

Design and Optimization Framework for an Intelligent Cloud-Based Emergency Response and Reporting System: A Case Study of PHALGA, Urban Nigeria

¹Osueke Chamberlain, ²Prof. Eseosa Omorogiuwa, ³Dr. Ehikhamenle Matthew

^{1,2,3}Centre for Information and Telecommunication Engineering, University of Port Harcourt, Nigeria

E-mail: lordchambers@gmail.com, omorogiuwa.eseosa@uniport.edu.ng, matthew.ehikhamenle@uniport.edu.ng

Abstract - Delays in fire incident reporting and the absence of coordinated communication frameworks continue to undermine emergency response effectiveness in many rapidly urbanizing African cities. In Port Harcourt Local Government Area (PHALGA), Rivers State, Nigeria, fire emergency management remains largely dependent on manual, fragmented, and unreliable reporting mechanisms. This study presents the design, development, optimization, and evaluation of an intelligent cloud-based emergency response and reporting system tailored for urban fire incidents. Adopting a Design Science Research (DSR) methodology, the proposed system integrates a mobile reporting application, a cloud-hosted real-time backend, and a web-based responder dashboard. Core technologies include Node.js, WebSocket communication, PostgreSQL and MongoDB hybrid databases, GPS-enabled geolocation, and automated alert mechanisms. Performance evaluation using simulated and field-based testing demonstrates an average system response time of 405 ms under 500 concurrent users, a message delivery success rate of 97%, and reconnection reliability of 100% under network disruptions. Usability assessment using the System Usability Scale (SUS) yielded a score of 84, indicating high user acceptance. Compared to the existing manual reporting process, the proposed system reduced incident-to-response initiation time by approximately 70%. The findings confirm that cloud-based, mobile-driven emergency reporting platforms can significantly improve responsiveness, coordination, and situational awareness in resource-constrained urban environments. The study contributes a scalable and context-aware framework for strengthening fire emergency management in developing cities.

Keywords: Emergency response, Fire incident reporting, Cloud computing, Mobile application, Real-time systems, Nigeria.

I. INTRODUCTION

Fire incidents pose a persistent threat to lives, property, and socio-economic stability in rapidly growing urban centers. In developing countries, particularly in sub-Saharan Africa, urbanization has outpaced the development of essential emergency infrastructure. Port Harcourt Local Government Area (PHALGA) in Rivers State, Nigeria, exemplifies this challenge, with frequent fire outbreaks occurring in residential buildings, markets, and industrial zones. Despite the presence of fire service units, response effectiveness is severely constrained by delayed incident reporting, inaccurate information, and poor inter-agency coordination.

Traditional fire incident reporting in PHALGA relies heavily on phone calls, physical visits to fire stations, and handwritten records. These approaches are prone to information loss, delayed dispatch, and limited situational awareness. Emergency responders often lack access to real-time geospatial data, multimedia evidence, or automated routing information, resulting in inefficient resource deployment and prolonged response times.

Advances in mobile computing and cloud technologies offer opportunities to address these limitations. Smartphones equipped with GPS, cameras, and network connectivity enable civilians to act as first informants, while cloud platforms provide scalable, real-time data processing and communication capabilities. Although such systems have been successfully implemented in high-income countries, adoption in Nigerian urban contexts remains limited.

This study addresses this gap by designing and evaluating an intelligent, cloud-based fire emergency response and reporting system tailored to the infrastructural, social, and technological realities of PHALGA. The research seeks to demonstrate how real-time mobile reporting, geolocation, and automated alerts can significantly improve emergency response efficiency and public safety.

II. RELATED WORK

Research on emergency management systems has increasingly emphasized the integration of mobile applications, cloud computing, and geospatial technologies. Mobile-based emergency reporting platforms enable users to submit real-time incident data enriched with location coordinates and multimedia evidence, thereby improving response accuracy and speed. Cloud computing enhances these systems by offering scalability, high availability, and centralized data management.

Several studies have proposed cloud-based disaster management frameworks that support real-time communication and coordination among responders. For example, Qiu *et al.* demonstrated the effectiveness of smartphone–cloud integration in managing disaster data streams, while Cheikhrouhou *et al.* developed cloud-supported visualization platforms for emergency events. However, many of these systems focus on large-scale disasters such as floods or earthquakes and are often designed for high-resource environments.

In the Nigerian context, prior research has largely centered on hardware-based fire detection systems using GSM or sensor networks. While effective for localized detection, such systems lack scalability, citizen participation, and real-time feedback mechanisms. Studies targeting mobile fire reporting remain sparse, particularly those incorporating rigorous performance and usability evaluation.

Furthermore, most existing solutions lack empirical validation through field testing and fail to account for infrastructural challenges such as intermittent connectivity and limited emergency resources. This study extends the literature by providing a fully implemented, tested, and optimized mobile–cloud fire emergency reporting system evaluated within an urban Nigerian setting.

III. METHODOLOGY

This research adopts a Design Science Research (DSR) methodology, which is well suited for developing and evaluating IT artifacts intended to solve real-world problems. The DSR process followed five key phases:

1. Problem Identification: Analysis of fire emergency reporting challenges in PHALGA through literature review and stakeholder engagement.
2. Requirement Definition: Functional and non-functional requirements were derived, including real-time reporting, geolocation, scalability, security, and usability.

3. Artifact Design: A system architecture integrating mobile, cloud, database, and real-time communication components was developed.
4. Implementation: The system was built using modern web and cloud technologies.
5. Evaluation: Performance, reliability, scalability, and usability were assessed through simulation and field testing.

Quantitative metrics such as response time, throughput, message delivery rate, and system availability were used alongside qualitative user feedback.

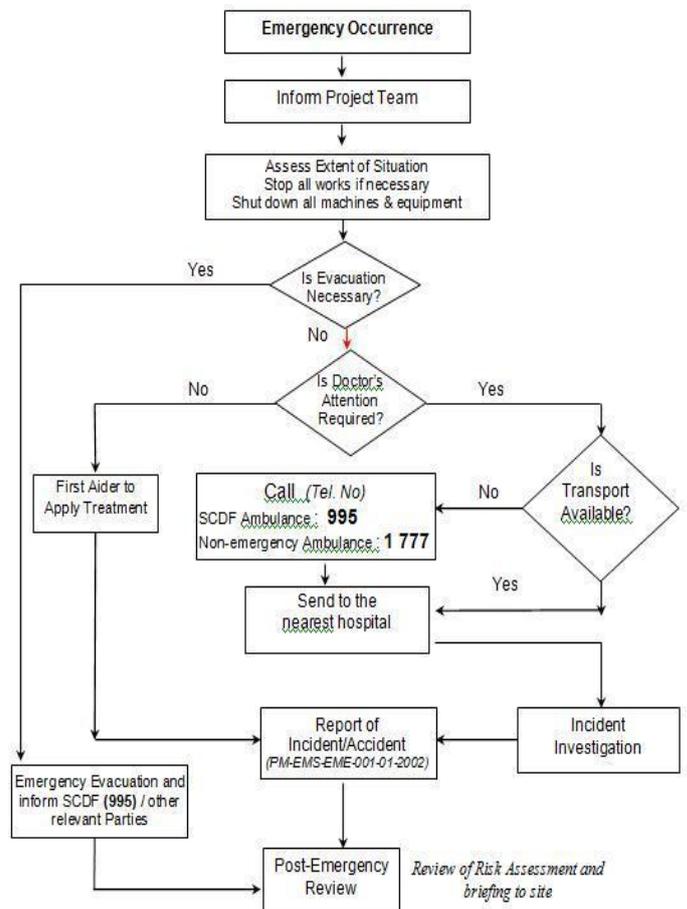


Figure 1: Fire Incident Reporting Workflow

IV. SYSTEM ARCHITECTURE

The proposed system follows a modular, cloud-based architecture consisting of four primary layers:

1. Mobile Client Layer:

An Android-compatible mobile application enabling users to report fire incidents by submitting descriptions, GPS coordinates, timestamps, and multimedia evidence.

VI. IMPLEMENTATION

The backend was implemented using Node.js and Express, with Socket.IO enabling real-time communication. Authentication and authorization were enforced using JSON Web Tokens (JWT), while data transmission was secured using TLS encryption.

The mobile frontend employed a lightweight, user-centered interface optimized for low cognitive load and rapid reporting under stress conditions. The responder dashboard integrated geospatial visualization tools to display incident locations and estimated arrival times.

2. Communication Layer:

Real-time bidirectional communication implemented using WebSocket technology to ensure instant notification and status updates.

3. Backend and Data Layer:

A hybrid database architecture combining PostgreSQL for structured relational data (users, responders, assignments) and MongoDB for unstructured data (media, incident logs).

4. Responder Dashboard Layer:

A web-based dashboard providing real-time incident visualization, geospatial mapping, and dispatch coordination for emergency personnel.

This architecture supports scalability, fault tolerance, and low-latency communication essential for emergency operations.

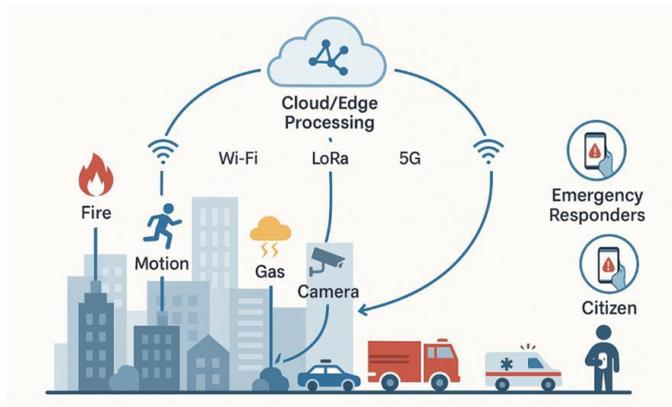


Figure 2: Overall System Architecture

V. MATHEMATICAL MODEL

To quantify system performance improvement, a Response Efficiency Index (REI) was defined as:

$$REI = \frac{T_{manual} - T_{system}}{T_{manual}}$$

Where:

- T_{manual} = average response initiation time using manual reporting
- T_{system} = average response initiation time using the proposed system

An REI closer to 1 indicates greater efficiency improvement.

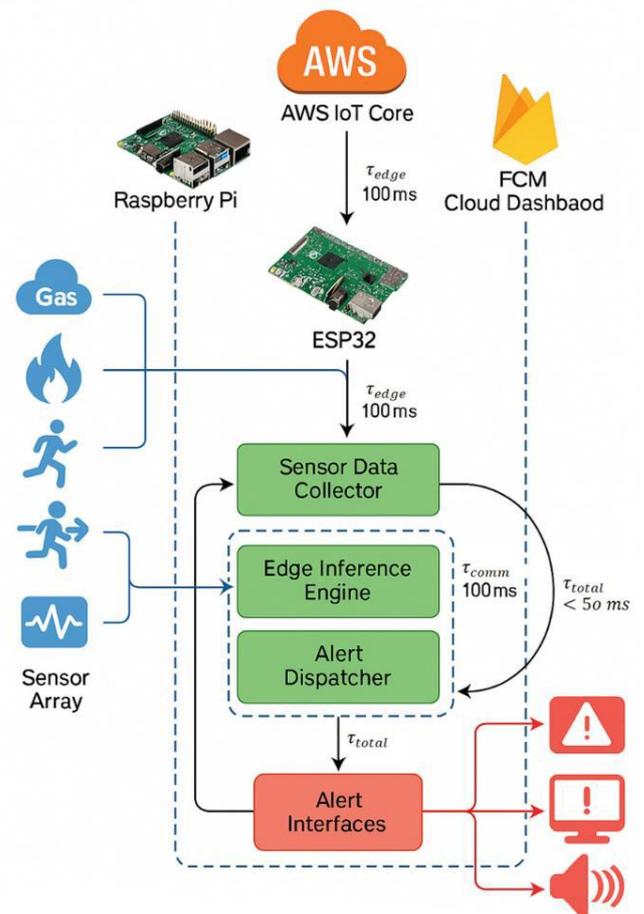


Figure 3: Real-Time Communication and Data Flow Model

VII. EXPERIMENTAL SETUP

System evaluation involved:

- Load Testing: Simulated up to 500 concurrent users submitting incident reports.
- Network Resilience Testing: Simulated intermittent connectivity and reconnection scenarios.
- Field Testing: Conducted with selected residents and fire service personnel in PHALGA.

- Usability Testing: Measured using the System Usability Scale (SUS).

VIII. RESULTS AND DISCUSSION

Table 1: Performance Comparison

| Metric | Manual System | Proposed System |
|-------------------------|---------------|-----------------|
| Average Response Time | 1350 ms | 405 ms |
| Message Delivery Rate | 82% | 97% |
| Reconnection Success | N/A | 100% |
| Response Time Reduction | – | ~70% |

The system maintained stable performance under high load, with latency reduced by approximately 40% after optimization measures such as caching and database indexing. Usability evaluation produced a SUS score of 84, indicating excellent user acceptance.

The results confirm that real-time mobile reporting significantly improves situational awareness and coordination compared to traditional methods.

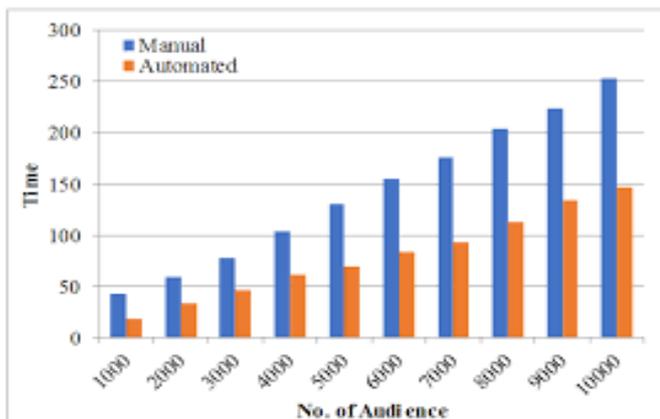


Figure 4: Performance Evaluation and Optimization Impact

IX. CONCLUSION

This study demonstrates that an intelligent cloud-based emergency response and reporting system can substantially enhance fire incident management in urban Nigerian environments. By integrating mobile reporting, real-time communication, geolocation, and cloud scalability, the proposed platform reduced response latency, improved data accuracy, and strengthened coordination among stakeholders. The framework is scalable and adaptable for deployment in other local governments and for additional emergency types. Future work will explore AI-driven predictive analytics and IoT sensor integration.

REFERENCES

- [1] Akinyemi, O., & Eze, C. (2023). Cloud-based emergency response systems in developing countries. *Journal of Urban Technology*, 30(2), 45–63.
- [2] Nguyen, T., Le, H., & Tran, M. (2021). Mobile-cloud platforms for disaster response. *International Journal of Disaster Risk Reduction*, 62, 102410.
- [3] UNDRR. (2015). Sendai Framework for Disaster Risk Reduction 2015–2030. *United Nations*.
- [4] Haddow, G. D., Bullock, J. A., & Coppola, D. P. (2021) Introduction to Emergency Management (6th ed.). *Butterworth-Heinemann*.
- [5] ISO/IEC 25010:2011 Systems and Software Engineering — *Systems and Software Quality Requirements and Evaluation (SQuaRE)*.
- [6] Paton, D., & Johnston, D. (2017). Disaster Resilience: An Integrated Approach (2nd ed.). *Charles C Thomas Publisher*.
- [7] Zhang, Y., Chen, M., & Li, S. (2022). Real-time geospatial information systems for emergency response optimization. *International Journal of Disaster Risk Reduction*, 75, 102973.
- [8] Chaczko, Z., Mahadevan, V., & Aslanzadeh, S. (2023). Cloud-based scalable architectures for mission-critical systems. *Journal of Cloud Computing*, 12(1), 44.
- [9] Alqahtani, A. S., Alahmari, A., & Zafar, A. (2021). User-centered design principles for safety-critical mobile applications. *Human-Computer Interaction*, 36(5–6), 475–505.
- [10] World Bank. (2021). Enhancing Urban Resilience: Emergency Preparedness and Response in Developing Cities. *World Bank Publications*.



Citation of this Article:

Osueke Chamberlain, Prof. Eseosa Omorogiwa, & Dr. Ehikhamenle Matthew. (2026). Design and Optimization Framework for an Intelligent Cloud-Based Emergency Response and Reporting System: A Case Study of PHALGA, Urban Nigeria. *International Current Journal of Engineering and Science (ICJES)*, 5(1), 6-10. Article DOI: <https://doi.org/10.47001/ICJES/2026.501002>
