several strands of prior research. Alkinani et al. proposed a 5G enabled IoT emergency response system with edge processing and vehicle to everything coordination, but the architecture depends on advanced 5G infrastructure and does not define a fallback communication mechanism [1]. Li et al. showed that integrated satellite terrestrial communication improves resilience during infrastructure failure, but their work focused on disaster scenarios rather than low power vehicle level accident reporting [5]. Tahemeen and Patil demonstrated the value of lightweight MQTT messaging for real time sensor communication, yet the evaluation was

limited to local Wi Fi networks and did not assess hybrid cellular satellite operation [8].

The review also notes that recent IoT accident reporting surveys repeatedly identify communication instability, latency, and absent failover logic as open problems [4], [6]. Zambuk et al. advanced satellite-based accident surveillance for Nigeria, but the study identifies that the architecture does not provide an explicit runtime failover mechanism for dependable message delivery in vehicle centric emergency reporting [7]. These gaps motivate a system that is simpler than 5G dependent frameworks, more resilient than GSM only solutions, and better aligned with coverage constrained environments [1], [4], [7].

III. METHODOLOGY

➤ Layered Architecture

The proposed system is organized into sensing, communication, cloud, and application layers. The sensing layer captures impact, motion, speed, and location data. The communication layer prioritizes a GPRS path and switches to satellite when the primary channel is unavailable. The cloud layer stores and processes structured accident data, while the application layer presents alerts through dashboard and map interfaces. Although MQTT is part of the conceptual architecture, the implementation abstracts MQTT behavior through internal Node RED routing while preserving the intended event driven communication logic [8].

➤ System Architecture

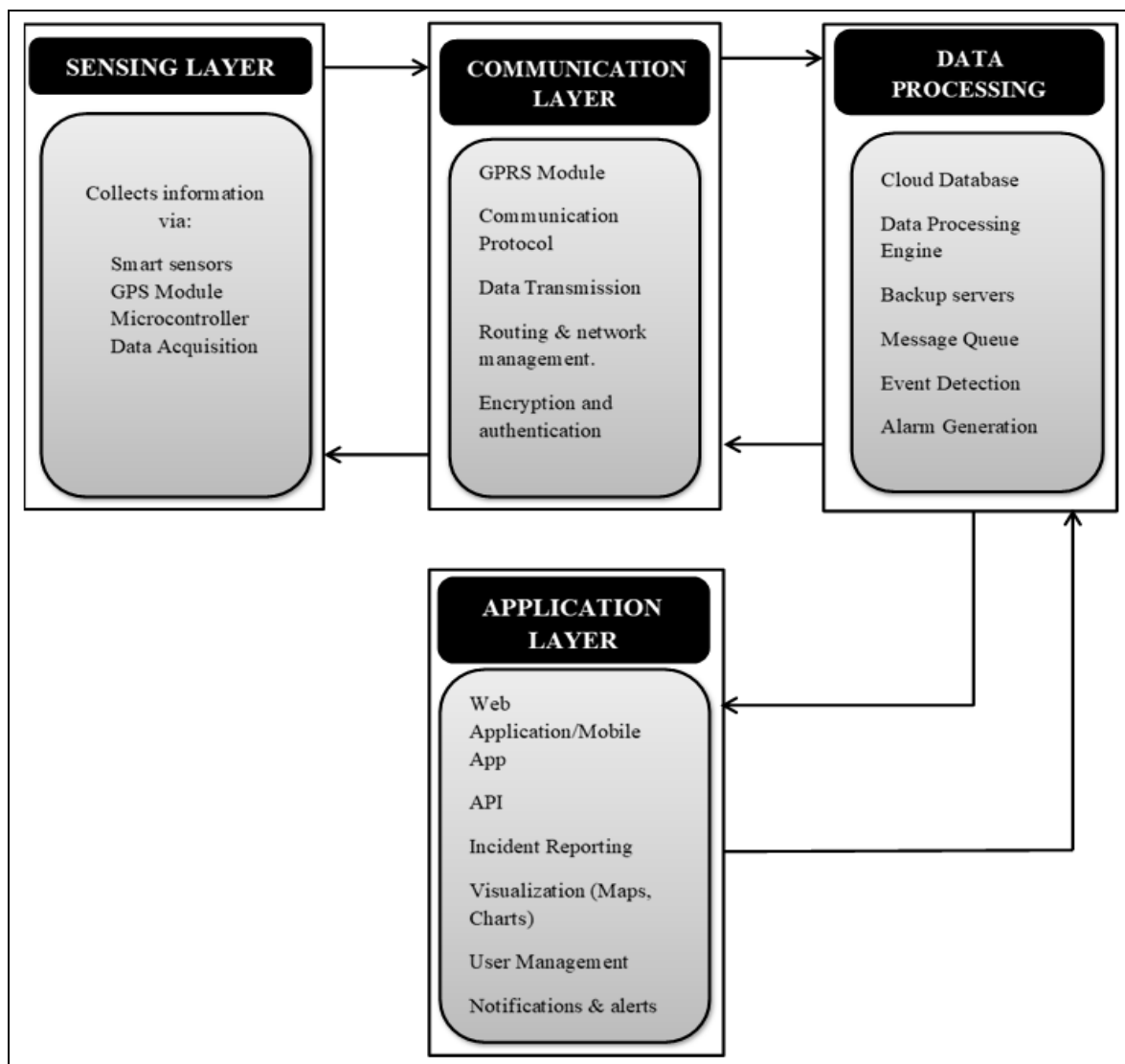


Fig 1 Proposed System Architecture Extracted from the Study

➤ Event Generation and Severity Logic

In the simulation, accident-related events were generated every thirty seconds. Vehicle speed ranged from zero to one hundred thirty nine kilometers per hour, crash probability was zero point three five, and generated locations

were distributed across more than fifty Nigerian coordinates with small random offsets. The severity of each event was classified using the rule set reported in the study and summarized in Table I [8].

Table 1 Severity Classification Parameters

Severity class	Condition
Critical	$v > 80 \text{ km/h}$ and $I > 4 \text{ G}$
Serious	$v > 60 \text{ km/h}$ or $I > 3 \text{ G}$
Minor	Otherwise

➤ *Communication and Failover Model*

The communication layer uses probabilistic network availability to simulate failover. Cellular availability is modeled at zero point seven five, satellite failover at zero point two five, and a five second delay is added on the satellite path. The implementation writes accident records to Firebase using HTTP POST and periodically refreshes cloud state through HTTP GET. This design supports analysis of

continuity, routing behavior, and alert timing under degraded primary network conditions [8].

$$T_s = T_c + 5 \tag{1}$$

Where T_s is the average satellite path delay and T_c is the average cellular path delay [8].

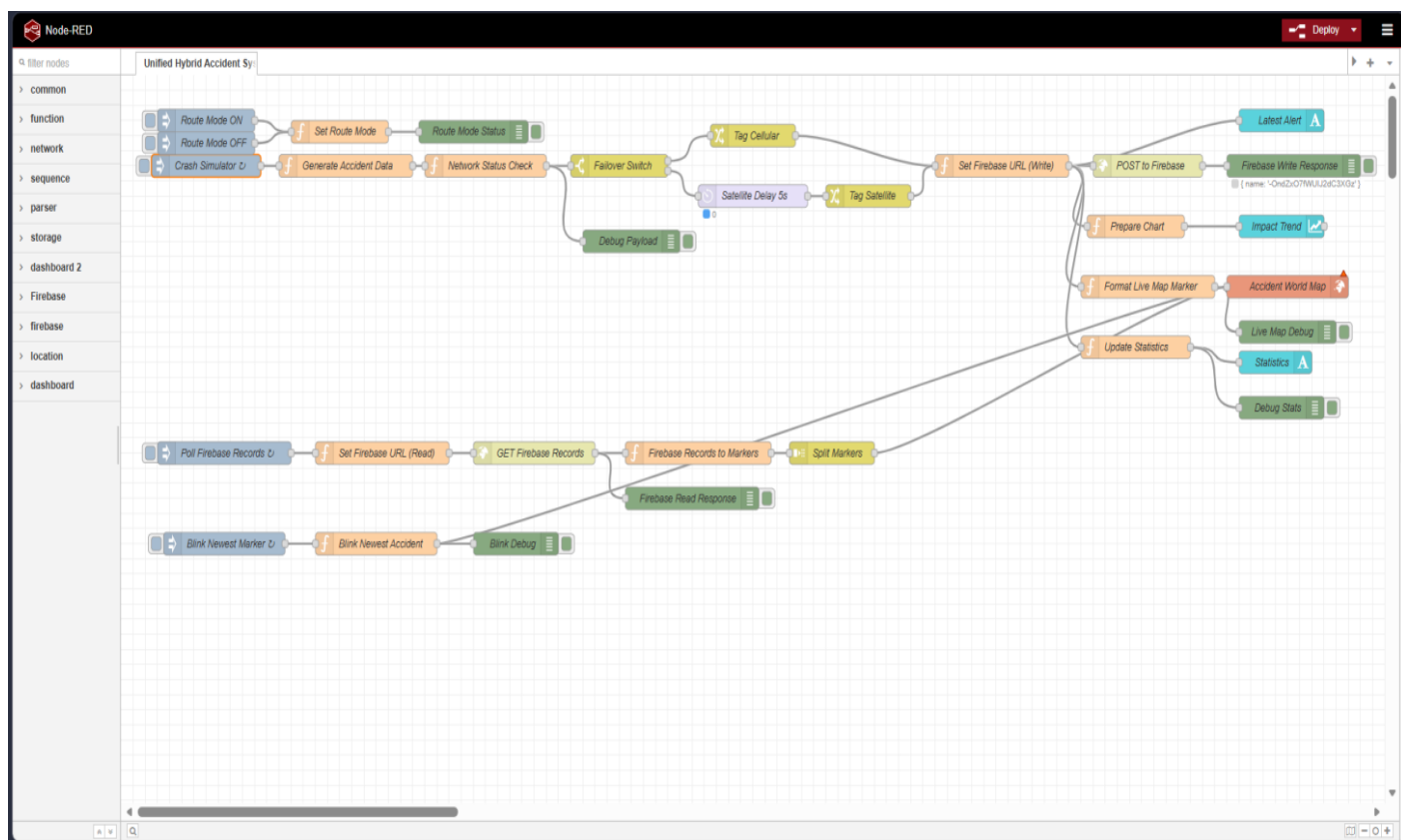


Fig 2 Node RED Unified Implementation Flow for Hybrid Accident Reporting

IV. IMPLEMENTATION AND RESULTS

➤ *Implementation Environment*

The simulated prototype was implemented with Node RED for flow programming, Firebase Realtime Database for

cloud storage, FlowFuse Dashboard for live monitoring, and Node RED World Map for geospatial visualization. This tool chain allowed event generation, communication control, cloud synchronization, dashboard updates, and map rendering to be evaluated in one workflow [8].

Table 2 System Implementation Environment

Component	Tool Platform	Purpose
Flow programming environment	Node RED	Simulation logic, message routing, failover switching, HTTP based cloud synchronization
Cloud database	Firebase Realtime Database	Real time storage and retrieval of accident records
Monitoring interface	FlowFuse Dashboard	Text and chart based live incident monitoring
Map visualization	Node RED World Map	Display of accident markers and pop up details across locations
Cloud communication method	REST API HTTP GET POST	Writing and reading accident records from Firebase
Runtime environment	Node js and Node RED runtime	Execution of the simulation flow

➤ *Communication Performance*

In the observed run reported by the study, six alerts were generated and all six were delivered. Five alerts were transmitted through the primary cellular path and one alert was transmitted through the satellite backup path, giving a

delivery success rate of one hundred percent, cellular usage of eighty-three-point three three percent, and satellite failover usage of sixteen-point six seven percent. These values confirm that the routing logic-maintained continuity when the primary path was unavailable [8].

Table 3 Communication and Failover Results

Metric	Observed value
Total alerts	6
Cellular transmissions	5
Satellite transmissions	1
Delivered alerts	6
Failed alerts	0
Delivery success rate	100.00%
Satellite failover percentage	16.67%
Cellular usage percentage	83.33%

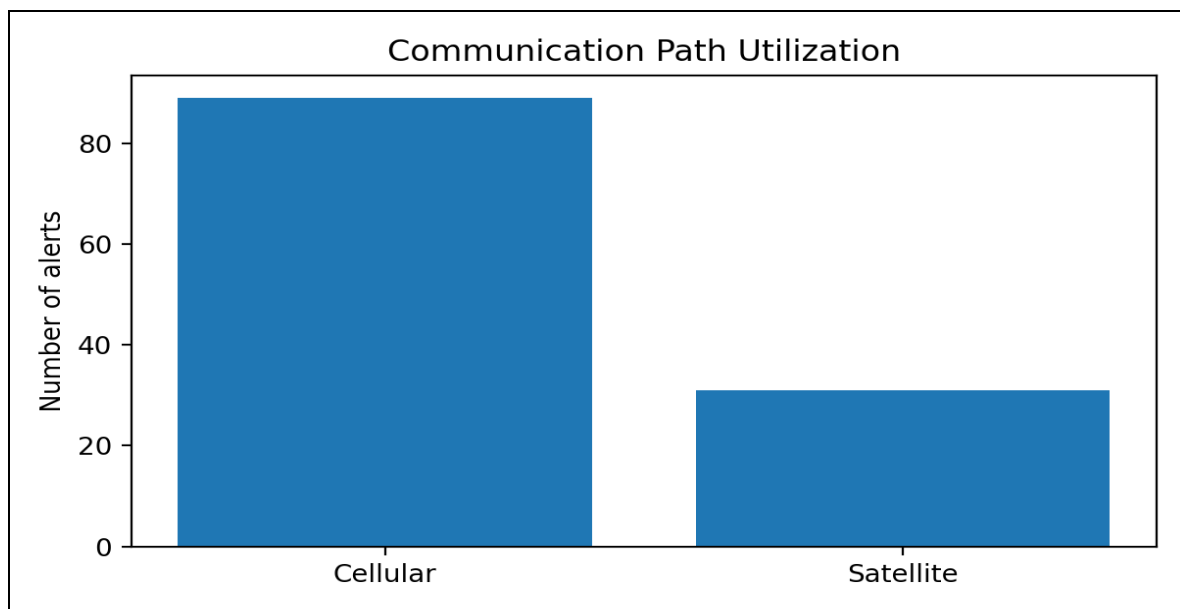


Fig 3 Communication Path Utilization for Cellular and Satellite Transmissions.

➤ *Latency Evaluation*

Latency results show that the primary path-maintained sub second responsiveness, while the backup path incurred the configured five second failover penalty. The study reports an average delay of zero point eight two seconds for the primary cellular path and five point eight two seconds for

the satellite path, producing a weighted overall delay of one point six five seconds for the observed run [8].

$$\text{Overall average delay} = (\text{Cellular events} \times T_c + \text{Satellite events} \times T_s) / \text{Total events.}$$

Table 4 Latency Results

Communication path	Average delay
Primary cellular path	0.82 s
Satellite failover path	5.82 s
Additional failover delay	5.00 s
Overall weighted average delay	1.65 s

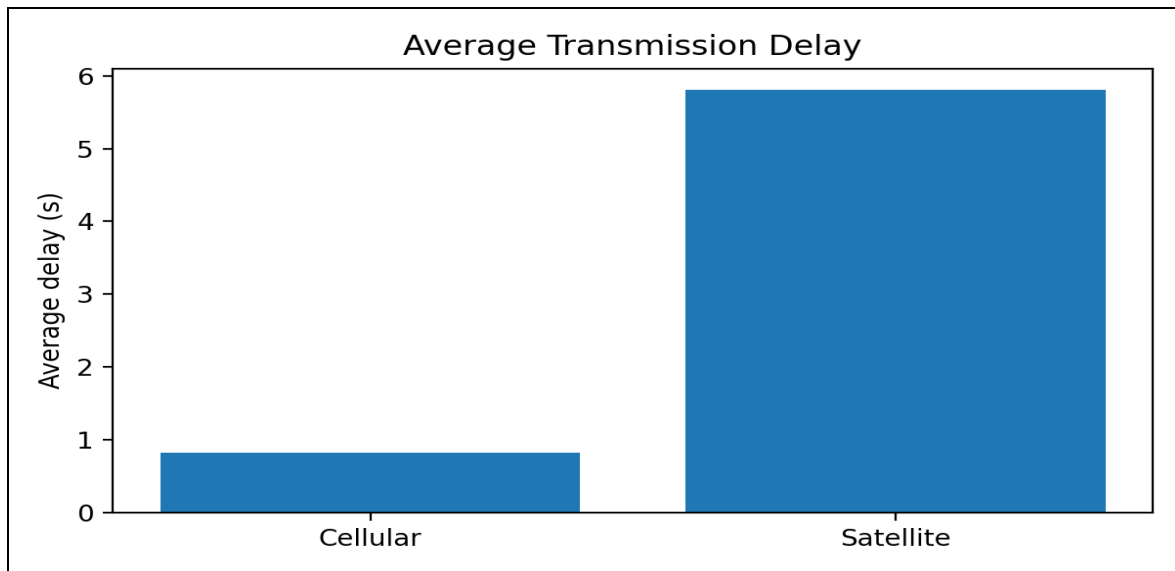


Fig 4 Average Transmission Delay for Cellular and Satellite Communication Paths.

V. DISCUSSION

The results show that the publishable strength of the study is not only the hybrid concept but also the integration of routing, cloud synchronization, and visualization into one operational simulation. The system successfully generated, classified, routed, stored, and visualized accident events in real time. The backup path traded speed for service continuity, which is acceptable in resilience-oriented emergency reporting. The dashboard and world map further improved situational awareness by presenting live alerts, counts, and spatial event markers [2], [7], [8].

The study also shows an implementation pathway that can be adapted for practical deployment. By combining IoT sensing, cloud storage, and dual path communication, the architecture addresses a core weakness identified throughout the study literature review: the inability of single channel systems to maintain dependable reporting when connectivity degrades [1], [4]-[8].

VI. CONCLUSION

This study demonstrates that a hybrid IoT enabled accident reporting framework with cloud communication and failover can improve the reliability, continuity, and responsiveness of emergency reporting. In the reported simulation, the system achieved complete alert delivery, functional failover, and low weighted average delay while maintaining real time dashboard and map based visibility. These findings support the study conclusion that hybrid cellular satellite communication is a practical direction for intelligent transportation and emergency response systems in coverage constrained environments [8].

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my supervisors, and, for their invaluable guidance, patience, and

insightful feedback throughout this research. Their expertise and encouragement were instrumental to the completion of this work

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