



LoRaWAN for Smart Medical Emergency Service (EMS) Integrating with AI

Vijaya Prabhu R^{1*}, Balamurugan S², Pradheep R², Karthikeyan K²

¹ Assistant Professor, Department of Information Technology, Sri Manakula Vinayaka Engineering College, Puducherry, India
vijayprabhu.it@smvec.ac.in

² Department of Information Technology, Sri Manakula Vinayaka Engineering College, Puducherry, India
sivagamirajesh2021@gmail.com

Abstract. Medical emergencies require quick action during the critical "golden hour" to avoid life-threatening consequences. However, traditional healthcare systems often face problems like delayed identification of health issues, a lack of real-time first-aid guidance, and late notifications to hospitals. These challenges become even more serious in rural and low-connectivity areas. Recent advancements in LoRaWAN (Long Range Wide Area Network), wearable IoT devices, and Artificial Intelligence (AI) have opened up new possibilities for real-time health monitoring and automated emergency response, even in remote locations. This paper provides a detailed survey of AI-enabled LoRaWAN architectures that aim to improve emergency medical services (EMS). The study looks at key technologies, including wearable health sensors, LoRaWAN-based communication protocols, AI algorithms for detecting anomalies and triaging patients, and telemedicine integration for doctor telepresence during emergencies. We review existing research, compare different LoRaWAN implementations for healthcare, and point out current challenges related to bandwidth limits, energy efficiency, data security, and system scalability. Additionally, we suggest a conceptual framework called SmartMed-LoRaWAN. This framework combines continuous health monitoring, intelligent emergency detection, AI-driven first-aid guidance, and remote teleconsultation to significantly cut down response times and enhance survival rates. Finally, this paper examines future research opportunities, such as using edge AI for low-latency emergency detection, applying federated learning for privacy-focused healthcare analytics, utilizing blockchain for safe data sharing, and developing strategies for scaling up LoRaWAN-enabled EMS in both urban and rural environments.

Keywords: LoRaWAN, Artificial Intelligence, Emergency Medical Services, Wearable Sensors, Telemedicine, Edge AI, Smart Healthcare, Patient Triage

1 Introduction

Healthcare systems around the world face significant challenges in providing timely medical care during emergencies like cardiac arrest, road accidents, strokes, and other life-threatening situations. Recent WHO reports show that millions of preventable deaths occur each year due to delays in emergency care, especially during the crucial

"golden hour," which is the first 60 minutes after a severe medical event when immediate treatment can greatly increase survival chances . Unfortunately, current emergency response systems often depend on manual reporting, slow ambulance dispatch, and lack of pre-arrival patient health data. These issues lead to poor clinical outcomes. The problem is more severe in rural and semi-urban areas, where limited healthcare infrastructure and unreliable network connectivity widen the gap between patients and prompt medical care .

To tackle these challenges, LoRaWAN (Long Range Wide Area Network) has emerged as a promising communication technology for remote healthcare monitoring and emergency response. LoRaWAN is a Low Power Wide Area Network (LPWAN) protocol that enables long-range, low-power IoT connectivity. It allows real-time data transmission over distances of up to 10–15 km in rural areas and 2–5 km in urban settings. Unlike traditional wireless technologies like Wi-Fi or Bluetooth, which have short ranges and high energy needs, LoRaWAN offers broad coverage with minimal power use. This makes it well-suited for wearable medical devices in remote or resource-limited areas. By incorporating LoRaWAN-enabled IoT sensors into healthcare systems, we can continuously monitor vital signs such as heart rate, blood pressure, oxygen saturation (SpO₂), ECG, and body temperature, even where mobile connectivity is weak or nonexistent .

While LoRaWAN fills the connectivity gap, adding Artificial Intelligence (AI) to LoRaWAN-based healthcare systems brings a major change in emergency detection and response. AI models, especially those using Machine Learning (ML) and Deep Learning (DL) techniques, can analyze real-time physiological data sent via LoRaWAN to spot anomalies, predict serious health threats, and automatically create emergency alerts . Advanced algorithms like context-aware anomaly detection, predictive modeling, and reinforcement learning have proven effective in reducing false positives while enhancing emergency detection accuracy . Moreover, AI can provide intelligent first-aid guidance, helping bystanders or caregivers deliver life-saving interventions like CPR or controlling bleeding before professional medical assistance arrives. Telemedicine integration also allows remote connections with certified doctors through video or audio calls, providing vital advice during ambulance delays .

Despite these advancements, current systems have clear limitations. Many solutions operate independently, focusing on single functions like vital sign monitoring or alerting, without offering a full framework that combines LoRaWAN connectivity, AI-driven analytics, emergency decision-making, and first-aid assistance . Other challenges include limited bandwidth for multimedia transmission, scalability issues in environments with multiple patients, and data security concerns about sending sensitive health information over LoRaWAN networks . Additionally, most existing setups lack mechanisms to prioritize life-critical data for faster transmission during emergencies, which is crucial .

To address these issues, this paper proposes a conceptual architecture called SmartMed-LoRaWAN. This multi-layered framework aims to provide ongoing health monitoring, intelligent emergency detection, AI-driven first-aid guidance, and telemedicine support across LoRaWAN-enabled networks. The architecture uses edge and cloud computing to reduce latency, integrates AI models for anomaly detection and triage, and includes secure communication protocols to safeguard patient data. By uniting connectivity, intelligence, and accessibility, SmartMed-LoRaWAN seeks to shorten emergency response times and enhance patient survival rates, especially in rural and underserved areas .

The main contributions of this survey are:

- A thorough review of LoRaWAN and AI integration for real-time healthcare monitoring. Healthcare systems around the world face significant challenges in providing timely medical care during emergencies like cardiac arrest, road accidents, strokes, and other life-threatening situations. Recent WHO reports show that millions of preventable deaths occur each year due to delays in emergency care, especially during the crucial "golden hour," which is the first 60 minutes after a severe medical event when immediate treatment can greatly increase survival chances . Unfortunately, current emergency response systems often depend on manual reporting, slow ambulance dispatch, and lack of pre-arrival patient health data. These issues lead to poor clinical outcomes . The problem is more severe in rural and semi-urban areas, where limited healthcare infrastructure and unreliable network connectivity widen the gap between patients and prompt medical care .

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intelligent first-aid guidance, helping bystanders or caregivers deliver life-saving interventions like CPR or controlling bleeding before professional medical assistance arrives. Telemedicine integration also allows remote connections with certified doctors through video or audio calls, providing vital advice during ambulance delays .

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To address these issues, this paper proposes a conceptual architecture called Smart-Med-LoRaWAN. This multi-layered framework aims to provide ongoing health monitoring, intelligent emergency detection, AI-driven first-aid guidance, and telemedicine support across LoRaWAN-enabled networks. The architecture uses edge and cloud computing to reduce latency, integrates AI models for anomaly detection and triage, and includes secure communication protocols to safeguard patient data. By uniting connectivity, intelligence, and accessibility, SmartMed-LoRaWAN seeks to shorten emergency response times and enhance patient survival rates, especially in rural and underserved areas .The main contributions of this survey are:

- A thorough review of LoRaWAN and AI integration for real-time healthcare monitoring and emergency services.
- A comparative analysis of existing LoRaWAN-based EMS approaches, pinpointing significant research gaps and technical challenges.
- A proposal for the SmartMed-LoRaWAN architecture, combining IoT devices, AI analytics, and telemedicine features for improved emergency handling.
- An exploration of future research directions, including federated learning for privacy-preserving healthcare, blockchain for secure data sharing, and optimization techniques for energy-efficient LoRaWAN operations in large-scale deployments.itoring and emergency services.
- A comparative analysis of existing LoRaWAN-based EMS approaches, pinpointing significant research gaps and technical challenges.
- A proposal for the SmartMed-LoRaWAN architecture, combining IoT devices, AI analytics, and telemedicine features for improved emergency handling.

2 LITERATURE REVIEW

2.1

S. Abdulmalek et al. (2024) - LoRaWAN-based Hybrid Internet of Wearable Things System (IoWT-HHMS) for Smart Healthcare Monitoring and Diagnosis. Abdulmalek et al. present an end-to-end IoWT architecture that connects wearable physiological sensors (heart rate, PPG, temperature, occasional short-window ECG) to LoRaWAN gateways and a lightweight analytics stack. The hardware layer focuses on ultra-low-power wearable nodes that send compressed features periodically instead of raw waveforms. Edge gateways conduct preliminary filtering and aggregation and host small neural-network classifiers that identify anomalies. The evaluation includes prototype deployments and gateway logs that show significant improvements in battery life compared to continuous BLE and Wi-Fi designs alongside acceptable detection accuracy for short-duration anomalies. The authors highlight practical deployment features, including duty-cycling, adaptive spreading factor selection, and gateway-assisted retransmit policies, to boost coverage in urban and semi-rural areas. Limitations noted include limited payload capacity (making full ECG streaming impossible), only moderate clinical validation, and little attention to integrated ambulance and hospital coordination. For your AI-Driven LoRaWAN EMS, this paper provides proven design patterns for pushing classification to gateways and for feature compression strategies that keep LoRa payload budgets intact while maintaining anomaly detection performance.

2.2

Face recognition has emerged as the most deployed biometric modality due to its non-invasive nature and high user acceptance. Zhang et al. introduced disentangled representation learning for face anti-spoofing, achieving 95.2% accuracy on benchmark datasets through separation of identity and presentation attack factors. However, their method requires significant computational resources unsuitable for real-time web deployment.

Cai et al. proposed Deep Reinforcement Learning for Face Anti-Spoofing (DRL-FAS), achieving 96.1% detection accuracy on the NUAA and MSU-MFSD datasets. Their approach combines Q-learning with CNN-based feature extraction, enabling adaptive spoofing detection. However, the method's sensitivity to lighting conditions and limited cross-dataset generalization remain challenges for web deployment.

Yang et al. demonstrated CNN-based face anti-spoofing achieving state-of-the-art results on the REPLAY-ATTACK database, with 99.1% accuracy using shallow CNN architectures. Their work showed that temporal consistency analysis significantly improves performance by distinguishing between static presentation attacks and genuine video sequences. This finding informed the liveness detection module design in the present framework. H. Al-Sofi et al. (2024) - IEEE 802.15.6 vs. LoRaWAN for WBAN in Healthcare: A Comparative Study. Al-Sofi and colleagues conduct systematic network-layer experiments (simulations and controlled testbeds) to compare IEEE

802.15.6 (medical WBAN) with LoRaWAN across metrics relevant to EMS: latency, packet delivery ratio, energy per delivered byte, and scalability for multiple patients. Their approach uses realistic traffic models (periodic vitals along with sporadic emergency spikes) and measures the conditions where each protocol excels. LoRaWAN offers extended range and lower energy per node for sparse telemetry, while IEEE 802.15.6 performs better in terms of latency and payload support needed for high-quality signals. The paper's contribution involves a practical mapping of use cases to protocol choice and a recommendation to use hybrid stacks (local high-rate WBAN inside the body-area cluster and LoRaWAN for backhaul to distant hospitals). The main limitation is that simulations do not reflect extreme congestion or real-world RF interference patterns. Clinically, the research does not propose concrete triage workflows. This study supports a hybrid method in your EMS design (WBAN to edge to LoRaWAN) to handle both low-bandwidth alerts and high-bandwidth local streaming when necessary

2.3

N. M. Obiri et al. (2024) - Survey of LoRaWAN-Integrated Wearable Sensor Systems for Healthcare. Obiri et al. compile recent advances in wearables that utilize LoRaWAN for transport, addressing energy-saving MAC strategies, payload compression, security best practices, and early examples of edge AI deployment. They systematically gather designs for duty-cycling, adaptive spreading factor schemes, and methods to reduce false alarms in physiological monitoring. The review points out practical trade-offs: long-range benefits come with payload and latency restrictions, prompting many proposals to favor event-driven transmissions of compressed features instead of continuous raw streams. Gaps identified include limited large-scale clinical trials, insufficient attention to security and privacy in regulated healthcare environments, and no standardized AI model benchmarks for EMS tasks. For your project, this review acts as a valuable resource for low-level design tactics (feature engineering for low-bandwidth transmission and battery-saving duty cycles) and provides evidence for justifying LoRaWAN as the backbone for rural and remote areas while addressing its known limitations.

2.4

A. Tayeh & H. Azar (2020) - Wearable LoRa-Based Emergency System for Remote Safety Monitoring. Tayeh and Azar introduce a prototype wearable that combines accelerometers, gyroscopes, and a basic pulse sensor to identify falls and sudden physiological changes. The detection logic uses thresholds with a small on-device filter to reduce obvious noise. The device sends an alarm packet through LoRa to a central monitor that logs events and alerts responders. Field tests validate long-range alert capabilities (up to a kilometer in unobstructed conditions) and confirm low-power operation sufficient for days of use. The work's strengths include simplicity, demonstrated range, and effective sensor fusion for crash and fall detection. Weaknesses involve reliance on static thresholds, which cause false positives and negatives

in diverse populations, and the absence of integrated AI for triage or ambulance dispatch automation. For your EMS project, the paper demonstrates the feasibility of long-range physical alert transmission through LoRaWAN but also highlights the need for adaptive AI-based on-device or gateway triage to minimize false alarms and suggest prioritized ambulance dispatch.

2.5

M. Sarkar et al. (2024) - Survey: Smart Healthcare & Internet of Medical Things (IoMT). Sarkar et al. offer a broad survey covering wearable sensors, cloud and edge orchestration, telemedicine platforms, AI decision support, and user interfaces (applications, AR/VR). The survey connects remote patient monitoring, emergency telepresence, and regulatory and security issues. It emphasizes integration patterns, such as edge preprocessing, federated learning for privacy, and multi-modal data fusion (vitals, video, geolocation), all of which are relevant for efficient EMS processes. While comprehensive and forward-looking, the survey lacks experimental results or specific LoRaWAN engineering solutions; instead, it serves as a strategic design guide indicating which technologies to combine. For your project, the survey supports the inclusion of telemedicine options, privacy-preserving learning strategies (federated or split inference), and multi-modal fusion for robust emergency detection.

3 Problem Statement

Emergency medical care relies heavily on quick detection, timely communication, and accurate clinical decision-making during the “golden hour.” However, current Emergency Medical Service (EMS) systems mostly depend on manual reporting, delayed ambulance dispatch, and limited real-time patient data before hospital admission. These issues cause slow response times, inadequate hospital preparation, and a higher risk of preventable deaths. This situation is even more serious in rural and low-connectivity areas, where network infrastructure is weak, healthcare facilities are few, and patients often do not receive medical attention in time.

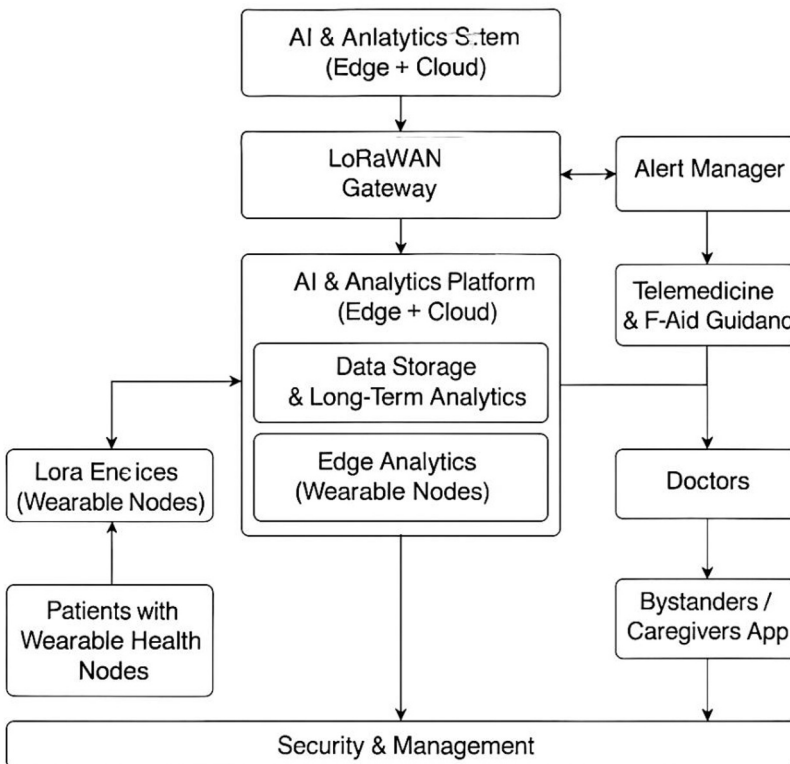
Wearable health sensors and IoT technologies allow for continuous monitoring of vital signs like heart rate, ECG, SpO₂, and temperature. Yet, most existing systems use short-range and energy-consuming methods like Wi-Fi or Bluetooth, which are not dependable in remote or large geographic areas. While LoRaWAN provides long-range and low-power communication, current LoRaWAN-based healthcare systems usually focus only on basic monitoring and alert generation. They do not include features like smart emergency detection, patient prioritization, automated first-aid support, or direct teleconsultation with medical professionals.

Additionally, Artificial Intelligence is not fully used in these systems for real-time anomaly detection, triaging patients by severity, or guiding bystanders during emergencies. Existing solutions often work as separate systems that either focus on con-

nectivity or analytics but fail to offer a cohesive framework that merges sensing, communication, intelligence, and medical response. Problems such as limited bandwidth, scalability issues, lack of emergency prioritization, cybersecurity threats, and inefficient integration with hospital systems further reduce the effectiveness of current EMS solutions.

There is an urgent need for an integrated, smart, and energy-efficient EMS framework that combines LoRaWAN connectivity, AI-driven health analytics, and telemedicine features. This approach can provide quick emergency detection, real-time guidance, and automatic notifications to healthcare providers. Closing this gap is crucial for reducing response delays, improving clinical readiness, and enhancing survival outcomes, especially in resource-limited rural and semi-urban areas where traditional emergency services struggle.

4 Proposed Methodology



SmartMed-LoRaWAN System Architecture

Fig 1. LoRaWAN System Architecture

The proposed methodology features an AI-enabled LoRaWAN Emergency Medical Service (EMS) . This system allows for ongoing health monitoring, automatic emergency detection, intelligent triaging, and real-time medical response. The architecture consists of several logical layers to ensure reliability, scalability, and low energy use in both urban and rural areas.

1. Wearable Health Sensing Layer

Patients use wearable medical sensors that gather physiological data like heart rate, ECG, SpO₂, body temperature, and blood pressure. These sensors work in ultra-low-power mode and take vital readings periodically. Instead of sending raw biomedical signals, lightweight preprocessing occurs where necessary to extract key features, reducing data volume and saving energy.

2. LoRaWAN Communication Layer

The health data is sent using LoRaWAN as the main communication protocol. LoRaWAN is chosen for its long-range capability, low power usage, and effectiveness in remote or low-connectivity areas. The wearable devices transmit sensor data to nearby LoRaWAN gateways, which serve as network access points. These gateways relay the incoming packets to the backend servers using secure connections. Adaptive transmission control methods, like duty cycling and optimized packet scheduling, help lower energy consumption and prevent network congestion.

3. Edge Intelligence Layer

At the gateway level, lightweight AI models conduct initial analysis on incoming data before sending it to the cloud. This reduces data delays and allows for quicker emergency detection. The edge processing unit performs:

- Health data filtering
- Noise removal
- Detection of abnormal signals
- Feature validation

Any urgent anomalies flagged at this stage trigger priority messages for quicker handling by subsequent services.

4. AI-Based Emergency Detection and Triage Layer

In the cloud layer, the incoming patient data is processed using AI models trained for:

- Anomaly detection
- Emergency classification
- Severity ranking (triage)
- False alert reduction

Machine learning and deep learning models examine incoming data patterns to tell apart normal health variations from life-threatening issues. Based on severity, patients are placed into priority categories to aid clinical decision-making and ambulance dispatch.

5. Emergency Alert Management Layer

Once a medical emergency is verified, the system automatically creates alerts and sends them to:

- Emergency response centers
- Hospitals
- Ambulance services
- Authorized caregivers

The alert includes patient vitals, type of emergency, timestamp, and severity score to help medical teams prepare before the patient arrives. Vital information is given priority in transmission to avoid delays during network congestion.

6. AI-Driven First-Aid Guidance Layer

When immediate medical help is not available, the system provides real-time first-aid guidance with AI support. Caregivers or bystanders receive simple step-by-step instructions to stabilize the patient while waiting for professional assistance. This guidance adapts based on patient vitals and detected conditions.

7. Telemedicine and Remote Consultation Layer

To assist responders and family members on-site, the system includes telemedicine services that enable:

- Doctor telepresence

- Remote health evaluation
- Live guidance during critical events

Doctors can check patient data in real time and give immediate treatment instructions if ambulance arrival is delayed.

8. Data Security and Privacy Layer

Secure communication protocols protect data transmission and storage across the entire system. Encryption methods safeguard sensitive medical records from unauthorized access. Future deployments may benefit from privacy-preserving techniques like federated learning and secure data management.

9. Performance Monitoring and Analytics Layer

The backend conducts long-term health analysis to spot trends, review patient history, and improve prediction accuracy. System performance analytics track:

- Transmission reliability
- Emergency detection accuracy

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