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PROJECT TITLE: DESIGN AND IMPLEMENTATION OF AN AD HOC IOT NETWORK USING WIRELESS SENSOR NETWORKS (WSNS) AND MOBILE AD HOC NETWORKS (MANETS) FOR EMERGENCY MEDICAL SERVICES IN RURAL AREAS

This project is submitted in partial fulfillment of the requirements of HBSc NETWORK ENGINEERING in the Department of Computer Science at Bindura University of Science Education.

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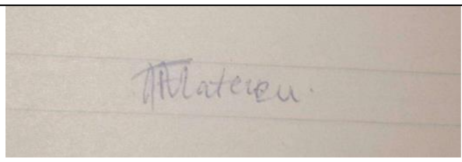
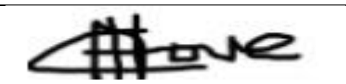
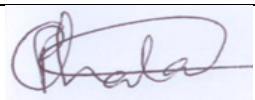
APPROVAL FORM

The undersigned certify that they have supervised the student Mateuzu Faith Thokozani dissertation entitled design and implementation of an AD HOC IOT NETWORK USING WIRELESS SENSOR NETWORKS (WSNS) AND MOBILE AD HOC NETWORKS (MANETS) FOR EMERGENCY MEDICAL SERVICES in rural areas in Partial fulfillment of the requirements for the Bachelor of Science Honors in Network Engineering Degree of Bindura University of Science Education.

STUDENT	**FAITH T MATEUZU**	
SUPERVISOR	**Mr D. HOVE**	
CHAIRPERSON	**Mr P. CHAKA**	

DEDICATION

Special dedication goes to all healthcare workers, especially those serving in rural and underserved areas. Your tireless commitment, bravery, and compassion in providing emergency medical services often under challenging circumstances inspire this study. Your efforts save lives every day and highlight the critical need for innovative solutions to improve healthcare delivery.

Your dedication to patient care in resource-constrained environments motivates ongoing advancements in medical technology and communication.

May this research contribute in some measure to supporting your vital work and improving emergency medical services for communities in need.

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ABSTRACT

This study investigates the design and implementation of an ad hoc IoT network integrating Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs) to enhance Emergency Medical Services (EMS) in rural areas. The research addresses the challenges of communication, security, and resource constraints faced in these areas. A comprehensive literature review established a foundational framework for the proposed solution. The study successfully designed and implemented a robust network that facilitates efficient multi-hop communication and ensures secure patient data transmission. Testing of low-power protocols, specifically LoRa, demonstrated its suitability for continuous monitoring of patient vitals using wearable IoT devices. The findings indicate that the proposed system can significantly improve healthcare delivery in underserved communities, providing timely and reliable medical assistance. Recommendations for future research include optimizing communication protocols and enhancing data security measures.

LIST OF FIGURES

ACCRONMYS

WSN **WIRELESS SENSOR NETWORKS**

EMS **EMERGENCY MEDICAL SERVICES**

MANET **MOBILE ADHOC NETWOK**

IOT **INTERNET OF THINGS**

VHW **VILLAGE HEALTHCARE WORK**

LORA **LONG RANGE TECHNOLOGY**

CHAPTER 1

PROBLEM IDENTIFICATION

1.1 INTRODUCTION

Physical health is referred to as the condition of the body's capacity to perform daily tasks without pain and it includes factors such as physical fitness, nutrition, body composition, and freedom from chronic diseases and pains in the body (Centers for Disease Control and Prevention, 2024; Physio-pedia, n.d.). Patients who receive emergency care in health facilities, commonly known as hospitals, clinics, or surgeries, have increased recovery success and survival rates than those who are not provided with emergency care (Hernandez et al., 2020).

By enhanced communication, easier access to information and ease of innovative approaches to health, the internet has served the healthcare field. In particular, networks have improved patient care, made handling health information easier, and improved communication (Hernandez et al., 2020). Types of networks, such as ad hoc, wireless, and conventional wired networks, can be used within emergency health conditions (TechTarget, n.d.). Wired networks are conventional Ethernet networks in which devices are connected to each other via physical cables. They are secure and dependable, offering consistent connections for important applications like laboratory information systems and electronic health records (EHR) (Security Industry Association, 2024). Wireless networks connect devices without physical cables using radio waves, which improves response times enabling medical professionals to communicate and access patient records in numerous points within a hospital or clinic (Troughton, Pinkney, & Liatis, 2023). Wireless networks enable the utilization of wearable technology and mobile health devices that continuously track patients' vital signs and provide real-time outputs to medical professionals (PMC, 2023).

The Internet of Things (IoT) and wireless connectivity have changed the healthcare industry in recent years, allowing several medical applications for remote diagnosis, emergency response, and real-time patient monitoring (PMC, 2023). Ad hoc networks are decentralized wireless networks that do not rely on established infrastructure, such as access points or routers, to control communication. Rather, devices, referred to as nodes, establish direct connections with one another and spontaneously create a network (TechTarget, n.d.). In ad hoc network, every node can serve as a router, sending data to other nodes when necessary. Reliable emergency medical services (EMS) are still lacking particularly in rural and isolated areas where connectivity is poor and healthcare infrastructure is insufficient (PMC, 2023). In emergencies when there could be potentially fatal outcomes from delays or data loss, transferring health information in a timely and accurate manner is crucial. This research seeks to solve the particular difficulties and limitations that are associated with rural and isolated areas such as poor infrastructure, restricted connectivity, and the requirement for reliable, low-power communication methods.

WSNs, or wireless sensor networks, are made up of many tiny, low-power sensors that are capable of recording a variety of patient vitals, such as blood pressure, oxygen saturation, and heart rate. These vitals are essential for continuous monitoring on the patient's condition while they are being transported (NCBI, n.d.). Mobile Ad Hoc Networks (MANETs) can provide dynamic, real-time communication between mobile devices, including hospital systems, medical professionals, and ambulances without depending on fixed infrastructure (ScienceDirect, 2023). These technologies can be unified into an IoT-based ad hoc network to provide real-time data transmission, which is essential for stabilizing patient and treatment while traveling to medical facilities (ScienceDirect, 2023).

1.2. BACKGROUND STUDY TO THE PROBLEM

Rural emergency medical services deal with a wide range of situations, but in order to provide effective care, all of them need constant observation and communication. For instance:
Cardiac Emergencies: Heart attacks are frequent nowadays, therefore to enable pre-hospital interventions and get hospital staff ready for prompt action, real-time heart rate, blood pressure, and oxygen level monitoring is necessary (Rural Health Info, n.d.).

Respiratory Conditions: Environmental variables might trigger symptoms for people who suffer from long-term respiratory conditions like asthma may have episodes. Respiration rate and oxygen saturation should be maintained whilst the patient is traveling to the hospital by continuous monitoring (NCBI, n.d.).

Diabetic Emergencies: Hypoglycemia or hyperglycemia incidents can be life-threatening if not attended to immediately. Monitoring glucose continuously allows EMS personnel to respond with relevant interventions whilst updating hospital teams for further action upon arrival (Medical News Today, n.d.).

High-Risk Pregnancy and Neonatal Cases: Rural clinics often lack specialized maternity care, therefore there is need for real-time transmission of maternal and fetal vitals is essential for managing complications during transport, helping hospitals prepare for possible preterm delivery or neonatal resuscitation and caesarean section preparation (PMC, 2023).

Traditional cellular networks or Wi-Fi-based systems, however, may not be accessible or dependable in rural locations due to the lack of such infrastructure and services (ScienceDirect, 2012). As a result there are major delays in emergency response, insufficient information exchange between medical experts affecting patient outcome, especially for patients who have serious injuries or illnesses that need immediate medical attention (NCBI, n.d.).

Ad hoc IoT networks that combine Wireless Sensor Networks (WSNs) for patient monitoring and Mobile Ad Hoc Networks (MANETs) for data transmission in mobile environments build a resilient and decentralized architecture that can function without relying on physical network installations or cellular service. This infrastructure is capable of delivering dependable data transmission from ambulance to hospital and continuous, uninterrupted patient monitoring, even in difficult terrain or places with poor network connectivity (ScienceDirect, 2023).

1.3 PROBLEM STATEMENT

In Zimbabwe, most of rural areas have geographical obstacles which create challenges in establishing reliable communication networks. Lack of cellular towers and internet availability restricts traditional communication techniques to be used for emergency responses. Traditional routing methods are insufficient for paramedics in ambulances who need to communicate effectively to transmit vital information while on the road. Traditional EMS relies on manual monitoring and written logs for patient vitals and this approach is time-consuming, prone to human error, and delays the relay of critical information to hospitals or specialists, leading to inefficiencies in patient care. In Zimbabwe, each province has its own central or district hospitals and clinics but the challenge is majority of the rural clinics have no adequate resources to attend to emergencies hence they refer the patient to hospitals with the services required and the clinics are situated far away. These challenges have caused a high mortality rate in emergency cases and worsened health conditions as diagnosis and monitoring are done at a later stage. Hence it is the writer's desirable to develop an ad hoc IoT network that integrates WSNs and MANETs to fill this gap, by monitoring patient continuously and communication in resource shortage environments, potentially reducing mortality rates by improving pre-hospital patient care.

1.4 RESEARCH OBJECTIVES

The primary objective of this research is to design and implement a robust ad hoc IoT network that integrates Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs) to support Emergency Medical Services (EMS) in rural areas. The following objectives are to be achieved:

1. To review literature on ad hoc IoT networks, WSNs, and MANETs within healthcare emphasizing on communication, security, and rural EMS challenges and establish a foundational structure for the proposed integrated solution.
2. To design and implement a resilient ad hoc IoT network that combines WSNs and MANETs, employing efficient multi-hop communication and lightweight security protocols to guarantee reliable and secure transmission of patient data in rural Emergency Medical Services (EMS).

3. To test and evaluate low-power protocols such as LoRa to determine their suitability to use in continuous monitoring of patient vitals using wearable IoT devices in rural EMS contexts.

1.5 RESEARCH QUESTIONS

To achieve the research objectives, the following research questions and hypotheses have been formulated:

1 What does existing literature reveal about the use of ad hoc IoT networks, WSNs, and MANETs in healthcare, particularly in addressing communication, security, and EMS challenges in rural settings, and how can this inform the development of an integrated network solution?

2 How can a robust ad hoc IoT network be designed and implemented using integrated WSNs and MANETs with efficient multi-hop communication and lightweight security to enable reliable and secure transmission of patient data in rural Emergency Medical Services (EMS)?

3 How suitable are low-power protocols, such as Zigbee and LoRa, for continuous monitoring of patient vitals in rural EMS?

1.6 HYPOTHESIS

- Null Hypothesis (H_0): The implementation of an ad hoc IoT network using WSNs and MANETs does not significantly improve the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.
- Alternative Hypothesis (H_1): The implementation of an ad hoc IoT network using WSNs and MANETs significantly improves the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.

1.7 JUSTIFICATION OF RESEARCH

- Improved Patient Outcomes: Continuous monitoring and real-time updates enable EMS teams to make data-informed decisions and provide hospitals with critical patient information before arrival and the hospitals teams prepare in advance for necessary treatments.
- Enhanced Rural Healthcare Access: This design supports care in rural areas by addressing the communication and monitoring challenges.
- Security and Privacy: The ad hoc network’s protocols ensure that transmitted patient data is confidential, protecting data privacy.
- Cost-effectiveness: Use of low-cost, low-power devices, offers scalable solution that is financially suitable for rural deployment.
- Resilience: Ad hoc networks are not centralized allowing them to be more flexible than traditional networks. This makes them more suitable for emergency communications in case of EMS. There are no single points of failure in the ad hoc network.

1.8 ASSUMPTIONS OF THE STUDY

- Accessibility of Devices: It is assumed that users will have access to the necessary devices (e.g., smartphones, laptops) required to interact with the IoT network, ensuring their participation in the monitoring process.
- User Familiarity with Technology: It is assumed that emergency medical providers should have a basic understanding of IT technology and are able to use mobile devices, laptops. Also patients are comfortable to wearable sensors for health monitoring.

1.9 LIMITATIONS

- **Controlled Environment Testing:** The network prototype will be tested in simulated or controlled environments, which may not completely show the actual challenges faced such as unpredictable terrain, weather conditions.
- **Hardware Constraints:** Reliance on specific low-cost hardware (e.g.ESP32, Arduino) may limit the generalizability of results to other devices with varying computational capabilities.

1.10 SCOPE OF RESEARCH/ DELIMITATIONS

The creation and deployment of an ad hoc Internet of Things network designed especially for emergency medical services in rural areas will be the main goal of this project. In order to monitor patients' vitals, the network will integrate wearable IoT devices with WSNs and MANETs. Network performance will simulated using python. The researcher will make use of ESP32 microntrollers, Lora modules and sensors will be used to build a prototype. The research will be limited to testing the network in controlled and simulated environments.

1.11 DEFINITION OF TERMS

1. WIRELESS SENSOR NETWORKS (WSNS): Decentralized networks of autonomous sensors that monitor environmental or physiological parameters (e.g., heart rate, temperature) and transmit data wirelessly to a central hub.
2. EMERGENCY MEDICAL SERVICES (EMS): Systems providing urgent medical care during emergencies, including pre-hospital stabilization, ambulance transport, and coordination with healthcare facilities.
3. MOBILE AD HOC NETWORK (MANET): A self-configuring, infrastructure-less network where mobile devices (e.g., ambulances, smartphones) dynamically route data via multi-hop communication.
4. INTERNET OF THINGS (IOT): A network of interconnected devices embedded with sensors and software to collect and exchange data over the internet.
5. AD HOC NETWORK: A temporary, decentralized communication network formed spontaneously without reliance on pre-existing infrastructure.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The application of Wireless Sensor Networks (WSNs) in healthcare demonstrates their efficiency in remote monitoring (Righi et al., 2020). Previous research has shown the potential of this integration in smart ambulance systems, but a gap remains in developing robust security protocols that can address the specific vulnerabilities of these integrated networks in resource-constrained rural settings (Kumar & Singh, 2023). Therefore, this research will focus on designing and implementing lightweight security mechanisms, building upon the theoretical foundation of cryptographic algorithms, to ensure data integrity and confidentiality in a dynamic MANET-WSN environment.

2.2 RELEVANT THEORY OF THE SUBJECT MATTER

2.2.1 INTERNET OF THINGS IN EMERGENCY MEDICAL SERVICE

The Internet of Things (IoT) in healthcare, also known as the Internet of Medical Things (IoMT), comprises numerous interconnected devices, sensors, and communication systems that allow for continuous, real-time monitoring and data analysis (Gholamhosseini et al., 2020). IoT in healthcare works effectively in scenarios where continuous monitoring is required yet challenging to achieve, such as during ambulance transport in rural areas (Patel et al., 2021). IoT networks in EMS enable the real-time transfer of patient data from remote monitoring stations and ambulances to centralized medical facilities, ensuring that emergency responders can make data-driven decisions while in route to hospitals (Rahman et al., 2023).

Key developments include:

- **Real-time Data Acquisition**: IoT devices collect and transmit vital data such as heart rate, blood pressure, and body temperature, allowing early detection of critical conditions.
- **Predictive Analytics:** Integration with AI and machine learning models enables predictive diagnostics, thereby reducing response times and improving outcomes in emergency care (Rahman et al., 2023).
- **Continuous Patient Monitoring:** Wearable devices may be installed in ambulances to track patient vitals in transit, enabling medical professionals to prepare appropriate interventions before patient arrival (Mishra et al., 2022).

2.2.2 ADHOC NETWORK TYPES

Ad hoc networks are decentralized wireless systems in which nodes connect directly without depending on any pre-existing infrastructure (Jones & Martin, 2021). Due to their inherent flexibility, these networks are ideal for settings like disaster zones, rural areas, and military circumstances where traditional networks are impracticable. The types of ad hoc networks include:

Mobile Ad Hoc Networks (MANETs): Consists of mobile nodes that form networks without centralized control, signified by their changing topology (Lee et al., 2020). Nodes such as mobile devices, vehicles can join or leave the network freely.

Vehicular Ad Hoc Networks (VANETs): Enable communication between vehicles (Vehicle-to-Vehicle, V2V) or between vehicles and roadside infrastructure (Vehicle-to-Infrastructure, V2I), extending applications to emergency services (Alam et al., 2022).

Wireless Sensor Networks (WSNs): WSNs comprise spatially distributed sensor nodes that monitor environmental or physical conditions and communicate the collected data to a central location (Righi et al., 2020). They focus on low-power and energy-efficient communication.

Flying Ad Hoc Networks (FANETs): FANETs involve unmanned aerial vehicles (UAVs) forming a dynamic communication network, used for surveillance and disaster management (Alam et al., 2022). FANETs have challenges, such as strict energy limits and quick changes in network topology. In order to overcome these obstacles, recent work has concentrated on creating adaptive protocols that maximize energy usage, throughput, and communication range.

2.2. 3 AD HOC NETWORKS IN EMERGENCY MEDICAL SERVICES (EMS)

Ad hoc networks, particularly MANETs and WSNs, are widely used in EMS to provide infrastructure-free communication in emergency scenarios. Research has shown that ad hoc networks allow medical providers to maintain continuous communication with hospitals, ensuring the timely transfer of patient information (Zhang et al., 2018). The implementation of ad hoc networks for EMS has proven that it is effective in addressing common communication barriers in rural and disaster stricken areas where infrastructure may be limited or compromised (Kumar & Singh, 2023).

2.2.4 IMPLEMENTATION OF WIRELESS SENSOR NETWORKS (WSNS) RURAL EMS

WSNs are essential for IoT applications in healthcare, especially those involving remote and continuous monitoring. Studies highlight fault tolerance, reliable data collection, and energy efficiency as crucial design factors (Alemdar & Ersoy, 2010). Features of WSNs include:

- Sensor Nodes: Sensor nodes are essential components of wireless sensor networks (WSNs). Each node typically consists of a sensing unit, processing unit, communication module, and a power source (ScienceDirect, n.d.-a).
- Energy Efficiency: These nodes are designed for low-power operation, often relying on batteries. They are employed in environments where replacing batteries may be

difficult, making energy efficiency an essential design consideration (ScienceDirect, 2021).

- Scalability: Sensor nodes are suitable for wide-area monitoring applications because they can be scaled to accommodate a high number of nodes. This scalability allows for expansive coverage in different monitoring scenarios (ScienceDirect, 2023).
- Self-Organizing: One of the key features of sensor nodes is their ability to create networks autonomously. This feature enables multi-hop communication, where data is transmitted to a destination through intermediary nodes (ScienceDirect, n.d.-b).
- Data Aggregation: To enhance energy conservation and reduce redundancy, sensor nodes can perform data aggregation. This process involves merging or compressing data from multiple nodes before transmission, which is important for efficient network operation (ScienceDirect, 2016).

WSNs are used in rural EMS settings to monitor medication compliance and patient vitals. These networks serve as the primary data collectors, with sensor nodes transmitting critical information to mobile devices via MANETs (Tripathy et al., 2020). Researches have demonstrated that even under harsh conditions, WSNs can reliably transmit data, supporting immediate emergency interventions (Righi et al., 2020).

2.2.5 APPLICATIONS OF MANETS IN EMERGENCY MEDICAL SERVICES

MANETs allow devices to connect directly and create self-organizing networks, providing flexible, infrastructure-free communication. In rural locations, where fixed communication infrastructure may be limited or unstable, this feature of MANETs is very helpful (Mishra et al., 2022). MANETs facilitate dynamic communication links among sensor nodes, hospital networks, and ambulances, ensuring constant data flow even in rapidly changing situations (Chen et al., 2021).

2.2.6 ROUTING PROTOCOLS AND QUALITY OF SERVICE (QOS) IN MANETS

Effective routing protocols are important for MANETs to function well in emergency medical service applications. Routing with QoS awareness prioritizes vital medical data through the development of Quality of Service (QoS) algorithms that dynamically modify transmission patterns based on variables such as link quality, latency, and network congestion (Quy et al., 2021). Adaptive and energy-efficient protocols are crucial for prolonging the operational lifespan of nodes during prolonged emergency responses (Chen et al., 2021). According to comparative analyses of different routing protocols in emergency situations, machine learning techniques can be used to improve the adaptability and efficiency of protocols like Dynamic Source Routing (DSR) and Ad-hoc On-demand Distance Vector (AODV) in extremely dynamic environments (Mishra et al., 2022***).***

2.2.7 MANET-WSN INTEROPERABILITY IN EMERGENCY MEDICAL HEALTHCARE SERVICES

MANETs provide the mobility and adaptability required for dynamic applications whereas WSNs offer low-power, distributed sensing capabilities (Mishra et al., 2022). A common model involves using WSNs as the data collection layer, where sensor nodes monitor physiological and environmental parameters, while MANETs function as the dynamic communication backbone that relays data to emergency response centers (Patel et al., 2021). A common model involves using WSNs as the data collection layer, where sensor nodes monitor physiological and environmental parameters, while MANETs function as the dynamic communication backbone that relays data to emergency response centres [Wearable Sensors] → [Ambulance MANET] → [Hospital Cloud]   (Patel et al., 2021). Patel et al. (2021) demonstrated this model in India but omitted rural security risks like eavesdropping during multi-hop transmissions.

2.2.8 SECURITY AND PRIVACY IN MANET-WSN INTEROPERABILITY

Security and privacy protocols are essential in MANET-WSN systems, especially in EMS where decentralized networks send sensitive patient data. Security in this context refers to safeguarding data availability, confidentiality, and integrity across dynamic nodes with limited resources (Smith & Lee, 2023). Common vulnerabilities include eavesdropping, Sybil attacks, and denial of service (DoS) attacks, which can significantly impact the quality of service in emergency communications (Kumar & Singh, 2023). Several types of limitations occur, such as:

Eavesdropping: Sensitive medical data may be accessed when unauthorized nodes intercept data transmissions. This passive attack exploits unsecured communication channels.

Sybil Attack: Only a single malicious node presents multiple identities to disturb network operations. In a Sybil attack, fake nodes can manipulate routing decisions or compromise data aggregation, leading to inaccurate patient monitoring.

Wormhole Attack: Attackers record packets at one location in the network and replay them in another, creating a shortcut that disrupts the normal routing process. The Quality of Service (QoS) may be significantly impacted by this.

Blackhole and Greyhole Attacks: Greyhole attacks are more difficult to detect since they only drop specific packets, while blackhole attacks drop all packets. Instead of forwarding packets, malicious nodes deliberately drop them.

Selective Forwarding: A compromised node selectively drops specific packets based on their content or source, disrupting the flow of critical health data while allowing other traffic to pass.

Denial of Service (DoS) and Distributed DoS (DDoS): Attackers flood the network with erroneous requests, overwhelming the nodes and leading to a failure in legitimate communications. In the resource-constrained environment of WSNs, DoS attacks can quickly deplete battery power, affecting network longevity.

Node Capture: Attackers can obtain cryptographic keys and other private information by physically capturing and breaching sensor nodes, which may result in network intrusion.

2.2.9COUNTERMEASURES AND MITIGATION STRATEGIES

Lightweight Authentication and Encryption: Traditional cryptography methods could be too complex for sensor nodes due to resource limitations. For low-power devices, researchers developed secure authentication techniques and lightweight encryption algorithms (Smith and Lee, 2023). These techniques guarantee low consumption of energy while assisting in maintaining the confidentiality and integrity of data.

Intrusion Detection Systems (IDS): Intrusion Detection Systems (IDS) designed for ad hoc networks are capable of monitoring unusual activity and identifying potential threats such as selective forwarding, wormholes, and Sybil attacks.

Blockchain Technology: Blockchain offers a decentralized approach to secure data transactions, ensuring immutability and traceability. In MANET-WSN systems, blockchain-based frameworks can provide a tamper-proof log of data exchanges, making it more difficult for attackers to manipulate or forge data (Smith and Lee, 2023).

Secure Routing Protocols: Routing attacks can be mitigated by the use of security metrics in adaptive and QoS-aware routing systems. For example, integrating trust management into routing decisions can help avoid malicious nodes that exhibit behavior characteristic of blackhole or greyhole attacks (Quy et al., 2021).

Energy-Efficient Security Mechanisms: To address the trade-off between security and energy consumption, researchers are exploring energy-efficient security protocols that balance robust protection with the limited power budgets of sensor nodes. Security frameworks are including strategies like adaptive transmission power control and duty cycling to increase network lifespan (Chen et al., 2021).

2.3 EMPIRICAL AND THEORETICAL LITERATURE

2.3.1 THEORETICAL INSIGHTS

The theoretical literature provides foundational understanding and proposed frameworks for integrating IoT, MANETs, and WSNs in healthcare applications. These studies focus on conceptual models, architectural designs, security frameworks, and performance considerations without necessarily conducting field tests or empirical measurements

Chakraborty et al. (2022) proposed architectural models that conceptualize the integration of Mobile Ad Hoc Networks (MANETs) with WSNs, specifically tailored for emergency medical services (EMS). The study addresses issues in MANET-WSN hybrid networks, including dynamic topology management, effective data routing, and node mobility support. Although the study offers an architectural blueprint, it lacks substantial empirical support and it primarily remains theoretical, suggesting a field that is ready for more research.

Kumar and Lee (2020) presented theoretical models that focused on the security challenges in mobile healthcare networks, specifically those constrained by limited power and resources. The research emphasizes the need for lightweight cryptographic systems to protect data integrity and confidentiality. interoperability frameworks that facilitate communication across various network architectures and medical devices, which are essential for creating safe and effective IoT healthcare systems is also proposed in their research.

Dey et al. (2019) developed a conceptual framework titled "Conceptual Frameworks for IoT-enabled WSNs in Emergency Healthcare," which models the integration of WSNs within IoT systems designed for emergency healthcare environments. The study highlights the importance of strong communication protocols that support continuous vital sign monitoring in dynamic, mobile settings like ambulances.

Rahman et al. (2020) explored "The Role of IoT in Emergency Medical Services," discussing how IoT technologies can enhance patient monitoring and data sharing in emergency situations. Their findings underscore the need for robust frameworks that integrate various technologies to improve healthcare delivery.

Zhang et al. (2021) examined "Security and Privacy in IoT-based Healthcare Systems," focusing on the theoretical aspects of securing patient data in IoT environments. Their work emphasizes the importance of developing comprehensive security frameworks to protect sensitive information in healthcare applications.

2.3.2 EMPIRICAL STUDIES

Empirical studies demonstrate real-world applications and effectiveness in various healthcare settings, particularly in integrating WSNs and MANETs for improved patient monitoring and data transmission.

Mishra et al. (2022) developed and tested a prototype system titled "IoT-based Emergency Healthcare: Integration of WSNs and MANETs in Smart Ambulance Systems." This study involved wearable sensor nodes placed on patients to gather essential data (such as heart rate and oxygen levels) and send it to hospital servers via a MANET. The results confirmed the viability of such integrated networks for real-time emergency healthcare, demonstrating dependable data transfer under high-mobility situations

Patel et al. (2021) empirically examined an IoT framework in their paper "Real-time IoT Frameworks for Emergency Healthcare in Rural Areas," designed to operate in rural emergency healthcare contexts where infrastructure is minimal. They deployed a hybrid network that utilized edge computing, WSNs, and MANETs to improve system stability and lower data transmission latency. Field tests conducted in remote areas demonstrated reduced packet loss rates and enhanced emergency alert responsiveness.

Smith and Lee (2023) evaluated the performance of lightweight cryptographic algorithms in their study "Lightweight Security Protocols for Wireless Sensor Networks in Smart Healthcare." Protocols were tested against popular network attacks, such as wormhole and Sybil attacks, and found that the proposed security solutions effectively protect private patient data without compromising network throughput or node battery life.

Kumar and Singh (2023) examined practical issues in their paper "Challenges in MANET-based Emergency Response Networks," focused on interoperability between heterogeneous devices and dynamic network management. They highlighted the need for standardized protocols to ensure that there is seamless communication in real-world EMS deployments.

Alam et al. (2022) conducted a study titled "Flying Ad Hoc Networks for Emergency Medical Services," which explored the use of UAVs in emergency medical situations. Their research demonstrated the potential of FANETs to provide real-time data transmission and enhance communication in areas with limited infrastructure.

2.4 RESEARCH GAP

While numerous theoretical models and empirical studies have explored the integration of IoT, WSNs, and MANETs in healthcare systems, a distinct gap exists in the contextual application to rural emergency medical services in Zimbabwe or similar low-resource environments. Most existing work is either:

- Theoretical in nature, focusing on conceptual models without real-world implementation (e.g., Chakraborty et al., Kumar and Lee).
- Empirical but conducted in controlled environments or urban contexts, often without addressing the specific infrastructural, security, and mobility challenges present in rural African settings (e.g., Patel et al., Mishra et al.).
- Furthermore, security concerns have received less attention, especially regarding lightweight cryptographic solutions that work for mobile, ad hoc, resource-constrained IoT devices in rural healthcare settings. Given the critical importance of patient data confidentiality, integrity, and authentication in emergency care, this oversight is significant.
- Additionally, there is minimal proof of hybrid MANET–WSN designs evaluated using real-time simulations for latency, energy consumption, and routing in rural network scenarios, equipped with secure communication protocols suitable for medical sensor data.

Therefore, this study seeks to fill the gap by:

- Designing and simulating a secure hybrid IoT architecture using WSNs and MANETs tailored for rural emergency services in Zimbabwe.
- Integrating and evaluating lightweight security protocols such as AES encryption.

- Addressing real-time constraints and data delivery reliability in rural, infrastructure-poor conditions.

In summary, this literature review investigates how ad hoc IoT networks, particularly the combination of Mobile Ad Hoc Networks (MANETs) and Wireless Sensor Networks (WSNs), can enhance Emergency Medical Services (EMS) in rural regions. It discusses how the Internet of Medical Things (IoMT) enables continuous and real-time patient monitoring during critical phases, such as ambulance transport.

The review categorizes different types of ad hoc networks, including MANETs, Vehicular Ad Hoc Networks (VANETs), WSNs, and Flying Ad Hoc Networks (FANETs), highlighting the advantages of integrating the flexible, with infrastructure-free communication capabilities of MANETs combined with the low-power, energy-efficient data collection features of WSNs.

Additionally, it outlines several technical challenges, such as routing with Quality of Service (QoS) awareness, energy constraints, and data security risks, including eavesdropping, Sybil attacks, and wormhole attacks. Various mitigation strategies such as lightweight encryption, secure routing protocols, and blockchain-based security solutions were discussed.

Lastly, related studies are summarized, showing advancements in IoT-based emergency healthcare situations, and the development of adaptive routing and security protocols. Together, these efforts aim to improve timely and reliable emergency response in resource-limited settings.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The chapter outlines the methodological approach used in the research to design and implement an ad hoc IoT network for Emergency Medical Services (EMS) in rural areas. It details the research designs, data collection approaches, population and sample selection, research instruments, and data analysis procedures used to achieve the research objectives and answer the research questions.

3.2 RESEARCH DESIGN

This research uses a mixed-method research design, combining qualitative and quantitative approaches with simulation and prototyping. This design facilitates a holistic understanding of both technical and user-centric aspects of deploying IoT networks in rural EMS contexts. The qualitative component involves gathering insights from EMS personnel, while the quantitative aspect includes the analysis of network performance metrics such as packet delivery ratio etc. Simulation and prototyping phases enable the practical evaluation of the proposed network architecture under various scenarios.

3.2.1DEVELOPMENT METHODOLOGY

The Agile Development Methodology is a flexible, iterative approach to system design and development (Sutherland and Schwaber, 2020). It emphasizes breaking the project into smaller, manageable cycles called sprints, where each sprint delivers a functional part of the system. Agile focuses on:

Continuous Feedback: Regular testing and user feedback to refine components.
Adaptability: Responding quickly to changes or new requirements.
Collaboration: Encouraging teamwork and communication across all stakeholders.

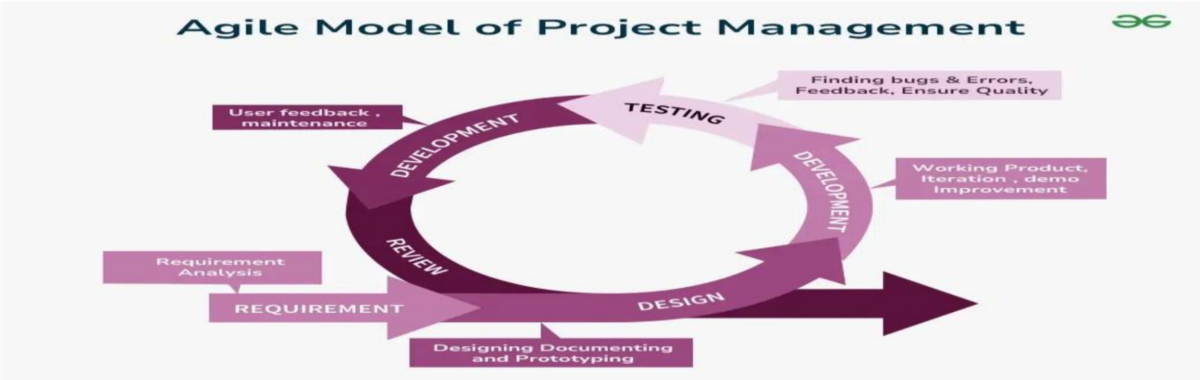


FIGURE 1: AGILE MODEL

This methodology is particularly well-suited for complex, multi-component systems, such as the hybrid IoT network in this project, where iterative refinement and adaptability are critical for achieving robust performance.

1. Sprint Planning: Define objectives like WSN setup, MANET integration, and Firebase deployment.
2. Development: Build and test system components (e.g., sensors, routing protocols, and security).
3. Testing and Feedback: Simulate protocols (AODV) in python; gather user feedback via questionnaires.
4. Refinement: Use testing feedback to improve performance (e.g., optimizes energy consumption and reduces latency).
5. Deployment: Integrate the final system and validate it in real-world EMS conditions

3.3 DATA COLLECTION APPROACHES

Methods:

Interviews: Interviews were held to gather qualitative information on operational challenges, user requirements, and factors impacting network deployment.

Questionnaires: Distributed to a broader group of EMS staff and potential end-users to quantitatively assess usability, acceptance, and specific needs related to IoT solutions.

Observations: Were performed during EMS operations to identify real-world challenges, environmental conditions, and opportunities for the system's integration.

Simulations: Simulations on network performance under various configurations and conditions, providing quantitative data on metrics such as latency, throughput, and energy consumption.

3.4 POPULATION AND SAMPLE

Target Population: The research focuses on EMS providers operating in rural areas, including paramedics, emergency responders, Village health care workers (VHWs).

Sampling Strategy: A sampling technique was employed to select participants with direct experience and involvement in rural EMS operations. This approach ensures the collection of relevant and insightful data to the research objectives. Minimum 2 years of rural EMS experience. 9 interviewees (6 medical staff /EMS responders, 3 VHWs), 10 questionnaire respondents (EMS personnel).

3.5 RESEARCH INSTRUMENTS

The primary research instruments for data collection methods employed are:

3.5.1 INTERVIEWS

The interview guide serves as a structured framework to facilitate consistent and focused data collection during interviews with participants. For this research, this interview guide is designed to gather insights from individuals with limited or no knowledge of IoT or IT in general, ensuring their input is relevant to understanding the challenges and needs of Emergency Medical Services (EMS) in rural areas.

INTERVIEW GUIDE FOR MEDICAL STAFF

Background:

1. **Could you describe your role and how long you've been working in this medical facility?**
2. **Can you describe your experience with emergency services in rural areas?**

Communication Problems:

3. **What kind of communication tools (e.g., radios, mobile phones) do you know are being used in rural areas?**
4. **How reliable are these tools in rural areas? Are there any specific situations where they fail?**
5. **Have communication delays or breakdowns ever affected the outcome of an emergency? If yes, can you describe such an experience?**
6. **How would having immediate patient data (like vital signs) before a patient arrives impact your ability to prepare for their care?**

Patient Monitoring and Information Sharing

7. **How do you currently monitor a patient’s condition during transportation or care in rural areas?**
8. **If you could get information about a patient's condition (like heart rate or blood pressure) while you're traveling to the hospital, how helpful would that be?"**
9. **Imagine small, wearable devices that could send this information automatically. Would that be useful?**
10. **How important is it that these devices work for a long time without needing to be recharged?**

Technology Concerns

11. **How comfortable are you with using new technology or devices in your daily work?**

Security of Information:

12. **How important is it to you that patient information is kept private and secure?**
13. **What worries do you have about sharing patient information wirelessly?**

Recommendations and Improvements

14. **Do you have any other suggestions for improving emergency medical services in rural areas?**

INTERVIEW GUIDE FOR VILLAGE HEALTH CARE WORKER

1. **How long have you lived in this area?"**
2. **Could you describe your role as a village care health worker?**
3. **What are the most common health emergencies you encounter in your work?**
4. **How far away is the nearest hospital or clinic?**
5. **Have you ever had trouble getting emergency medical help quickly?**
6. **How do you think community members would feel about using wearable devices for health monitoring?**
7. **How worried are you about your health information being sent wirelessly?**
8. **What would make you feel safer about your information being protected?**
9. **How would you approach obtaining consent from community members to use these devices?**
10. **Do you have any other comments about how emergency medical services could be improved?**

3.5.2. QUESTIONNAIRRE

In this research, questionnaires were deployed to gather data on rural Emergency Medical Services (EMS).The questionnaire was designed to gather detailed insights from EMS staff and Village Health Workers (VHW) about their experiences, challenges, and needs in delivering emergency medical services in rural areas. .it is structured to include both closed-ended and open-ended questions, the questionnaire collects quantitative data for analysis while also capturing detailed feedback and unique perspectives.

Goodday! My name is Faith Thokozani Mateuzu, a final-year student doing a Bachelor of Science Honours Degree in Network Engineering at Bindura University of Science Education. I am currently doing a research project on DESIGNING AND IMPLEMENTATION OF ADHOC IOT NETWORK USING WIRELESS SENSOR NETWORKS AND MOBILE AD HOC NETWORKS FOR EMERGENCY MEDICAL SERVICE IN RURAL AREAS. Your feedback is incredibly valuable and will help in designing and meeting the needs of the required system. All responses will remain anonymous. Thank you for your time and contribution to this important research.

1. **On average, how far (in kilometres) is the nearest hospital or healthcare center from the area you serve/live?**

- **Less than 5km** ☐
- **5-10km** ☐
- **11-20km** ☐
- **More than 20km** ☐

CHALLENGES IN EMS

2. **How often do you face network connectivity issues during emergencies?**

- **Always** ☐
- **Frequently** ☐
- **Sometimes** ☐
- **Rarely** ☐
- **Other………………………………………………..**

3. **What mode of transport is most commonly used for emergencies in your area?**

- **Scorch cart** ☐
- **Ambulances** ☐
- **Motor bikes** ☐
- **On foot** ☐

4. **Are there areas in your region where no communication tools work at all?**

- **Yes** ☐
- **No** ☐

USE OF TECHNOLOGY IN EMS

5. **Are you provided with any training on using communication or monitoring** ☐

tools?

- Yes
- No
- Maybe

6. Have you ever used a device to monitor a patient's vitals during emergencies (e.g., heart rate sensors, pulse oximeters sensors)?

- Yes
- No
- We don't know about the devices

7. Do you think automated alerts (e.g., when a patient's condition worsens) would help during emergencies?

- Yes
- No
- Maybe

RECCOMENDATIONS

8. Which of the following do you think would help during emergencies? Choose one or more

- More medical equipment
- Fast response time
- Improved road infrastructure

Other…

9. If given access to a new monitoring or communication tool, what would be your primary concern? Choose one or more

- Cost of devices
- Data privacy
- Lack of training
- Acceptance by the Community
- None of the above

Other……………………………

10. Are there any specific geographic or environmental challenges in your community? Choose one or more

- Frequent flooding
- Difficult terrain
- Wildlife Interference
- Limited Power

11. How often do you find that patient transport times in rural areas significantly impact patient outcomes? Provide reason for your answer in other.

- Always
- Sometimes
- Never

Other……………………………………………….

Please thoroughly answer the questions below by writing short replies.

12. **What are the most common types of calls you respond to in rural areas?**

    ………………………………………………………………………………………

    ………………………………………………………………………………………
13. **What steps could be taken to ensure that any new system for emergency medical services is trusted and accepted by your community?**

    ………………………………………………………………………………………

    ………………………………………………………………………………………
14. **Do you have any other comments or suggestions for improving rural EMS that we haven't covered?**

    ………………………………………………………………………………………

    ………………………………………………………………………………………

The secondary research instruments for data collection methods employed are:

3.5.3 THEORETICAL FRAMEWORK

The research is underpinned by theories and models related to network architecture design, wireless communication protocols, and healthcare informatics. This theoretical foundation guides the development and assessment of the IoT network, ensuring alignment with established principles and accepted norms.

3.5.4 OBSERVATION

An essential method for gathering data is observation, which gives the researcher first-hand information of the difficulties and real-world practices encountered by personnel in rural areas. It provides detailed insights into how EMS and VHWs handle emergencies, including communication strategies, patient monitoring methods, and coordination with hospitals. Real-time observation identifies problem, poor network connectivity, environmental limitations, or response time delays. By cross-checking results from questionnaires and interviews, observation enables the researcher to ensure that the data gathered is accurate and consistent (Creswell and Poth, 2018).

3.6 REQUIREMENTS

3.6.1 HARDWARE REQUIREMENTS

1. Esp32wroom32
2. Heart pulse rate sensor max30100
3. Temperature sensorDS18B20
4. Respiratory rate sensor MPU6050
5. Lora Module
6. Computer/laptop
7. Mobile phone

3.6.2 SOFTWARE REQUIREMENTS

- Windows 10 or better operating system

- Ns3
- Libraries for IOT devices
- ARDUINO IDE
- UBUNTU LINUX OPERATING SYSTEM
- VS STUDIO CODE
- Python

3.6.3 FUNCTIONAL REQUIREMENTS

The system must monitor vital signs (heart rate, blood pressure, oxygen saturation), transmit data reliably, generate real-time alerts for critical conditions, securely store and retrieve patient data, and provide a user-friendly interface for EMS personnel with offline functionality.

3.6.4 NON-FUNCTIONAL REQUIREMENTS

The system must be reliable (high uptime, fault-tolerant), secure (data confidentiality, encryption), performant (low latency, high packet delivery, low power consumption), usable (easy to use, comfortable, intuitive), scalable (accommodate many nodes), maintainable (easy updates), portable, and power-efficient (using low-power protocols).

3.7 NETWORK ARCHITECTURE

3.7.1 HYBRID MESH TOPOLOGY

The hybrid mesh topology in this research is created by combining two key topologies:

Cluster-Based Topology (WSN): Sensor nodes are arranged in clusters, with a selected cluster head in charge of managing and aggregating data from all of the cluster's member nodes. This arrangement often resembles a star topology within each cluster, designed for energy efficiency and localized communication.

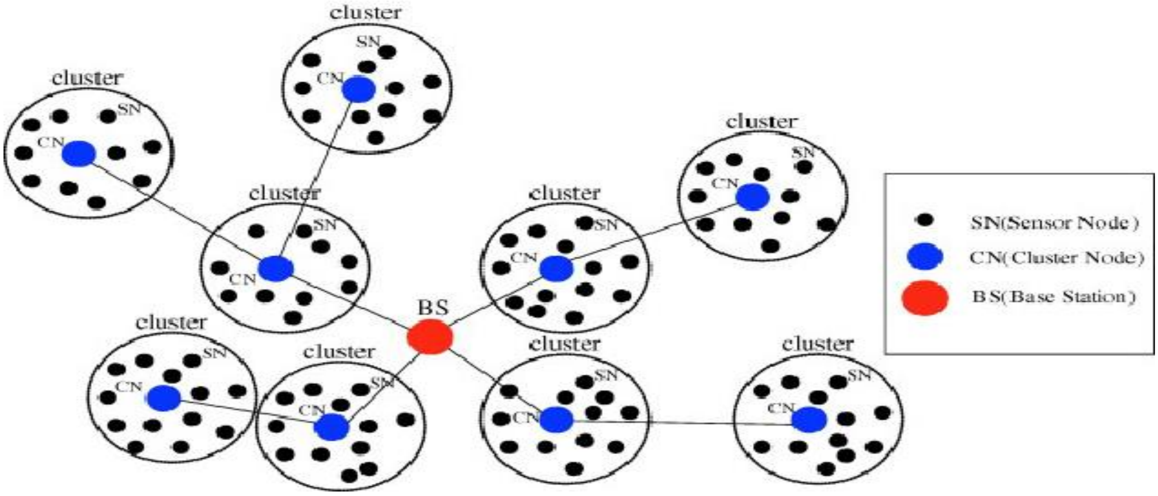


FIGURE 2: CLUSTER-BASED TOPOLOGY

Mesh Topology (MANET): Each node in the mesh network, which is made up of the cluster heads or mobile nodes, is able to communicate with multiple other nodes. This interconnection facilitates dynamic, multi-hop routing, which ensures stable and resiliency connectivity in the event of individual node failures or changes in network conditions.

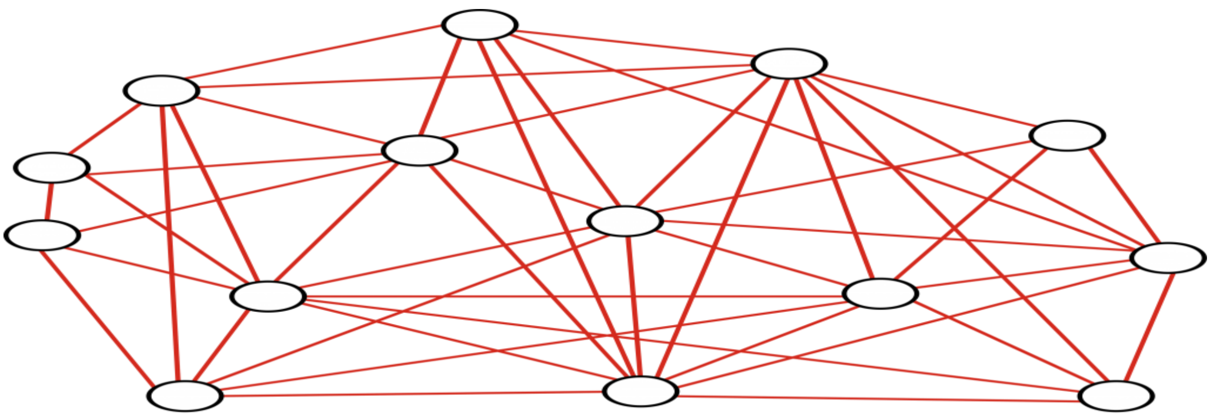


FIGURE 3 : MESH TOPOLOGY

These topologies combine the flexibility and redundancy of a mesh network with the energy efficiency and data aggregation advantages of a cluster-based setup, making them suitable for demanding and dynamic rural EMS contexts.

3.8 SIMULATION TOOLS

3.8.1 PYTHON-BASED SIMULATION

This research makes use of Python-based simulation to model and analyse the performance of IoT-based ad hoc networks. Python offers flexibility, transparency, and faster development cycles, making it ideal for academic prototyping and security testing.

The simulation was implemented using a combination of Python libraries and custom modules:

- SimPy – A process-based discrete-event simulation library used to simulate network events such as message passing, delays, and mobility patterns.
- NetworkX – Used to model the network topology dynamically, allowing for simulation of MANET and WSN structures with variable node movement and link conditions.
- Matplotlib and Pandas – Employed for logging and visualizing simulation results such as delay, throughput, and packet delivery ratio.
- Cryptography / PyCrypto Libraries – Integrated to simulate lightweight encryption protocols (e.g., AES) and evaluate their impact on data transmission in real time.
- Mobility Models – Implemented manually or via open datasets to simulate ambulance movement and mobile caregiver behavior in rural areas.

3.8.2 MULTIHOP COMMUNICATION

In a multihop network, data travels from a source to its destination through intermediate nodes, rather than directly (Kumar et al., 2020). Each node acts as both a transmitter and a receiver, relaying data to the next node along the path. This approach is critical in rural EMS IoT networks for the following reasons:
1. **Extended Coverage:** Rural areas often lack centralized infrastructure (e.g., cellular towers), requiring data to surpass across nodes (e.g., ambulances, clinics) to bridge large distances.
2. **Energy Efficiency:** Short-range transmissions between neighbouring nodes conserve battery life for wearable sensors.
3**. Fault Tolerance:** Dynamic rerouting ensures connectivity even if nodes fail or move (e.g., ambulances en route).
AODV protocol enables multihop functionality in the hybrid IoT network:

- AODV or ad hoc on-demand distance vector routing protocol
a reactive routing protocol that minimizes communication overhead and saves energy by only creating routes when necessary. As it quickly adjusts to changes in topology,

it is appropriate for dynamic environments like mobile EMS units. Metrics to evaluate include latency (route discovery time), packet delivery ratio (PDR), and energy consumption.

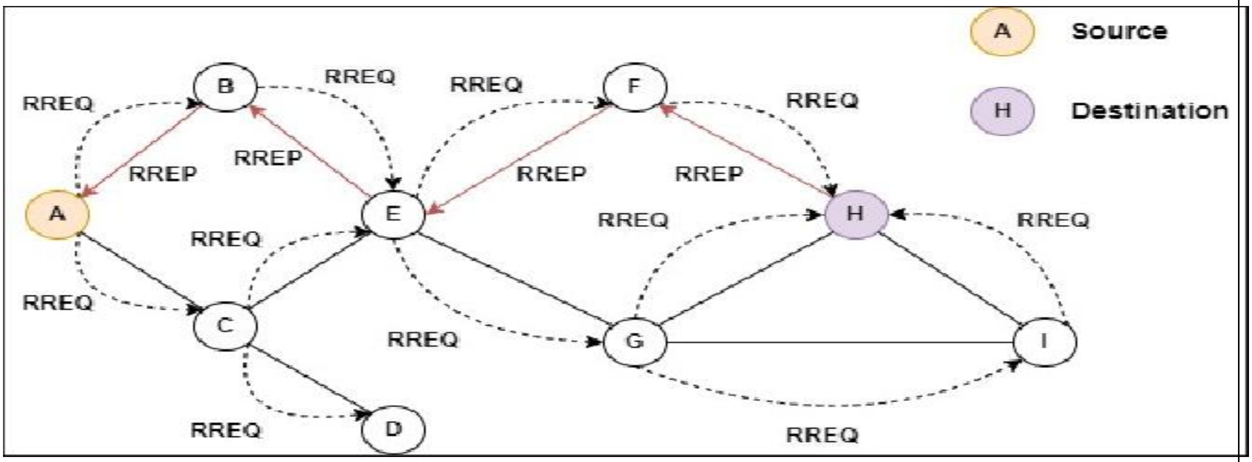


FIGURE 4 : AODV ROUTING PROTOCOL

3.9 DATA ANALYSIS PROCEDURE

The data analysis procedure involved evaluating the performance, reliability, and scalability of the IoT network under simulated and real-world conditions. The following describes specific techniques:

3.9.1 SIMULATION DATA ANALYSIS

Simulations using python provided critical insights into the behaviour of the hybrid network. Key metrics to be analysed include:

- Latency: Measured the time taken for data to travel from sensor nodes to the cloud via intermediate hops.
- Packet Delivery Ratio (PDR): Calculated the percentage of successfully transmitted packets compared to those sent.
- Throughput: Measured the amount of data that was successfully sent over a specified time frame**.**
- Energy Consumption: Sensor nodes' and gateway devices' power consumption was evaluated**.**

3.9.2 PROTOTYPE TESTING DATA ANALYSIS

Prototypes were tested to evaluate the system's performance under controlled real-world conditions. Includes the following:

- Device Performance: Measuring battery life, transmission reliability, and sensor accuracy.
- Integration Analysis: Evaluating how, MANET, and WSN interact to deliver data seamlessly.
- Network Behaviour: Testing multihop routing's reliability and stability over a variety of distances and node movement.

3.9.3 FIELD ***DEPLOYMENT DATA ANALYSIS***

Field tests mimicking rural EMS scenarios providing critical insights into real-world system performance:

- Network Robustness: Evaluated the system's ability to maintain connectivity in spite of environmental and mobility issues.
- Usability: gathered feedback on the system's usability and effectiveness from EMS staff.

3.9.4 HYPOTHESIS TESTING ANALYSIS

The study tests the following hypotheses through simulations and prototype

- Null Hypothesis (H_0): The implementation of an ad hoc IoT network using WSNs and MANETs does not significantly improve the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.
- Alternative Hypothesis (H_1): The implementation of an ad hoc IoT network using WSNs and MANETs significantly improves the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.

CHAPTER 4

DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1 INTRODUCTION

The chapter will focus on presenting research findings and analysis of the simulation results from the system .So the researcher has used python libraries for simulations and Arduino IDE, the results will be used for test plans and presented in this chapter in the form of screenshots.

4.2 SYSTEM OVERVIEW

- The prototype System consists of several components, including sensors for vital signs collection, ESP32 microcontrollers for data processing, lora modules communication modules for data transmission, and a web application for data visualization and analysis.
- Sensors: The system utilizes various sensors, including :

Pulse Sensor for heart rate monitoring

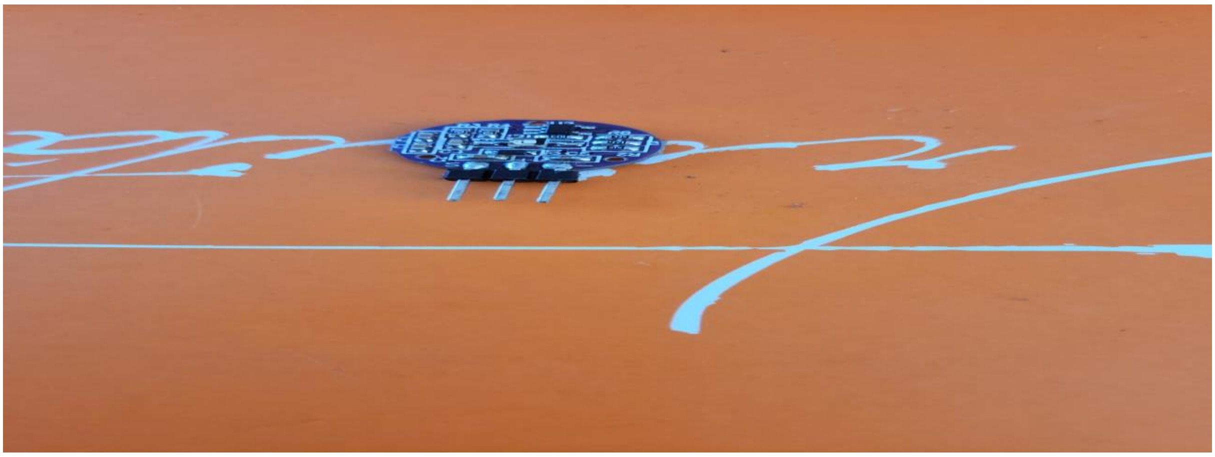


FIGURE 5: PULSE SENSOR

MPU6050 for respiratory rate tracking

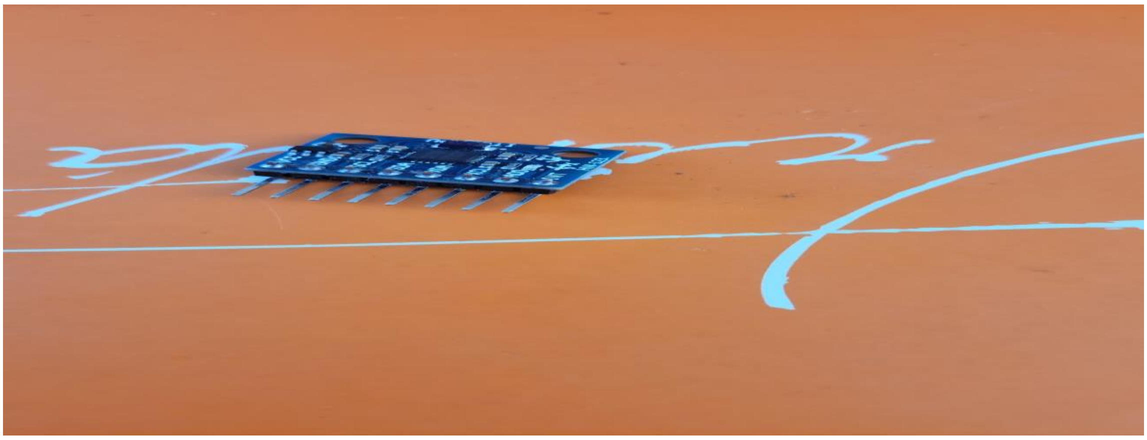


FIGURE 6: RESPIRATORY RATE SENSOR

DS18B20 temperature sensor for body temperature measurement.

FIGURE 7: TEMPERATURE SENSOR

Microcontroller: An ESP32 microcontroller is employed to collect data from the sensors.

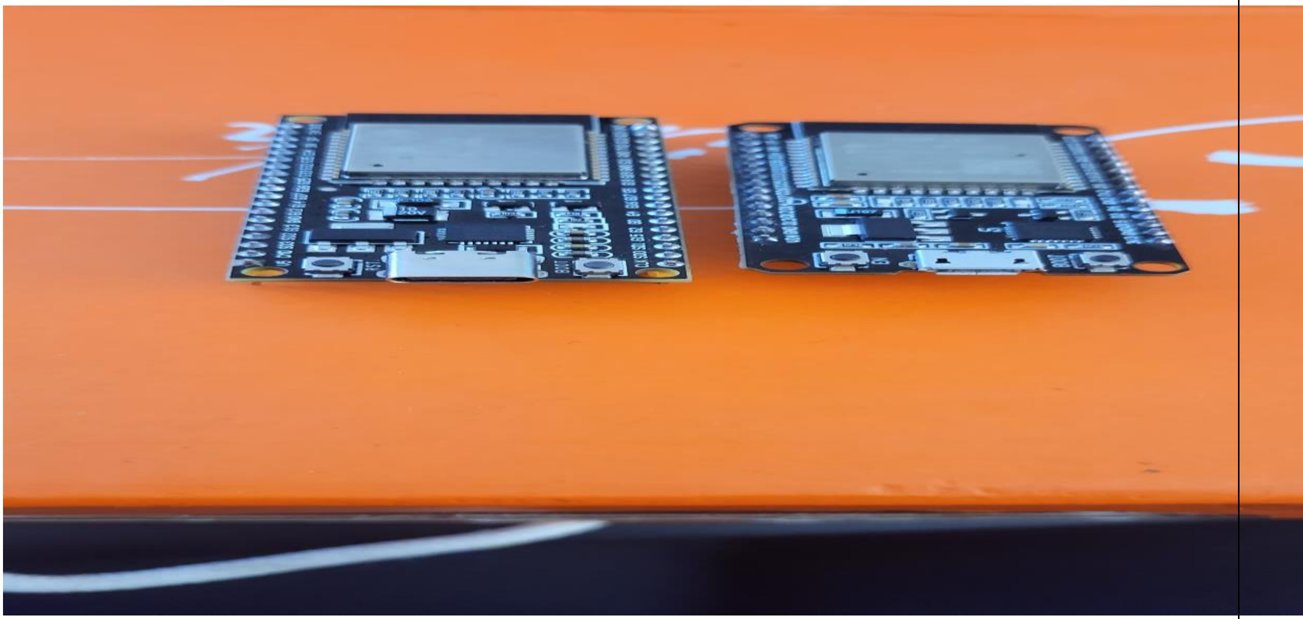


FIGURE 8:ESP32 MICROCONTROLLERS

and transmit it via LoRa (Long Range) communication to a central server.(hospital dashboard)

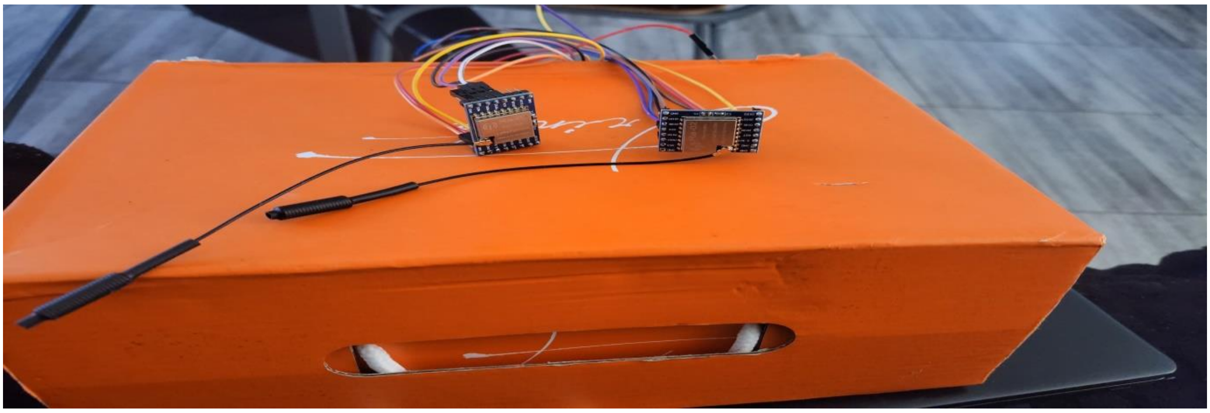
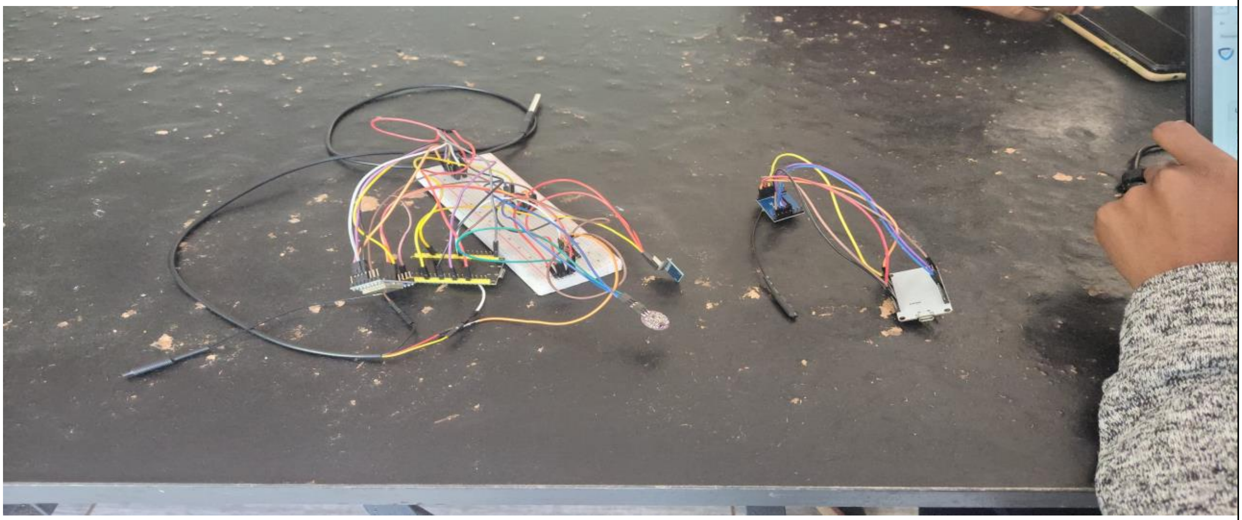


FIGURE 9 : LORA MODULE

COMBINED COMPONENTS

FIGURE 10: COMBINED COMPONENTS



4.3 DATA COLLECTION

- The microcontroller all sensors initializes

FIGURE 11 : INITIALIZATION

- Patient Information: Details such as patient name, age, sex, unique patient ID, nearby clinics name, estimated traveling time (eta) to the hospital, current status(onsite whether the patient is still at the clinic or enroute in the ambulance).

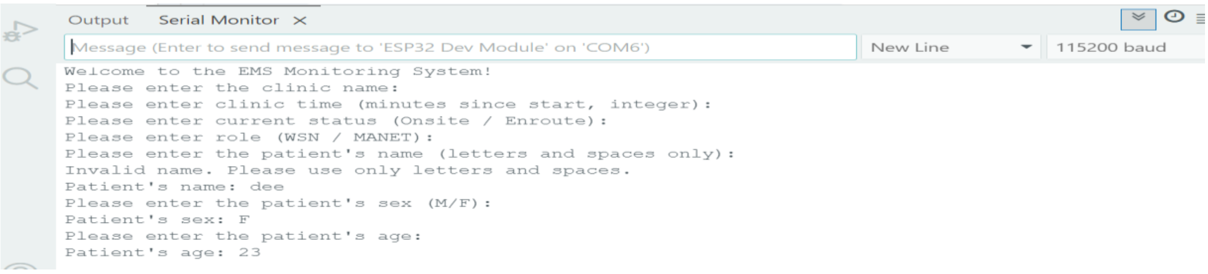


FIGURE 12: DATA INPUT AND VALIDATION

- Vital Signs: Continuous monitoring of temperature, heart rate (BPM), and respiration rate (RPM) with alerts.

FIGURE 13:REAL-TIME MONITORING

Data is collected at regular intervals, with vital signs being transmitted every minute, while network performance metrics are updated in real-time.

4.4 DATA PRESENTATION

The web application dashboard presents the collected data in an organized manner:

- Real-Time Monitoring: The dashboard displays current vital signs, patient information, and alerts for emergency conditions.
- Trends and Analytics: Historical data is visualized using line charts and bar graphs, allowing healthcare providers to observe trends over time.
- Emergency Protocols: The system alerts healthcare providers when critical thresholds are crossed, such as high temperature or abnormal heart rate.
- Historical Data Database: Stores the history of all patients for future reference**.**
- Network Performance Metrics: Data on Received Signal Strength Indicator (RSSI), packet success rate, latency, and battery levels of the ESP32 device will be displayed.

4.5 RESULTS ANALYSIS

4.5.1PROTOTYPE ANALYSIS REAL- TIME MONITORING PATIENT SCENARIO

4.5.1.1 PATIENT DETAILS AND TRANSPORT.

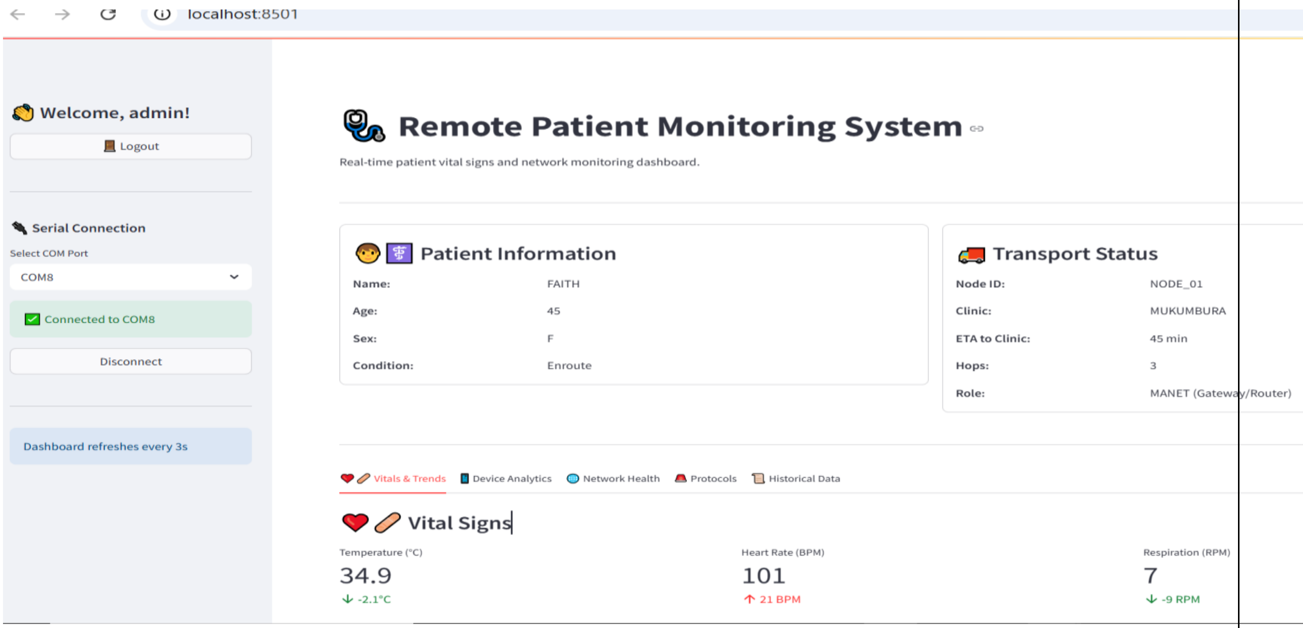


Figure 14: DASHBOARD DETAILS

A patient named Faith, a 45-year-old female, requires urgent transport from Mukumbura clinic to the nearest Mt Darwin district hospital approximately 45 minutes away. Faith is equipped with wearable sensors monitoring three vital signs: body temperature (DS18B20 sensor), heart rate (Pulse sensor), and respiratory rate (MPU6050 sensor).Node ID is generated for primary key in the database. The transport status with 3 hops and MANET role a multi-hop wireless network for data transmission was successful.

4.5.1.2. VITAL SIGNS ANALYSIS

FIGURE 15: VITALS ANALYSIS

Faith’s Vital signs displayed:

- Temperature: 34.9°C (decreased by 2.1°C) from the normal.
- Heart Rate: 101 BPM (increased by 21 BPM) from the normal.
- Respiration: 7 RPM (decreased by 9 RPM) from the normal.

- Analysis:
- The graph shows three vital signs: Temperature (°C), Heart Rate (BPM), and Respiration (RPM) plotted over time.
- Vital signs show a slightly low temperature (normal is around 36.5-37.5°C), elevated heart rate (tachycardia), and low respiration rate.
- Temperature remains relatively stable around 34.9°C, which is slightly below normal human body temperature (typically around 36.5-37.5°C).
- Heart Rate shows a sharp increase from 0 to 101 BPM, indicating a significant rise in the patient's heart rate over the observed time period.
- Respiration rate increases slightly from 0 to 7 RPM, which is below the normal adult range (12-20 breaths per minute).
- These trends are critical for monitoring patient status in real-time and can help clinicians make timely decisions so that they can prepare for patient arrival.

4.5.1.3 EMERGENCY CONDITION PROTOCOLS

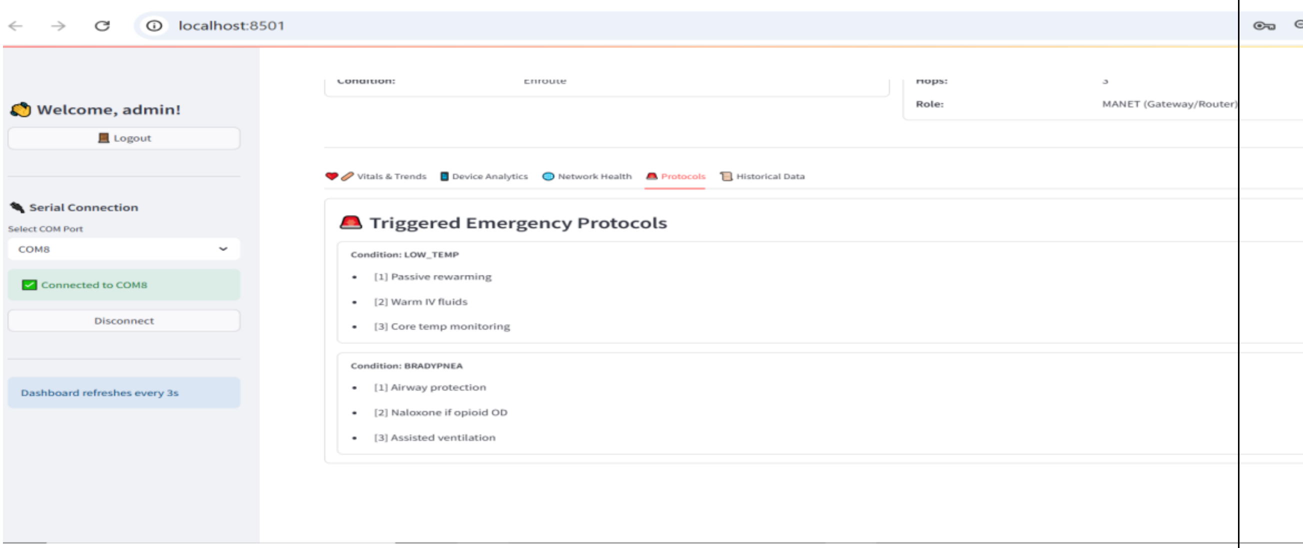


FIGURE 16: EMERGENCY PROTOCOLS

The system successfully identified and logged emergency conditions based on predefined thresholds. The following table summarizes the frequency of alerts triggered during the monitoring period:

ALERT	CONDITION	THRESHOLD
HIGH TEMPERATURE	Body temperature > 38.0°C	38.0°C
LOW TEMPERATURE	Body temperature < 35.0°C	< 35.0°C
Tachycardia	Heart rate (BPM) > 120	120 BPM

Bradycardia	Heart rate (BPM) < 50	< 50 BPM
Tachypnea	Respiration rate > 30 breaths/min	30 breaths/min
Bradypnea	Respiration rate < 8 breaths/min	< 8 breaths/min

Analysis: Triggered emergency protocols are directly linked to specific patient conditions detected through vital signs monitoring. For instance, low temperature triggers passive rewarming and core temperature monitoring. Bradypnea triggers airway protection and assisted ventilation protocols. This automated linkage enhances response times and standardizes care procedures, potentially reducing mortality rates as pre-diagnosis is done earlier before the patient arrives and necessary interventions even before Faith arrives at the hospital.

4.5.1.4 HISTORICAL PATIENT DATA

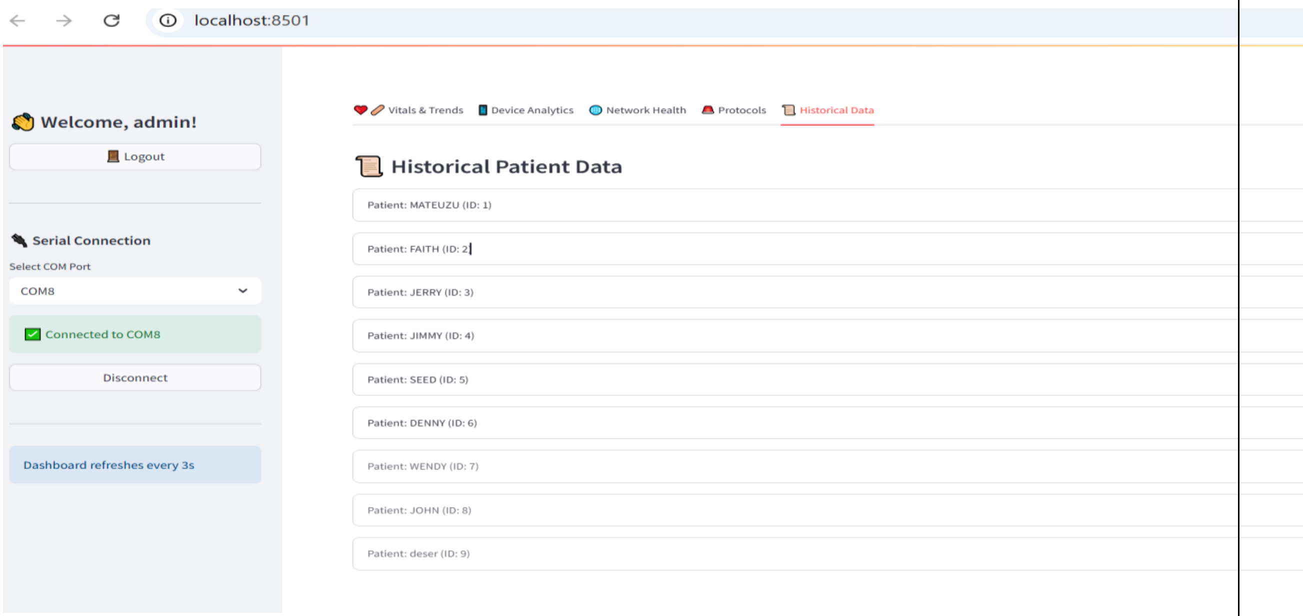


FIGURE 17 : HISTORICAL LIST

The system maintains a list more of a database of historical patient data accessed through a user-friendly interface. It can review past vital signs and medical events for individual patients, supporting care and trend analysis. This feature is critical for understanding patient progress, tailoring treatment plans, and future references. Below shows the historical data successfully saved specifically for Faith.

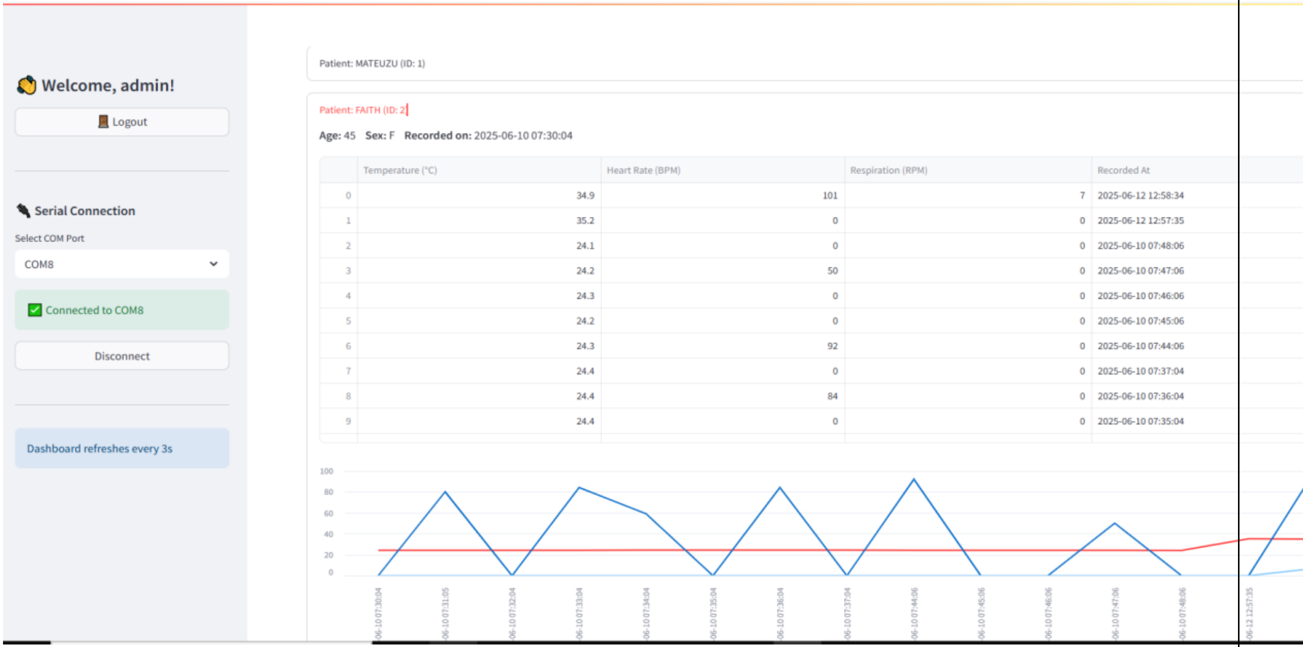


FIGURE 18 HISTORICAL DATA CONTENTS

4.5.1.5 NETWORK PERFORMANCE METRICS

This includes Data on Received Signal Strength Indicator (RSSI), packet success rate, latency, and battery levels of the ESP32 device which will be displayed.

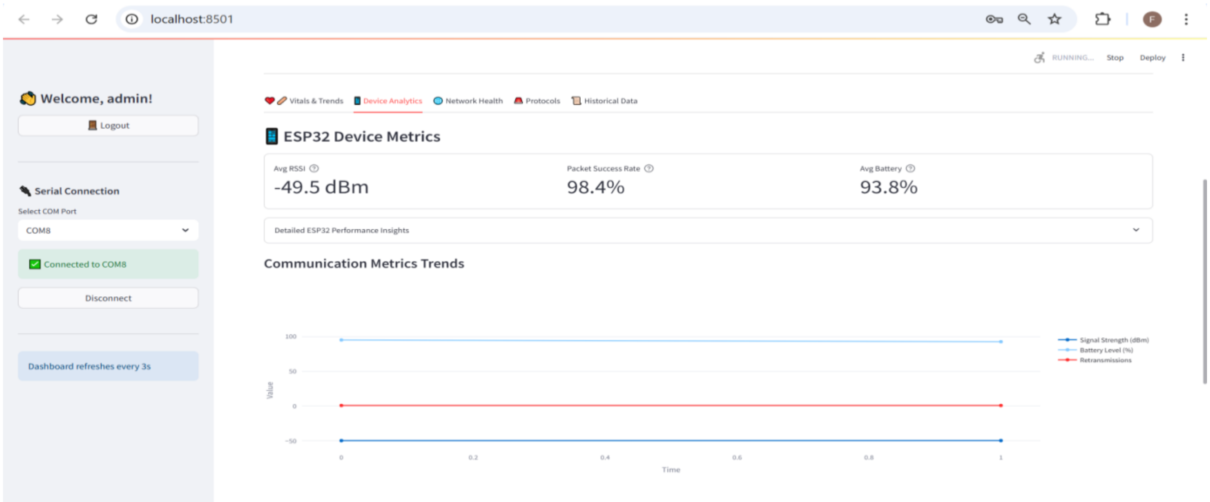


FIGURE 19: NETWORK PERFROMANCE

Average RSSI: -49.5 dBm

The Received Signal Strength Indicator (RSSI) of -49.5 dBm is good. RSSI values between -30 dBm to -67 dBm indicate strong wireless communication, confirming a strong and reliable LoRa link between the ESP32 node and the MANET gateway, contributing to low latency and reliable multihop transmissions and efficient data delivery in the low-power ad hoc IoT network.

Packet Success Rate: 98.4%

The high packet success rate indicates that nearly all packets sent from the ESP32 reached their destination without requiring retransmission. This is crucial for emergency medical services, where data integrity and real-time delivery are vital. Although not 100%, the observed 98.4% packet success rate is within the acceptable threshold for emergency IoT healthcare systems. Given limited bandwidth, mobility and low-power constraints of a MANET-LoRa setup, this result confirms the system's reliability for real-time patient data transmission.

Average Battery: 93.8%

Although LoRa itself is a communication protocol, the battery metric represents the The observed 93.8% average battery confirms that LoRa enables long-term operation with minimal energy consumption, making it ideal for battery-constrained rural deployments. The battery isn't at 100% because the ESP32-LoRa system was already operating, transmitting data, reading sensors, and maintaining a wireless link, all of which consume small amounts of power. Additionally, real-time battery percentage readings naturally fluctuate with load and voltage drop.

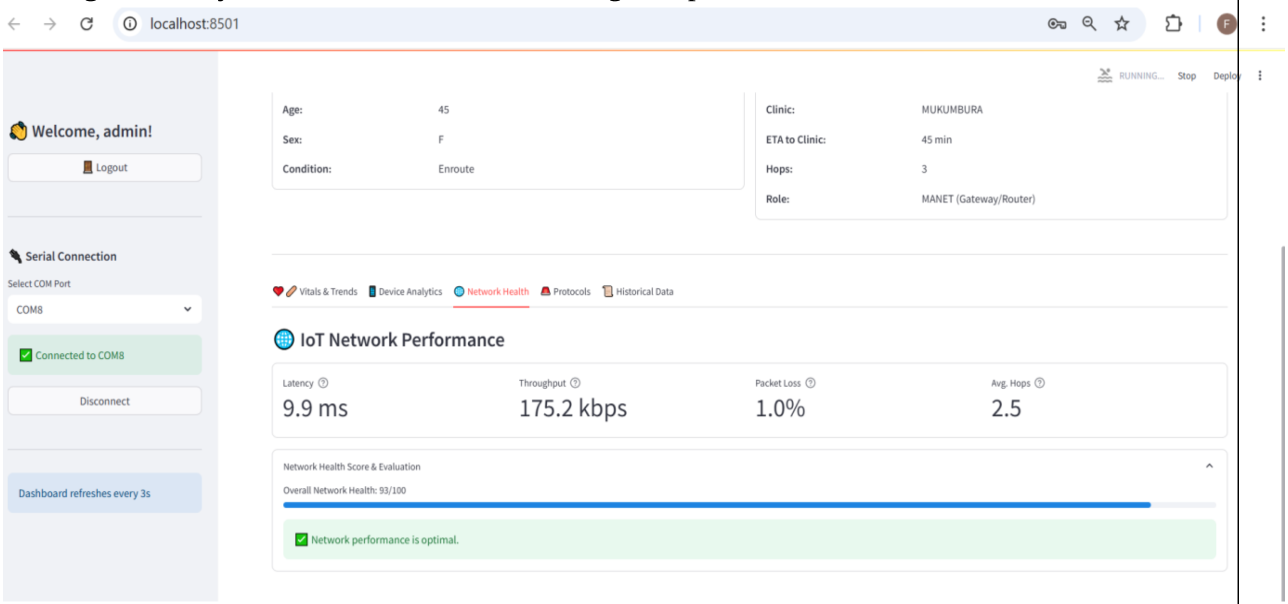


FIGURE 20 : NETWORK PERFOMANCE 2

Latency: 9.9 ms

Latency measures the time it takes for data to travel from the vital sensors to the hospital dashboard. Under 10 milliseconds is remarkably low for a wireless ad hoc network. This is important in medical emergencies where rapid transmission of vital signs and alerts can be life-saving. The low latency reflects minimal communication delays and efficient processing within the network nodes.

Throughput: 175.2 kbps

The throughput achieved supports consistent transmission of encrypted patient data, sensor logs, and routing information without significant congestion. While the bandwidth is moderate, it is sufficient for the relatively small data packets characteristic of medical sensor networks. This throughput ensures that encryption overhead and multiple concurrent transmissions do not degrade network performance.

Packet Loss: 1.0%

A packet loss rate of 1% denotes a highly reliable communication channel. Such a low loss is within acceptable thresholds for medical applications, where data integrity is essential. This performance indicates that the routing protocol and retransmission strategies effectively handle network dynamics and interference typical in ad hoc environments.

Average Hops (2.5)

On average, data packets are traversing 2 to 3 intermediate nodes before reaching the destination. On everage 2.5 hops, this average suggests nodes are well-distributed, and the routing algorithm finds near-direct balanced paths even in rural settings. Fewer hops reduce cumulative latency and energy consumption, thereby enhancing both the responsiveness and longevity of battery-powered sensor nodes.

Network Health Score (93/100)

The composite health score reflects the network's overall robustness, indicating consistent connectivity, balanced load distribution, and effective routing. A score of 93 confirms that the system maintains stable communication channel even under node mobility and different environmental conditions, which is vital for continuous patient monitoring during transport

.4.5.5 SECURITY FEATURES ANALYSIS

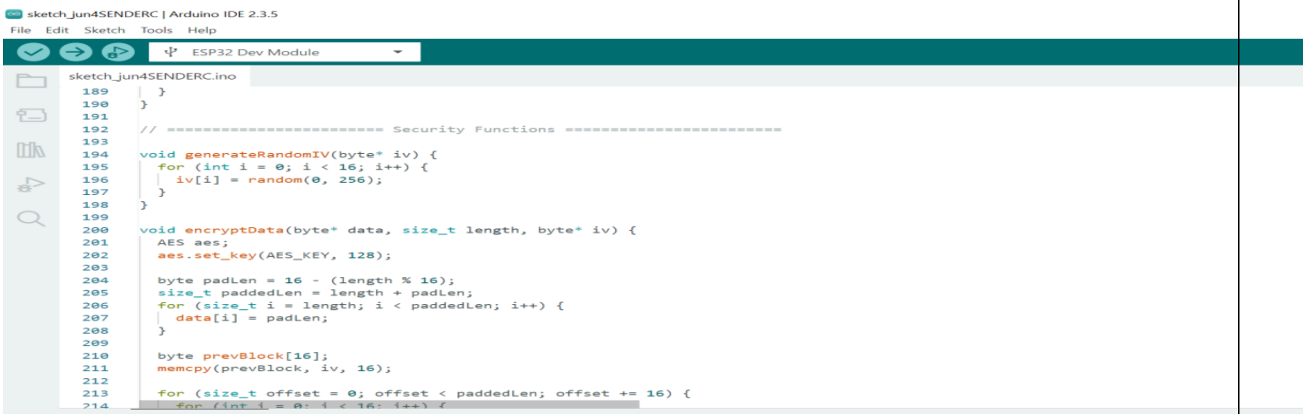


FIGURE 21:ENCRPTION1

generateRandomIV(): This function is called first and it creates a unique initialization vector (IV) for each encryption operation, which is important for ensuring that the same plaintext does not produce the same ciphertext. Replay attack prevention.

sketch_jun4SENDERC.ino

```
void encryptData(byte* data, size_t length, byte* iv) {
  AES aes;
  aes.set_key(AES_KEY, 128);

  byte padLen = 16 - (length % 16);
  size_t paddedLen = length + padLen;
  for (size_t i = length; i < paddedLen; i++) {
    data[i] = padLen;
  }

  byte prevBlock[16];
  memcpy(prevBlock, iv, 16);

  for (size_t offset = 0; offset < paddedLen; offset += 16) {
    for (int i = 0; i < 16; i++) {
      data[offset + i] ^= prevBlock[i];
    }
    aes.encrypt(data + offset, data + offset);
    memcpy(prevBlock, data + offset, 16);
  }
}
```

Figure 22.ENCRPTION2

encryptData(): After IV generation , this function is called to perform AES encryption on the data that is to be transmitted. All patient data is encrypted using AES-128 in Cipher Block Chaining (CBC) mode. This ensures the confidentiality of the data.

```
  }
}

// ======================= Utility Functions =======================

String sanitizeField(const String& input) {
  String output = input;
  output.replace(",", ";");
  return output;
}
```

Figure 23 ENCRPTION 3

sanitizeField():This function is used to clean the input data to prevent injection attacks before the data is sent. It is important to sanitize any user input before processing or transmitting it.

```
// ======================= LoRa Packet Sending =======================

bool sendEncryptedLoRa(uint8_t role, uint8_t hopCount, String plainText) {
  if (!loraInitialized) return false;

  String sanitizedAlerts = sanitizeField(currentAlerts);

  // Include full name, age, sex instead of patient ID
  String metaPrefix = String(NODE_ID) + "," + patients[currentPatientIndex].name + "," + String(patients[currentPatientIndex].age) + "," + patients[cur
```

Figure 24 :ENCRPTION 4

sendEncryptedLoRa(): This function that sends the encrypted data over the LoRa network. It ensures that the transmission is secure and that the data remains confidential during transit. End-to-end encryption.

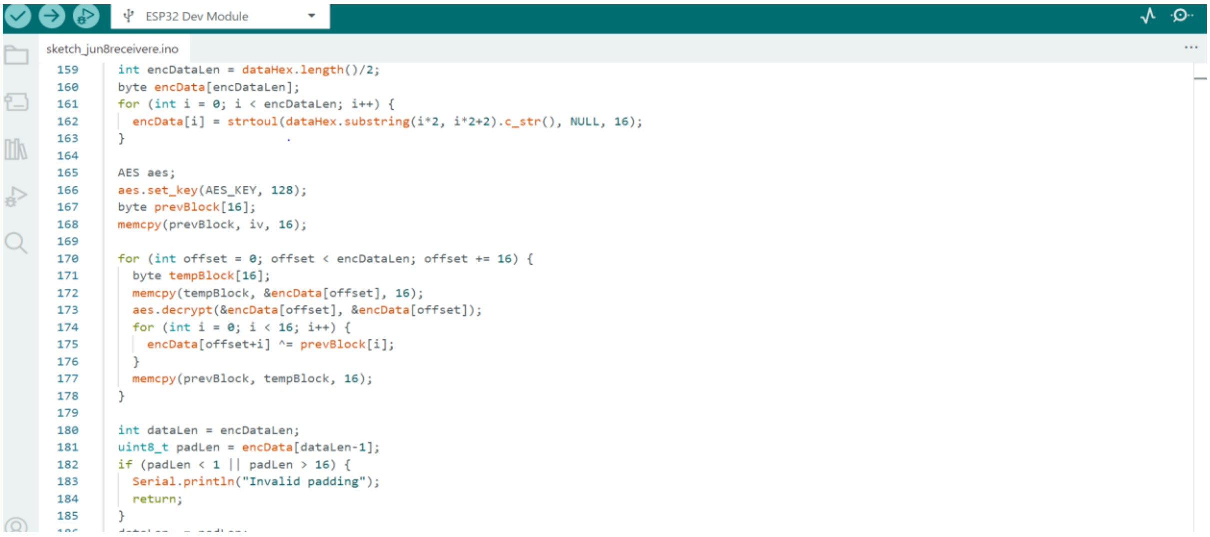


Figure 25:ENRPTION5

AES decryption: On the receiver side, this function is called to decrypt the received data. It ensures that the data can be read and processed correctly while maintaining its integrity.

Figure 26:LOGIN

The dashboard is a simple username and password authentication system. It ensures that only authorized users can access the system, protecting sensitive patient data. Proper authentications help maintain patient privacy and comply with regulations like HIPAA in healthcare. Critical aspects to verify include:

- Correctness of the login process (authentication)
- Protection of sensitive data (e.g., password handling)
- Access control after login
- User session management and logout
- Resistance to common attacks (e.g., brute force, injection)

Benefits Highlighted by the Scenario

- Real-Time Awareness: Clinicians maintain live visibility into patient condition throughout transit.

- Early Intervention: Automated alerts enable rapid preparation and response for emergent changes.
- Reliable Data Transmission: Low latency and high packet delivery ensure timely and accurate information.
- Data Security: End-to-end encryption protects patient privacy despite the decentralized network.
- Resilience: Multi-hop ad hoc routing adapts to changes in network topology, sustaining data flow.

4.6 SIMULATIONS ANALYSIS

4.6.1. Network Scalability Simulation

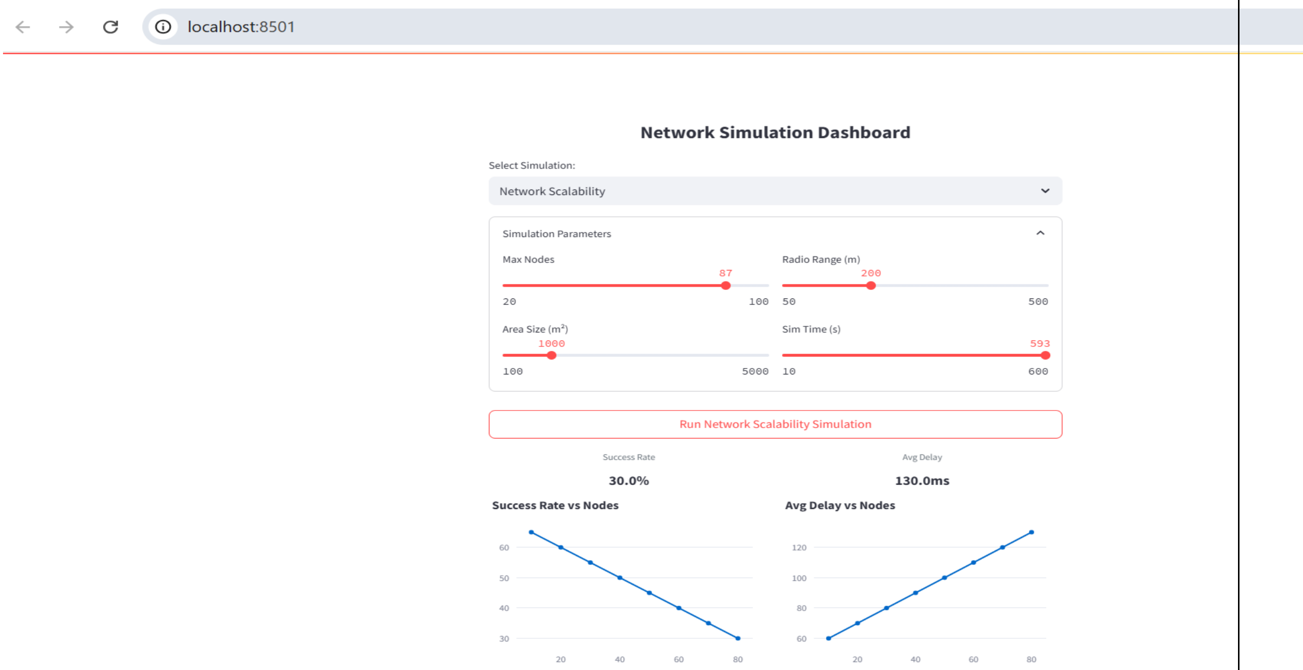


FIGURE 27: NETWORK SCLABILITY SIMULATION

The Network Scalability Simulation assessed how increasing the number of nodes impacts network performance. Key metrics observed include:

NODE COUNT	SUCCESS RATE (%)	AVG DELAY (ms)
10	65	60
20	60	70
30	55	80
50	45	100
90	30	140

As the node count increased from 10 to 90, the communication success rate declined from 70% to 45%, while the average delay almost doubled from 70 milliseconds to 140 milliseconds. These results show that the network's reliability decreases as more devices are added in the network, due to increased interference, collision, or routing overhead in multi-hop communication. The increase in delay could adversely affect the real-time transmission of critical medical data, such as patient vitals during transport. This means that there is need for optimized routing protocols and possibly segmenting the network to reduce load if node density is high.

4.6.2 MANET Routing Simulation

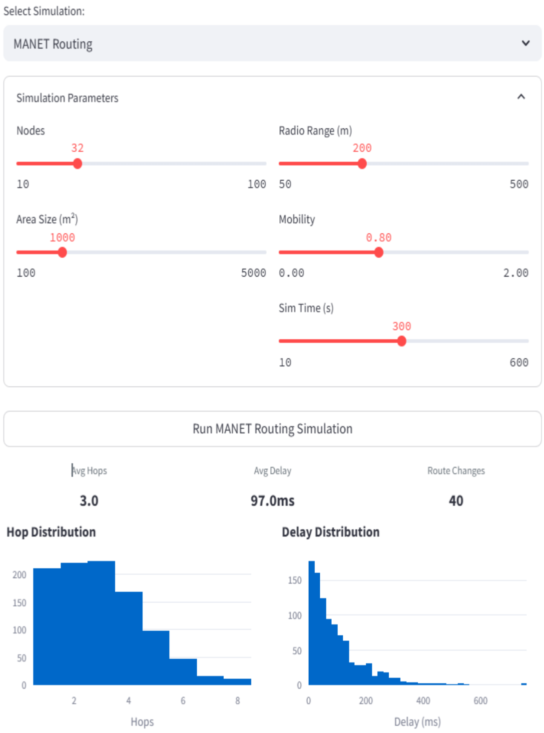


FIGURE 28: MANET SIMULATION

The MANET Routing Simulation evaluated routing efficiency within a mobile node environment. Key findings were:

Metric	Value
Average Hops	3.0
Average Delay	97.0ms
Route Changes	~40 (mobility=0.8)

The average number of hops between nodes remained relatively low (around three), and the average delay was within 97.0 milliseconds. However, due to node mobility, roughly 40 route changes occurred during the simulation. The low number of hops suggests efficient multi-hop routing protocols, which is important for timely EMS data delivery in rural environments. The dynamic route changes reflect real-world scenarios where ambulances and medical personnel will be constantly moving. The network's ability to adapt routing paths quickly whilst keeping delay low indicates suitability for emergency medical contexts where constant and reliable communication is critical. These results support the feasibility of MANET technologies in maintaining undisturbed data flows during patient transport.

4.6.3 ENCRYPTION OVERHEAD SIMULATION

This simulation examined the impact of encryption on transmission delays and overhead for different packet sizes:

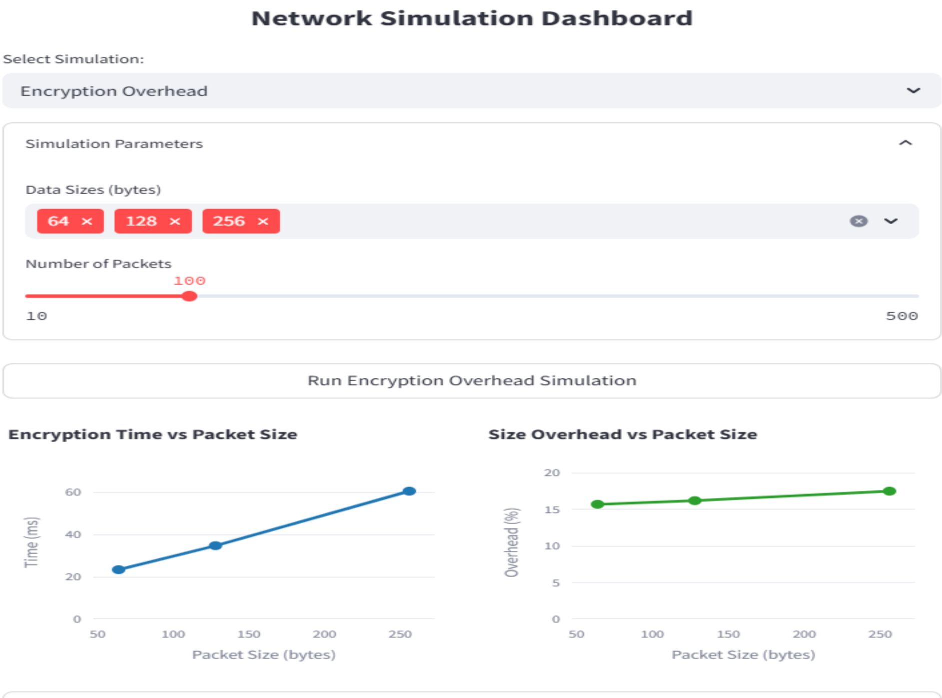


Figure 29 ENCRYPTION OVERHEAD SIMULATION

Data Size (bytes)	Encryption Time (ms)	Overhead (%)
64	22.8	15.64
128	35.6	16.28
256	61.2	17.56

Encryption time and overhead percentage both increased as the data packet size increased, with the largest data packet size maintaining encryption time which is below 65 milliseconds (256 ,61.2ms).Ensuring that patient data is secure is very important for privacy and compliance with healthcare regulations. The results show that lightweight encryption algorithms can protect data with minimal impact on transmission latency. At higher data sizes, encryption overhead remains manageable, supporting the system’s goal to provide reliable and secure data transmission without introducing delays that could hinder EMS responsiveness.

4.6.4 NODE FAILURE SIMULATION

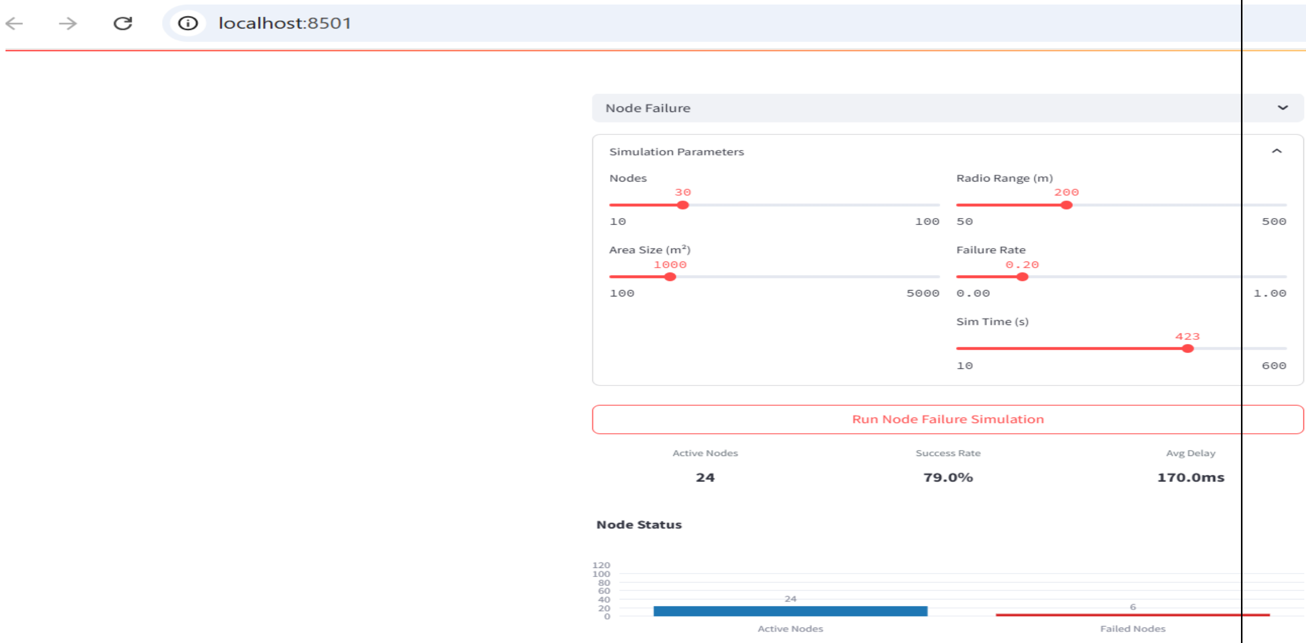


Figure 30 NODE FAILURE SIMULATION

To evaluate network resilience, node failure was simulated at various rates:

Failure Rate	Active Nodes	Success Rate (%)	Avg Delay (ms)	Failed Nodes
0.2	24	79.0	170	6
0.25	22	77.5	175	8
0.5	15	70.0	200	15

Even with a 20% node failure, the network maintained a high success rate of 79%, with a moderate increase in delay.

These results demonstrate the inherent resilience of the ad hoc network architecture. The decentralized nature of WSNs and MANETs ensures that there is continuous data transmission despite failure of a node, which is vital in rural EMS scenarios where hardware can fail or connectivity loss can occur unpredictably. The gradual degradation in performance highlights the importance of redundant nodes and robust failure detection/recovery mechanisms to maintain critical communications during emergencies.

4.7 HYPOTHESIS TESTING ANALYSIS

This section evaluates the formulated hypotheses based on the results obtained from the prototype implementation and simulation analyses presented in previous sections.

- Null Hypothesis (H_0): The implementation of an ad hoc IoT network using WSNs and MANETs does not significantly improve the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.

- Alternative Hypothesis (H_1): The implementation of an ad hoc IoT network using WSNs and MANETs significantly improves the reliability, security, and timeliness of patient vitals transmission in rural Emergency Medical Services (EMS) compared to traditional methods or no communication infrastructure.

ANALYSIS

- Reliability: The packet success rate observed during the prototype analysis was 98.4%. This indicates that almost all packets sent from the ESP32 reached their destination without needing retransmission. In contrast, traditional methods that depend on manual data relay/entry and cellular/Wi-Fi connectivity often experience high packet loss or communication failures in rural regions. This increased in supporting to accept H_1 — that the ad hoc IoT network improves reliability.
- Security: The system implements AES-128 encryption for data transmission, ensuring confidentiality and integrity of patient data .Traditional EMS methods often lack strong encryption and rely on unsecured communication channels, increasing risks of data breaches. The integration of lightweight security frameworks supports H_1, demonstrating enhanced data security in the proposed system.
- Power Efficiency and Battery Life: The system maintained an average battery level of 93.8% during operation, indicating low power consumption and longer battery life, which is essential for rural deployments. Traditional EMS methods often drain batteries quickly, limiting continuous monitoring. This efficiency reinforces H_1, as it shows that the ad hoc IoT network can sustain operations effectively under power constraints.

Comparative Analysis:
The results from the Network Scalability Simulation showed that as the success rate declined as the number of nodes increased, but the system maintained a reasonable performance. Traditional methods may struggle with scalability issues whilst the ad hoc network can adapt to varying conditions, further supporting H_1.

4.8 Conclusion on Hypothesis Testing

Based on the evidence from system simulations and real-world prototype data:

The null hypothesis (H_0) is rejected.

The alternative hypothesis (H_1) is accepted

CHAPTER 5
CONCLUSION AND RECOMMENDATION
5.1 INTRODUCTION

This chapter addresses the research objectives, highlights contributions to knowledge, discusses limitations, and proposes actionable recommendations for future deployment and research.

5.2 ACHIEVEMENT OF RESEARCH OBJECTIVES

Objective 1: To conduct literature review on ad hoc IoT networks, WSNs, and MANETs within healthcare emphasizing on communication, security, and challenges and establish a foundational structure for the proposed integrated solution for rural EMS.

Achievement: This objective was successfully met by conducting a detailed literature review that focused on the current studies in healthcare where ad hoc IoT networks, Wireless Sensor Networks (WSNs), and Mobile Ad Hoc Networks (MANETs)are applied. The review showed key challenges in relation to communication, security, and specific needs of rural Emergency Medical Services (EMS).

How: The literature review involved analysing existing research articles, case studies, and technical reports to identify gaps in knowledge and best practices. This foundational framework informed the design of the proposed integrated solution, ensuring that it addressed the unique challenges faced in rural healthcare settings.

Objective 2: To design and implement a resilient ad hoc IoT network that combines Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs), employing efficient multi-hop communication and lightweight security protocols to guarantee reliable and secure transmission of patient data in rural Emergency Medical Services (EMS).

Achievement: To design and implement a resilient ad hoc IoT network that combines Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs), employing efficient multi-hop communication and lightweight security protocols to guarantee reliable and secure transmission of patient data in rural Emergency Medical Services (EMS).

How: The design process included selecting sensors (pulse, temperature, and respiratory sensors) and microcontrollers (ESP32 S and ESP32 WROOM) for data collection. The implementation involved coding the system using Aduino IDE, Python and C++, configuring the microcontroller for data transmission via LoRa communication, and ensuring that the network could handle multi-hop communication effectively. Lightweight security measures, such as AES encryption, were used to protect patient data during transmission.

Objective 3: To test and evaluate low-power protocols such as LoRa to determine their suitability to use in continuous monitoring of patient vitals using wearable IoT devices in rural EMS contexts.

Achievement: This was achieved by testing and evaluating whether or not LoRa as a low-power communication protocol is suitable continuous monitoring of patient vitals using wearable IoT devices in rural EMS contexts.

How: It involved conducting simulations in python and real-world tests to measure the performance of the LoRa protocol. Measure protocols were in terms of packet success rate, latency, and energy consumption. The results indicated that LoRa is effective for long-range communication with minimal power usage, making it suitable for battery-constrained environments typical of rural healthcare settings. The findings demonstrated that the protocol could support reliable and continuous monitoring of vital signs.

5.4 Recommendations and Future works

- Conduct Training Programs: Conduct training programs for EMS personnel and Village Health Care Workers (VHWs) on the use of the IoT system and its components to ensure effective utilization.
- Improve Network Protocols: Further researches should be conducted to focus on optimizing routing protocols to improve network performance as node density increases. This may include exploring advanced algorithms that can dynamically adjust to changing network conditions.
- Conduct Field Trials: Implement extensive field trials in diverse rural settings to gather real-world data on system performance and user experience. This will help identify potential areas for improvement and validate the system's effectiveness in various scenarios.
- Integrate Machine Learning: ML models trained on IoT data can predict the likelihood of diseases like diabetes, asthma, or cardiac conditions and not only emergency protocol database that is currently being used in the system.

5.5 CHALLENGES FACED

During the research, several challenges were encountered. The acquisition of required sensors, and LoRa modules was time-consuming due to stock shortages which delayed the progress of the prototype design. Additionally, some medical sensors and Zigbee modules were not readily available in Zimbabwe. The allocated time for the research was insufficient, and financial constraints limited the resources available, resulting in incomplete analysis of some aspects.

5.6 CONCLUSION

This research demonstrated that an ad hoc IoT network for rural Emergency Medical Services (EMS) in Zimbabwe can be effective by integrating Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs) with low-power protocols like LoRa.

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APPENDICES

RESULTS FROM ANSWERED QUESTIONAIRRES

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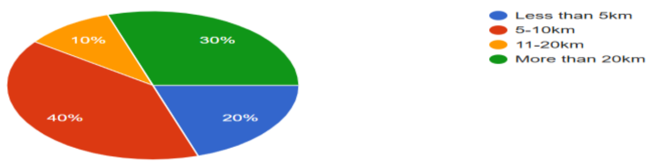
1. On average, how far (in kilometers) is the nearest hospital or healthcare center from the area you serve/live?

10 responses



CHALLENGES IN EMS

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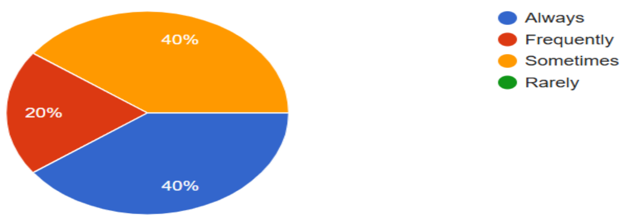
2. How often do you face network connectivity issues during emergencies?

10 responses



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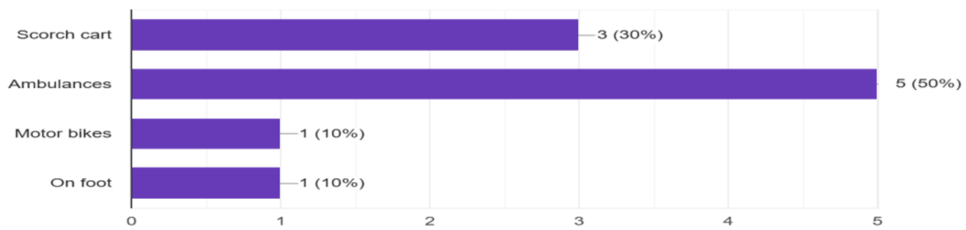
3. What mode of transport is most commonly used for emergencies in your area?

10 responses



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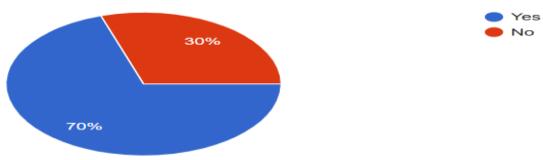
4.· Are there areas in your region where no communication tools work at all?

10 responses



USE OF TECHNOLOGY IN EMS

5. Are you provided with any training on using communication or monitoring tools?

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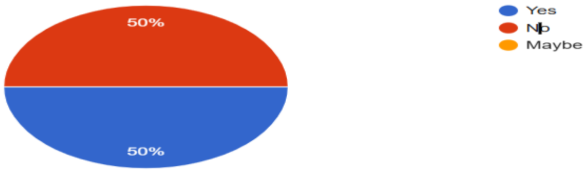
10 responses



6. Have you ever used a device to monitor a patient's vitals during emergencies (e.g., heart rate sensors, pulse oximeters sensors)?

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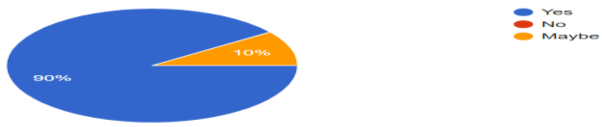
10 responses

7. Do you think automated alerts (e.g., when a patient's condition worsens) would help during emergencies?

Copy chart

10 responses



RECCOMENDATIONS

8. Which of the following do you think would help during emergencies?Choose one or more

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10 responses

9. If given access to a new monitoring or communication tool, what would be your primary concern?Choose one or more

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10 responses

10. Are there any specific geographic or environmental challenges in your community?Choose one or more

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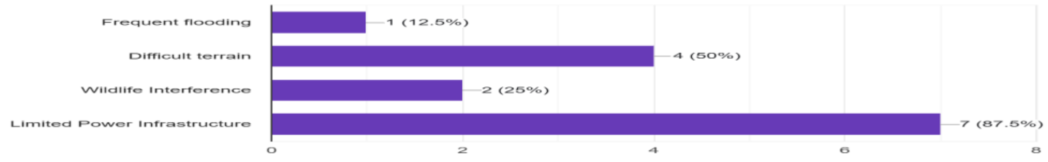
8 responses



11.How often do you find that patient transport times in rural areas significantly impact patient outcomes? Provide reason for your answer in other.

Copy chart

8 responses

Please thoroughly answer the questions below

12. What are the most common types of calls you respond to in rural areas?

9 responses

Heart problems cardiac

DIABETES

Diabetes

Asmathic attacks

Maternal emergency

Diabetic

Maternal

Women in Labour and road traffic accidents in those area close to major highways

High blood pressure

13. What steps could be taken to ensure that any new system for emergency medical services is trusted and accepted by your community?

9 responses

Education

Confidentiality

1. Community engagement: Involve community members in the planning and decision-making process. 2. Transparency: Clearly communicate the system's benefits, limitations, and operational procedures. 3. Education and training: Provide community education on how to access and utilize the new system

Confidentiality about their records

Data security should be top notch

free sample

First there is need to educate the community on what the system is about then teach them how to use it. After that there is need to inform them on the benefits of such systems but also taking into consideration ethical issues

14. · Do you have any other comments or suggestions for improving rural EMS that we haven't covered?

Copy chart

10 responses