SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Defense Energy-Efficient Lora Mesh Network Topologies in Disaster Operations

Khairol Amali Ahmad[1], Fakroul Ridzuan Hashim[2], Mohd Sharil Salleh[2]

[1] Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, Kuala Lumpur, Malaysia
[2] Centre for Research and Innovation Management, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 27 November 2026
Received in revised form 20 February 2026
Accepted 15 April 2026
Available online 4 May 2026

Keywords:
LoRa module, network communication, disaster operation

ABSTRACT

Amidst the changing realm of radio communication and IoT frameworks, the formulation of propagation models aligns with emerging IoT communication protocols for optimal performance. This study delves into the judicious arrangement of LoRa gateways and nodes to facilitate effective communication in the context of disaster operations. The complexities confronting emergency management, notably the Malaysia Civil Defence Force (MCDF), are heightened by the escalating intricacy of disasters and emergencies. The continuous amelioration of search and rescue operations, evacuation procedures, emergency medical services, and the provisioning of essential amenities is imperative. Consequently, a tangible solution materializes in the form of a prototype device integrating a comprehensive LoRa radio module. Functioning within the 433MHz and 868MHz frequency bands, this energy-efficient, long-range transceiver streamlines efficient communication. The proposed offline communication network incorporates primary LoRa modules and an array of LoRa submodules, providing Wi-Fi access points and facilitating communication through Wi-Fi-enabled smart devices. This setup empowers survivors to relay vital details to rescue teams via LoRa communication, thereby expediting essential actions. Suggestions for bolstering security measures for mobile devices operating in ad hoc mode and a meticulous examination of gateway-free solutions in LoRa mesh networks for practical disaster scenarios are put forth. Future work endeavours aim to augment the efficacy of disaster management initiatives reliant on LoRa technology.

1. Introduction

In the dynamic landscape of radio communication and IoT protocols, the development of new propagation models holds significant importance. It is crucial to align these models with the design of emerging IoT communication protocols to ensure optimal performance. The strategic placement of LoRa gateways and nodes becomes pivotal for achieving high-level efficiency. The advent of numerous IoT technologies promising long-range communications introduces the necessity for robust communication links, even in challenging environments. Public awareness of potential risks is paramount, enabling proactive measures and facilitating swift responses from rescue teams during events like landslides.

The intricacies faced by emergency management, particularly the Malaysia Civil Defence Force (MCDF), have amplified due to the increasing complexity of disasters and emergencies. The response

mechanisms orchestrated by disaster management agencies, such as search and rescue operations, evacuation procedures, emergency medical services, and provision of essential amenities, are integral components that necessitate continual enhancement. The evolving landscape of disasters requires emergency administrators to seek appropriate solutions to address emerging challenges effectively.

In response to these challenges, the development of a prototype device integrating a full-stack LoRa radio module, exemplified by the Microchip RN2483, emerges as a practical solution. Operating in the 433MHz and 868MHz frequency bands, this low-power, long-range transceiver facilitates efficient communication. The ATMEGA328p complements this by generating packets and managing the user interface. Prototyping, facilitated by readily available modules within the embedded systems community, streamlines the development process.

The proposed offline communication network embraces main LoRa modules and a cluster of LoRa submodules. These submodules serve dual purposes, offering a Wi-Fi access point and enabling communication via Wi-Fi-capable smart devices. The ubiquity of IEEE 802.11-equipped smartphones further enhances the applicability of this system. Survivors or victims can leverage this system by filling out forms and communicating critical details to rescue teams through LoRa communication, expediting necessary actions.

LoRa, denoting Long Range, stands as a pivotal technology in this context, patented by Semtech. The communication system involves both main LoRa modules and a grouping of LoRa submodules, ensuring versatile and robust connectivity. Despite some limitations and subjective preferences among users, the system proves effective in catering to the preferences and motivations of residents.

The hardware and software prototype presented leverages on low-power-consumption devices, offering a tangible solution to the challenges posed by disaster scenarios. The research community's commitment to design lightweight solutions aligns with the growing reliance on the Internet of Things (IoT) in various sectors. As industrial, commercial, and consumer applications increasingly depend on data collected by diverse and remotely located devices, LPWANs (low-power wide-area networks) have emerged as a crucial technology. Among these, LoRa (long-range) technology, integrating chirp spread spectrum (CSS) radio modulation and forward error correction (FEC), has gained prominence for enabling robust long-range communications in unlicensed frequency bands.

This introduction sets the stage for exploring LoRa mesh networks, emphasising the evolving landscape of communication technologies, disaster management, and emergency response. Integrating LoRa technology in prototypes and communication systems signifies a promising avenue for addressing the challenges posed by contemporary disaster scenarios and enhancing the effectiveness of emergency response efforts.

The following sections will touch on the challenges in implementing LoRa mesh network for various applications, the significance of LoRa deployment, the overview of LoRa propagation performance and some prior studies on LoRa mesh network implementation for emergency communications. Then, this paper discusses on the existing and previous solutions of relevant communications systems employed for disaster, search and rescue operations and finally, identifies some research gaps and future research recommendations.

2. Literature Review

2.1 Mesh Network Challenges in Various Applications

The proliferation of wireless communication technologies, particularly in the context of disaster management and environmental monitoring, has led to an increased reliance on Mesh Networks. Mesh networks, crucial for applications like search and rescue operations, emergency management,

disaster response, and environmental monitoring, face several challenges that impact their effectiveness and efficiency. These networks, characterized by their ability to establish connections through a decentralized and interconnected structure, offer unique advantages for overcoming challenges associated with traditional systems. At this moment, existing literature reveals several key themes and issues addressed by researchers in this domain, each offering unique insights.

According to (Shih, Pang, and Hsiu 2018), they underscored the critical "Golden 72 Hours" after a disaster, emphasizing the need for efficient Search and Rescue (SAR) operations. The proposed Doppler effect-based framework for Wi-Fi signal tracking introduces innovative solutions, such as generating larger Doppler shifts by shaking the phone. Challenges arise in precise motion detection, potentially requiring additional hardware, like a self-motion antenna system. Cooperation among multiple rescuers' devices is suggested to enhance the system's effectiveness, promoting collaborative information sharing for joint target searches.

One crucial area of focus revolves around the utilization of LoRa (Long Range) technology in disaster scenarios. (Leon et al. 2018) proposed a Flood Early Warning System that leverages LoRa and social media to provide real-time alerts. The limitations of traditional flood warning systems prompted the need for innovative approaches to enhance efficiency and responsiveness. Similarly, (Saraereh et al. 2020) addressed the power constraints of battery-powered IoT devices by introducing a UAV-enabled LoRa network for disaster management. The growth of IoT devices necessitated low-power wireless communication protocols, and the integration of UAVs offered a promising solution. (Pan et al. 2022) addressed the challenges of monitoring environmental parameters in disaster-stricken areas with insufficient ground network coverage. The proposed UAV-aided emergency environmental monitoring system using LoRa mesh networking introduces a specialized communication protocol for dynamic UAV-WSN systems, emphasizing timeliness and robustness.

The exploration of LoRa-based mesh networks introduces another dimension to the discussion. (Berto, Napoletano, and Savi 2021) challenged the conventional LoRaWAN star topology, proposing a peer-to-peer mesh network for long-range communication. This approach aims to eliminate the dependency on gateways, providing a more flexible and resilient network architecture. The study identifies specific use cases, including forest fire detection and urban drainage, where mesh networking capabilities are crucial. They also advocate for a lighter protocol stack without gateways, presenting an alternative to existing mesh networking solutions. The issue of energy consumption in LoRa wireless mesh networks emerges as a critical concern. (Son et al. 2023) addressed this challenge, emphasizing the limited battery life of sensor nodes in systems without electric mains. The proposed solutions, including energy-saving and energy-super saving modes, aimed to maximize the lifetime of LoRa mesh networks, especially in remote areas without access to a power grid. (Wu, He, and Shi 2020) focused on energy-saving measurements in LoRaWAN-based wireless sensor networks, aiming to address the congenital defects of mesh networks. The study introduces an energy-efficient scheduling method, recognizing the importance of developing strategies to prolong WSN lifetime.

(Khonrang et al. 2023) highlighted the limitations of LoRaWAN topology for direct communication in single-hop scenarios, especially in long-distance multi-hopping data transmission for wildfire sensors. The study addresses difficulties in sending data to a gateway over long distances in a star-of-stars topology, emphasizing the challenges of communication in such scenarios. Furthermore, (Huh and Kim 2019) explored the limitations of LoRaWAN in private networks with special operation scenarios, highlighting challenges related to network coverage and high data collision rates. The study emphasizes the need for simplicity, reliability, and scalability in the deployment of private ad-hoc networks, particularly in temporary scenarios like construction fields.

The research background on mesh networks reveals a multifaceted landscape with interconnected themes. Researchers are actively addressing challenges in disaster management,

environmental monitoring, network architecture, and energy consumption. The exploration of LoRa-based mesh networks, peer-to-peer communication, and innovative solutions for energy efficiency reflects the evolving nature of this field. As researchers delve deeper into these challenges, the aim is to pave the way for more resilient, efficient, and adaptable mesh network solutions, especially in critical scenarios where traditional infrastructure may falter.

2.2 Overview of LoRa Propagation

The study conducted by (Anzum et al. 2022) presents a comprehensive exploration of LoRa propagation in the unique environment of a Malaysian palm oil plantation. The primary focus is on developing a multiwall path-loss prediction model using the 433 MHz LoRa-WAN frequency, with a specific emphasis on characterizing the impact of foliage in the plantation setting. LoRa, operating on sub-gigahertz bands such as 433 MHz, is known for its robustness against harsh multipath interfaces and Doppler effects, making it suitable for challenging environmental conditions.In the plantation landscape, adult trees form distinct lines, creating a scenario akin to multiple intervening walls for non-line-of-sight (NLoS) propagation paths. The researchers propose a multiwall path-loss model tailored to the plantation's tree arrangement, viewing the planted trees as intervening walls influencing signal propagation. This study, situated in Kuala Kubu Bharu, Selangor, Malaysia, covers 2 km of farmland designated for experimentation.

The research methodology involves a detailed measurement campaign in various scenarios within the plantation area. Noteworthy is the consideration of line-of-sight (LoS) and NLoS links, with the latter examined through two approaches: propagation through the trunk and propagation through the canopy. The experiment utilizes different LoRa configurations, and measurements are collected for path-loss prediction modeling. Received signal strength indicator (RSSI) data is crucial, considering its role as a transmission quality indicator in LoRa communication. The analysis delves into empirical data, comparing LoS and NLoS propagation results. Trunk and canopy attenuations are quantified, revealing variations in signal losses. The study offers insights into the effects of foliage on signal quality, with observations on obstacle loss due to oil palm trees and the impact of propagation through different parts of the tree structure. This study has recognised the unique characteristics of the plantation environment, offering valuable insights into signal propagation challenges and paving the way for further improvements in prediction models tailored to diverse foliage conditions.

2.3 Prior Studies on LoRa Mesh Networks for Emergency Communication

In recent years, there has been a growing interest in leveraging wireless communication technologies for effective emergency management and disaster response. The exploration of Long Range (LoRa) mesh networks, which offer distinct advantages in terms of range and energy efficiency in emergency communication and disaster management has garnered considerable attention from researchers. Several studies have delved into the potential of LoRa technology, emphasizing its suitability for various applications. The following review provides an overview of prior studies related to LoRa mesh networks in the context of disaster management.

(Shih, Pang, and Hsiu 2018) introduced a Wi-Fi-based rescue system, reducing search and rescue times significantly. Although focused on Wi-Fi, the study emphasizes the importance of swift and accurate location methods in emergency scenarios, laying a foundation for the subsequent exploration of LoRa. (Sciullo, Trotta, and Felice 2020) characterized LoRa technology for emergency communication systems, introducing the LOCATE system. The study highlighted the efficacy of multi-hop dissemination and proposed dissemination schemes, establishing LoRa's potential in large-scale

emergency scenarios. (Leon et al. 2018) proposed a flood early warning system using LoRa, demonstrating successful testing of river-level nodes. The study emphasized the reliability of LoRa communication and suggested incorporating additional protocols and mesh network functionalities for improved communication.

(Saraereh et al. 2020) evaluated UAV-enabled LoRa networks for disaster management, noting improvements in packet reception rate. The study highlighted the scalability and reliability of such networks, opening avenues for diverse applications, including wildfire monitoring. (Matracia et al. 2022) conducted a comprehensive review of post-disaster communication networks, presenting LAP-based solutions and exploring the integration of different technologies. While not exclusively focused on LoRa, the study laid the groundwork for understanding the broader landscape of post-disaster communication. (Pan et al. 2022) proposed a UAV-aided emergency environmental monitoring system with a LoRa mesh networking approach. The study emphasized successful transmission, low delays, and robustness to environmental changes, offering insights into enhancing emergency monitoring systems.

(Berto, Napoletano, and Savi 2021) presented a LoRa-based mesh network for peer-to-peer communication, demonstrating feasibility and multi-hop capabilities. The study suggested further optimizations, scalability assessments, and security considerations for the proposed mesh network. (Son et al. 2023) proposed an energy-saving solution for LoRa wireless mesh networks, introducing a customizable architecture. The study emphasized real-world experiments and suggested further evaluations, optimizations, and the extension of applications beyond IoT sensors. (Wu, He, and Shi 2020) investigated energy-efficient scheduling in LoRaWAN-based wireless sensor networks, introducing a compressed sensing-based scheme. The study focused on reconstruction algorithms and scheduling methods, providing insights into energy-efficient network design. (Khonrang et al. 2023) proposed a LoRa-based mesh sensor network for long-distance data transmission, particularly for wildfire sensors. The study emphasized the system's practicality, suggesting investigations into antenna rates, transmission power, and system efficiency in diverse conditions.

(Huh and Kim 2019) studied LoRa-based private networks for IoT applications, proposing an improved protocol with mesh networking. The study addressed issues with LoRaWAN, showcasing the potential of mesh networking in various IoT scenarios. (Ebi et al. 2019) proposed a synchronous LoRa mesh network for monitoring urban drainage systems. The study demonstrated improved transmission reliability and flexibility, suggesting further analyses, optimizations, and considerations for larger deployments. Lastly, (Ajayi et al. 2022) developed the Waternet, a network for monitoring water quality. The study utilized machine learning for water quality assessment and suggested future directions, including deep learning models, unsupervised ML, and multi-criteria decision-making approaches.

In summary, the reviewed studies collectively demonstrate the potential of LoRa technology in emergency communication and disaster management. While each study addresses specific aspects, such as tracking, alert systems, flood warnings, UAV-enabled networks, and post-disaster communications, they collectively contribute to building a foundation for the exploration of LoRa mesh networks in diverse emergency scenarios. The findings underscore the importance of scalability, reliability, security considerations, and the integration of diverse technologies for robust and effective emergency communication systems. Future research directions should consider the integration of different communication technologies, scalability, reliability, security aspects, and optimization procedures to further enhance the effectiveness of LoRa in disaster response.

3. Proposed Methodology

3.1 Existing Solutions for Disaster Search and Rescue

The exploration of existing solutions for disaster search and rescue operations unveils innovative approaches to address the challenges faced in post-disaster scenarios. The dynamic landscape of disaster management, particularly in scenarios where infrastructure is non-existent or severely compromised, necessitates sophisticated systems for efficient and rapid response. Many notable contributions in this domain are discussed, each presenting unique perspectives on disaster search and rescue methodologies and research findings as listed in Table 1.

In the subsequent sections, these research contributions will be explored and analyzed to provide a comprehensive understanding of existing solutions for flood disaster search and rescue. The goal is to unravel the technological advancements, challenges, and potential synergies within the realm of disaster management and response.

Table 1
Existing solutions and previous research contribution

References	Objectives	Methodologies	Findings
(Shih, Pang, and Hsiu 2018)	Develop a rescue system using the Doppler effect for Wi-Fi signal tracking to aid rescuers in locating disaster survivors efficiently.	Investigated the impact of the search and rescue environment on Doppler effect accuracy. Proposed an algorithm with three mechanisms to address the challenge of small Doppler shifts.	Improved direction-finding accuracy by eliminating frequency fluctuation and enhancing sensitivity on small frequency shifts.
(Abdul Kadir, Efendi, and Rosa 2018)	Develop a smart monitoring system using LoRa WAN sensor and IoT for environmental monitoring, specifically targeting land and forest fires in Riau Province, Indonesia.	Proposed the use of LoRa WAN sensor and IoT technology for long-range, low-power wireless data communication to detect land and forest fires.	LoRa technology enables data transmission up to 30 miles, covering vast impacted areas. Introduces sensors to detect fires and high-definition cameras for environmental image analysis.
(Sardi and Razak 2019)	Assess the effectiveness of emergency response time during a landslide event.	Emergency Response Planning (ERP) with the right decisions at the 'initial stage' is crucial.	Promising results were found in the effectiveness of emergency response time, emphasizing the importance of addressing disaster preparedness challenges. An effective ERP is crucial for an early warning system,

			enhanced public awareness, and preparedness with structured training programs.
(Yuan et al. 2009)	Present the features of microgrids and their applications to emergency response and disaster relief. Propose a control scheme for coordinated operation in a microgrid to meet emergency response and disaster relief requirements.	Simulation studies on a microgrid with multiple distributed energy resources to demonstrate the effectiveness of the proposed control scheme.	The proposed control scheme effectively coordinates interconnected units in the microgrid to meet emergency response and disaster relief requirements.
(Queralta et al. 2020)	Provide a global overview of the main approaches in multi-robot search and rescue (SAR) systems. Identify challenges and constraints for various types of robots in different SAR environments.	Overview of approaches in multi-robot SAR systems, including projects like COMETS, PeLoTe, NIFTi, ICARUS, TRADR, and SmokeBot. Detailed exploration of challenges and opportunities in different SAR scenarios, such as maritime, urban, and wilderness.	The survey serves as an entry point for researchers in machine learning and control fields into multi-robot SAR systems. It provides insights into challenges faced by various robots in different environments.
(Flint and Brennan 2006)	Train local volunteers as first responders to emergencies, and shift focus to community building.	CERT training, community involvement, disaster policy analysis.	Emphasis on local involvement as a first line of defense, CERTs' role beyond terrorism and national security.
(Sciullo, Trotta, and Felice 2020)	Develop LOCATE, a LoRa-based mobile emergency management system.	LoRa technology, anycast protocol, trilateration algorithm.	Effective multi-hop dissemination of alert messages in scenarios with no traditional infrastructures, such as rural or post-disaster environments.
(Saha et al. 2017)	Implement IoT for disaster	IoT standards, wireless sensing	IoT enables a solution for

	management, identify challenges in deploying IoT for disaster scenarios.	networks, Compressed Sensing (CS), disaster management.	disaster management at all stages of the emergency management lifecycle.
(Yang, Schafer, and Ganz 2017)	Enhance disaster response by localizing victims in real time using Bluetooth Low Energy (BLE) sensors.	BLE-based localization algorithm, Kurtosis-based confidence metric, Maximum Likelihood (ML) based detector.	Improved victim localization with a low false positive rate and average accuracy of 11ft.
(Cecílio, Ferreira, and Casimiro 2020)	Evaluate LoRa technology in flooding prevention scenarios.	RTT measurements and hardware characteristics are used to derive a battery lifetime estimation model. Real-time monitoring of flow, precipitation level, and water level is crucial for flood prevention.	Communication distance and reliability in flooding scenarios are significantly affected by tides. A battery lifetime estimation model is proposed for effective maintenance planning.
(Leon et al. 2018)	Develop a flood early warning system using Twitter and LoRa.	Prototype river level nodes are tested, achieving a measurement range from 20 cm to 2 m. The receiving node, 500 m away, successfully receives data packets without loss.	A functional prototype for a flood early warning system using Twitter and LoRa is demonstrated. Effective river level measurement and data transmission are achieved.
(Sciullo et al. 2018)	Develop a LoRa-based mobile emergency management system.	Utilization of multi-hop MANETs, investigation of next-gen ECS leveraging mobile devices.	Proposal of a LoRa-based mobile emergency management system.
(Vithayathil et al. 2021)	Propose a LoRa-based wireless network for disaster rescue operations.	Use of LoRa and Wi-Fi technologies for offline communication; Implementation of portable wireless nodes in disaster areas.	Prototype system for emergency communication during disasters using LoRa technology.
(Ab. Aziz and Ab. Aziz 2011)	Review technological solutions for	Application of WSN in disaster management; Focus on disaster	Presentation of existing projects on WSN for various disaster

	managing disaster using WSN.	detection, alerting, and search and rescue operations.	management applications.
(Höchst et al. 2023)	Demonstrate benefits of mobile device-to-device communication using LoRa modems in crisis scenarios.	Integration into DTN7 delay-tolerant networking software, real-world LoRa transmissions, scalability tests, experimental evaluation.	Successful real-world device-to-device LoRa transmissions, scalability in urban and rural areas. Integration with DTN7.
(Saraereh et al. 2020)	Evaluate performance of UAV-enabled LoRa networks for disaster management applications.	Design and evaluation of UAV-enabled LoRa network, decentralized topology control algorithm for UAVs.	Proposed UAV-enabled LoRa network architecture, cost-effective and energy-efficient disaster management solution.
(Bravo-Arrabal et al. 2022)	Develop Hybrid Wireless Sensor Networks (H-WSN) based on ZigBee and LoRa for Search and Rescue (SAR) applications.	Design and validation of ZigBee and LoRa H-WSNs, realistic testing in SAR scenarios, creation of GUIs, and data acquisition methodologies.	LoRa demonstrated overall superior performance to ZigBee in realistic SAR scenarios. Complementary nature of ZigBee and LoRa in SAR operations.
(Alsaeedy and Chong 2019)	Introduce a survivor-centric network recovery paradigm for Search-and-Rescue Operations (SAROs) after large-scale disasters.	UE-based SAROs using Unmanned Aerial Vehicles (UAVs) as mobile eNBs to search for survivors with wireless mobile devices (UEs).	UE-based SAROs provide immediate crisis maps (UEBCMs) for disaster-impacted areas, offering vital information to prioritize/manage SAROs efficiently.
(Półka, Ptak, and Kuziora 2017)	Develop a UAV-based system for search and rescue operations, focusing on locating isolated victims during natural disasters.	The MOBNET system, utilizing mobile phones and a consortium of institutions for implementation.	The system aims to provide real-time location data, addressing the responders' need for rapid and effective search and rescue operations.
(Pan et al. 2022)	Design a UAV-aided emergency environmental monitoring system using LoRa mesh	Development of a LoRa-based mesh network protocol using custom slotted ALOHA	The proposed system facilitates quick data transmission, addressing the

	networking for areas with insufficient ground network coverage.	medium access mechanism.	challenge of data collection in areas with limited ground network coverage.
(Alobaidy et al. 2022)	Explore wireless transmissions, propagation, and channel modeling for IoT technologies, emphasizing applications and challenges.	Introduction of the Smart IoT-based Fire-Ground and Firefighter Monitoring (IoT-FFM) system with enhanced functions.	The proposed system enhances protection in risky situations, providing real-time danger notifications and location data transfer for improved decision-making.
(Berto, Napoletano, and Savi 2021)	Propose a LoRa-based mesh network for peer-to-peer long-range communication, eliminating the single point of failure in gateway-centric approaches.	Development and evaluation of a hardware/software LoRa-based solution enabling peer-to-peer communication among LoRa end devices.	The proposed solution eliminates the single point of failure, enhancing the reliability of communication in emergency applications.

3.2 LoRa Mesh Network Utilisation in Tropical Region

According to Table 1, (Shih, Pang, and Hsiu 2018) propose a Doppler effect-based framework for Wi-Fi signal tracking, catering specifically to post-disaster environments where traditional infrastructure is unavailable. The system leverages the prevalence of smartphones and wearable devices to aid rescuers in locating disaster survivors. The Doppler effect is employed to discern the direction of Wi-Fi signals emitted by survivors' mobile devices, providing a valuable tool for quick and accurate location determination. The proposed system operates independently on each rescuer's device, emphasizing the potential for cooperation among devices to optimize search efforts.

(Abdul Kadir, Efendi, and Rosa 2018) shifted the focus to environmental monitoring in the aftermath of disasters, specifically addressing the recurring issue of land and forest fires in Riau Province, Indonesia. The research introduces a smart monitoring system utilizing Long Range Wide Area Network (LoRa WAN) with low-power wireless data communication and Internet of Things (IoT) technology. The LoRa technology facilitates data transmission over extensive distances, covering the vast impacted areas effectively. With a focus on the environmental and health consequences of disasters, this research emphasizes the importance of early detection and efficient monitoring systems.

3.3 LoRa Mesh Network in Disaster

Landslide disasters pose a growing threat to Malaysia, significantly impacting lives, socio-economic conditions, and the physical environment. The escalating number of landslide incidents, as highlighted by the Malaysia Public Work Department, reveals a concerning trend. However, the recorded figures might not fully capture the extent, as many landslides go unreported. Effective

emergency response planning (ERP) at the initial stage of such disasters is crucial in mitigating their impact. The diverse nature of landslides, influenced by underlying risks, geomorphological processes, and specific characteristics, demands a nuanced approach to response efforts.

The intricacies of landslide causation, involving both internal and external factors, present a challenge. Inadequate design of retaining structures and slopes emerges as a significant contributor to these disasters. (Sardi and Razak 2019) delves into 28 historical landslide events in the Hulu Kelang area, revealing 21 cases triggered by rainfall. To enhance ERP effectiveness, this research assesses the issues and challenges associated with disaster preparedness, shedding light on the importance of structured training programs and public awareness. The study critically reviews several best practices in emergency response, emphasizing the need for an effective early warning system. The findings underscore the essential role of ERP in supporting such systems, emphasizing the importance of structured training programs.

Disaster management, especially in the context of flood-related scenarios, has garnered increasing attention in recent research endeavours. This article explores existing solutions for flood disaster search and rescue, drawing insights from collaborative control of microgrid systems and advancements in multi-robot search and rescue operations. The collaborative control of microgrid systems, as proposed by (Yuan et al. 2009), presents a novel approach to address technical and commercial challenges in integrating distributed energy resources into the bulk electric grid. The microgrid's potential to reduce the consequences of natural disasters, such as earthquakes, hurricanes, and snowstorms, has implications for enhancing emergency response and disaster relief efforts. The researchers emphasize the coordinated operation of interconnected units within the microgrid, showcasing its effectiveness through simulation studies. This approach becomes crucial, especially in regions prone to natural disasters, as demonstrated by the aftermath of the magnitude 8.0 Wenchuan Earthquake in 2008.

On a parallel trajectory, the work of (Queralta et al. 2020) delves into collaborative multi-robot search and rescue operations. Focusing on various types of robots (ground, aerial, surface, or underwater), the research addresses challenges in different Search and Rescue (SAR) environments, including maritime, urban, wilderness, and post-disaster scenarios. The survey provides a comprehensive overview of multi-robot SAR systems, emphasizing planning, coordination, perception, and active vision. The researchers highlight projects like COMETS, NIFTi, ICARUS, TRADR, and SmokeBot, showcasing the evolution of robotics in disaster response. In the realm of urban SAR, researchers have explored collaborative localization, perception, and the ability to perform triage in GNSS-denied environments. Additionally, advancements in marine SAR operations, involving heterogeneous multi-robot systems, demonstrate the potential for scalable solutions in monitoring harsh environments and post-disaster scenarios. The integration of various robots, such as UGVs and UAVs, underscores the importance of collaborative mapping and monitoring.

Natural disasters, such as floods, pose significant challenges to communities, necessitating effective emergency response strategies. This examination is an exploration of diverse perspectives and proposed solutions from multiple scholarly works. Two key sources contribute to this analysis: (Yuan et al. 2009) focus on microgrid applications for disaster response, while Flint and Brennan (2006) discuss the role of Community Emergency Response Teams (CERT) in disaster management. Additionally, (Sciullo, Trotta, and Felice 2020) introduce LOCATE, a LoRa-based mobile emergency management system. (Yuan et al. 2009) highlight the potential of microgrids in addressing challenges related to integrating distributed energy resources into the electric grid. Their emphasis is on reducing the impact of natural disasters, including earthquakes, hurricanes, and snowstorms. The work proposes a collaborative control scheme to ensure the coordinated operation of interconnected units within the microgrid during emergency response and disaster relief efforts. The

researchers emphasize the effectiveness of this approach, substantiated through simulation studies. (Flint and Brennan 2006) present the CERT program, designed to train local volunteers as first responders to various emergencies, including floods. They underscore the importance of local involvement and community capacity in disaster response, challenging the traditional perception of communities as helpless victims. The CERT program extends beyond disaster response to community-building initiatives, emphasizing economic development and environmental risk mitigation.

(Sciullo, Trotta, and Felice 2020) introduce LOCATE, a mobile emergency management system based on LoRa technology. This system enables opportunistic, multi-hop dissemination of alert messages in scenarios where traditional infrastructures are unavailable, such as rural or post-disaster environments. LOCATE leverages the proliferation of mobile devices to facilitate communication and information sharing among users, ensuring effective emergency response and resolution. While each source addresses distinct aspects of flood disaster search and rescue, there is a potential for integration. Microgrid applications, CERT programs, and LoRa-based systems offer complementary perspectives on disaster response. Microgrids can contribute to localized, sustainable energy solutions during emergencies, CERTs serve as on-the-ground responders, and LOCATE enhances communication in resource-constrained scenarios.

The devastating impact of natural and manmade disasters, such as floods, earthquakes, and terrorist acts, necessitates effective disaster management strategies. Among the various challenges faced by emergency responders, the localization and rescue of victims during floods present a particularly daunting task. In this context, researchers have explored innovative solutions, leveraging technologies like the Internet of Things (IoT) and Bluetooth Low Energy (BLE), to enhance disaster situation awareness and improve the efficiency of search and rescue operations. The foundation of disaster management lies in understanding the intricacies of emergency response lifecycles. (Saha et al. 2017) emphasize the critical processes involved, ranging from risk identification to disaster recovery. Notably, IoT emerges as a solution to address the challenges encountered at each stage of the emergency management lifecycle. The integration of IoT standards, early warning systems, and wireless sensing networks (WSNs) contributes to a comprehensive disaster management framework. Furthermore, the deployment of WSNs in disaster situations, facilitates the efficient gathering and transmission of critical information, laying the groundwork for improved response mechanisms.

Urban public safety emergency management systems, as highlighted by recent studies (Saha et al. 2017), underscore the importance of IoT in predicting, managing, and responding to disasters. The performance of omni-directional observation and management, coupled with accurate prediction and economical disposal, forms the backbone of these systems. The interconnected nature of IoT-enabled devices, including sensors on trees and infrared sensors, equips responders with real-time data to monitor various parameters such as temperature, moisture, and gas levels during a disaster. Addressing the challenges faced by emergency responders during floods, (Yang, Schafer, and Ganz 2017) introduce the DIORAMA disaster situation awareness and management system. This system utilizes BLE technology to implement a low-cost localization algorithm for victims. The BLE-based localization algorithm not only enhances the accuracy of locating stationary victims but also opportunistically re-localizes moving victims. The incorporation of a Kurtosis-based confidence metric and a Maximum Likelihood-based detector further refines the location estimation and movement detection, showcasing the system's potential to improve search and rescue operations during flood disasters.

The increasing frequency and severity of natural and man-made disasters globally have elevated the significance of effective search and rescue operations, particularly in the aftermath of floods. Urban Search & Rescue (USAR) groups have assumed a crucial role in these operations, guided by international standards such as the INSARAG Guidelines (Półka, Ptak, and Kuziora 2017). Amidst the

challenges faced by responders, technological innovations, specifically the utilization of Unmanned Aerial Vehicles (UAVs), offer promising solutions. One notable research endeavor by (Półka, Ptak, and Kuziora 2017) delves into the application of UAVs for search and rescue operations. The study emphasizes the importance of timely and efficient location of isolated victims during natural disasters, such as earthquakes and hurricanes. Their proposed MOBNET system strives to harness the ubiquity of mobile phones to locate individuals, catering to the needs expressed by responders. By deploying a consortium of institutions across EU member states, the researchers aim to provide a technologically advanced tool that enhances the capabilities of first responders, with field testing scheduled for November 2017.

In parallel, (Pan et al. 2022) contribute to the discourse with a focus on UAV-aided emergency environmental monitoring in infrastructure-less areas. The researchers propose a LoRa mesh networking approach, addressing challenges in areas where traditional ground networks are either insufficient or incapacitated by disasters. This approach ensures rapid backhaul of monitoring data, crucial for emergency response. The study designs a LoRa-based mesh network protocol, providing a solution for small data transmission and emphasizing real experiments to evaluate performance. Furthermore, (Alobaidy et al. 2022) shed light on the broader context of wireless transmissions, propagation, and channel modeling for IoT technologies, emphasizing applications and challenges. Within this landscape, the researchers highlight the significance of Smart IoT-based systems, including the proposed IoT-FFM (IoT-based Fire-Ground and Firefighter Monitoring) system. This system extends its utility beyond disaster scenarios to include medical applications and emergency monitoring, showcasing the versatility of IoT in disaster management.

Additionally, (Berto, Napoletano, and Savi 2021) contribute to the discussion by presenting a LoRa-based mesh network for peer-to-peer long-range communication. Their research addresses the limitations of gateway-centric approaches and proposes a gateway-free solution for peer-to-peer communication among LoRa end devices. This innovation is particularly relevant in scenarios where maintaining data locally is essential, such as in emergency applications for disaster recovery)

4. Recommendation and Future Work

The current landscape of disaster management, particularly in the context of LoRa-based mesh networks, reveals several avenues for future exploration and improvement. Existing research emphasizes the potential of LoRa technology for wireless communication in disaster scenarios, particularly for search and rescue operations. However, a critical research gap emerges in the need for enhanced security measures for mobile devices supporting ad hoc mode in the context of LoRa-based networks.

The identified research gap stems from the acknowledgement that while LoRa technology offers valuable advantages such as low power consumption and long-range communication, there is a need for a more comprehensive understanding and implementation of security measures in the ad hoc mode. The study by (Sciullo et al. 2018) has introduced the "LOCATE" application, which utilizes LoRa for mobile emergency management. However, the investigation of security measures for mobile devices operating in ad hoc mode, a crucial aspect in disaster scenarios, remains limited.

Additionally, the study by (Berto, Napoletano, and Savi 2021) highlights the potential of a LoRa-based mesh network for peer-to-peer long-range communication. This opens up opportunities for disaster recovery and first responders' support. Nevertheless, the research falls short in providing a detailed exploration and evaluation of this gateway-free solution, particularly in terms of privacy considerations and performance metrics. Further refinement and assessment are necessary to ascertain the practicality and effectiveness of this approach in real-world disaster scenarios.

In addressing this research gap, future studies should prioritize an in-depth investigation of security protocols for mobile devices operating in ad hoc mode within LoRa mesh networks. Understanding potential vulnerabilities and implementing robust security measures is imperative for ensuring the reliability and integrity of communication during disaster situations. Moreover, the exploration of gateway-free solutions in LoRa mesh networks demands a thorough evaluation, considering factors such as privacy concerns, network performance, and scalability. This will contribute to the development of more resilient and secure communication infrastructures, ultimately enhancing the effectiveness of disaster management efforts relying on LoRa technology.

Acknowledgement
The authors would like to express their gratitude to the Universiti Pertahanan Nasional Malaysia for their support.

References

[1] Aziz, Nor Azlina Ab, and Kamarulzaman Ab Aziz. "Managing disaster with wireless sensor networks." In *13th international conference on advanced communication technology (ICACT2011)*, pp. 202-207. IEEE, 2011.

[2] Kadir, Evizal Abdul, Akmar Efendi, and Sri Listia Rosa. "Application of LoRa WAN sensor and IoT for environmental monitoring in Riau Province Indonesia." In *2018 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, pp. 281-285. IEEE, 2018.

[3] Ajayi, Olasupo O., Antoine B. Bagula, Hloniphani C. Maluleke, Zaheed Gaffoor, Nebo Jovanovic, and Kevin C. Pietersen. "Waternet: A network for monitoring and assessing water quality for drinking and irrigation purposes." *IEEE Access* 10 (2022): 48318-48337. https://doi.org/10.1109/ACCESS.2022.3172274

[4] Alobaidy, Haider AH, Mandeep Jit Singh, Mehran Behjati, Rosdiadee Nordin, and Nor Fadzilah Abdullah. "Wireless transmissions, propagation and channel modelling for IoT technologies: Applications and challenges." *IEEE Access* 10 (2022): 24095-24131. https://doi.org/10.1109/ACCESS.2022.3151967

[5] Alsaeedy, Alaa AR, and Edwin KP Chong. "Survivor-centric network recovery for search-and-rescue operations." In *2019 Resilience Week (RWS)*, vol. 1, pp. 71-77. IEEE, 2019.

[6] Anzum, Rabeya, Mohamed Hadi Habaebi, Md Rafiqul Islam, and Galang PN Hakim. "A Study of LoRa Signal Propagation in Hilly Suburban Area for Smart City Applications." In *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, pp. 16-20. IEEE, 2021. https://doi.org/10.1109/ICSIMA50015.2021.9526306

[7] Anzum, Rabeya, Mohamed Hadi Habaebi, Md Rafiqul Islam, Galang PN Hakim, Mayeen Uddin Khandaker, Hamid Osman, Sultan Alamri, and Elrashed AbdElrahim. "A multiwall path-loss prediction model using 433 MHz LoRa-WAN frequency to characterize foliage's influence in a Malaysian palm oil plantation environment." *Sensors* 22, no. 14 (2022): 5397. https://doi.org/10.3390/s22145397

[8] Berto, Riccardo, Paolo Napoletano, and Marco Savi. "A lora-based mesh network for peer-to-peer long-range communication." *Sensors* 21, no. 13 (2021): 4314. https://doi.org/10.3390/s21134314

[9] Bravo-Arrabal, Juan, Pablo Zambrana, J. J. Fernandez-Lozano, José Antonio Gómez-Ruiz, Javier Serón Barba, and Alfonso García-Cerezo. "Realistic deployment of hybrid wireless sensor networks based on ZigBee and LoRa for search and Rescue applications." *IEEE Access* 10 (2022): 64618-64637. https://doi.org/10.1109/ACCESS.2022.3183135

[10] Cecílio, José, Pedro M. Ferreira, and António Casimiro. "Evaluation of LoRa technology in flooding prevention scenarios." *Sensors* 20, no. 14 (2020): 4034. https://doi.org/10.3390/s20144034

[11] Ebi, Christian, Fabian Schaltegger, Andreas Rüst, and Frank Blumensaat. "Synchronous LoRa mesh network to monitor processes in underground infrastructure." *IEEE access* 7 (2019): 57663-57677. https://doi.org/10.1109/ACCESS.2019.2913985

[12] Flint, Courtney, and Mark Brennan. "Community emergency response teams: From disaster responders to community builders." *Rural realities* 1, no. 3 (2006): 1-9. https://www.researchgate.net/publication/242760642

[13] Höchst, Jonas, Lars Baumgärtner, Franz Kuntke, Alvar Penning, Artur Sterz, Markus Sommer, and Bernd Freisleben. "Mobile Device-to-Device Communication for Crisis Scenarios Using Low-Cost LoRa Modems." In *Disaster Management and Information Technology: Professional Response and Recovery Management in the Age of Disasters*, pp. 235-268. Cham: Springer International Publishing, 2023. https://doi.org/10.1007/978-3-031-20939-0_12

[14] Huh, Heon, and Jeong Yeol Kim. "LoRa-based mesh network for IoT applications." In *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, pp. 524-527. IEEE, 2019.
[15] Khonrang, Jarun, Mingkwan Somphruek, Pairoj Duangnakhorn, Atikhom Siri, and Kamol Boonlom. "Experimental and Case studies of Long-distance Multi-hopping Data Transmission Techniques for Wildfire Sensors Using the LoRa-Based Mesh Sensor Network." *International Journal of Electronics and Telecommunications* 69 (2023). https://doi.org/10.24425/ijet.2023.144378
[16] Leon, Ernesto, Cristian Alberoni, Miguel Wister, and Jose A. Hernández-Nolasco. "Flood early warning system by Twitter using LoRa." In *Proceedings*, vol. 2, no. 19, p. 1213. MDPI, 2018. https://doi.org/10.3390/proceedings2191213
[17] Matracia, Maurilio, Nasir Saeed, Mustafa A. Kishk, and Mohamed-Slim Alouini. "Post-disaster communications: Enabling technologies, architectures, and open challenges." *IEEE Open Journal of the Communications Society* 3 (2022): 1177-1205. https://doi.org/10.1109/OJCOMS.2022.3192040
[18] Pan, Miaoxin, Chongcheng Chen, Xiaojun Yin, and Zhengrui Huang. "UAV-aided emergency environmental monitoring in infrastructure-less areas: LoRa mesh networking approach." *IEEE Internet of Things Journal* 9, no. 4 (2021): 2918-2932. https://doi.org/10.1109/JIOT.2021.3095494
[19] Półka, Marzena, Szymon Ptak, and Łukasz Kuziora. "The use of UAV's for search and rescue operations." *Procedia engineering* 192 (2017): 748-752. https://doi.org/10.1016/j.proeng.2017.06.129
[20] Queralta, Jorge Pena, Jussi Taipalmaa, Bilge Can Pullinen, Victor Kathan Sarker, Tuan Nguyen Gia, Hannu Tenhunen, Moncef Gabbouj, Jenni Raitoharju, and Tomi Westerlund. "Collaborative multi-robot search and rescue: Planning, coordination, perception, and active vision." *Ieee Access* 8 (2020): 191617-191643. 191617–43. https://doi.org/10.1109/ACCESS.2020.3030190
[21] Saha, Himadri Nath, Supratim Auddy, Subrata Pal, Shubham Kumar, Shivesh Pandey, Rakhee Singh, Amrendra Kumar Singh, Swarnadeep Banerjee, Debmalya Ghosh, and Sanhita Saha. "Disaster management using Internet of Things." In *2017 8th Annual Industrial Automation and Electromechanical Engineering Conference (IEMECON)*, pp. 81-85. IEEE, 2017.
[22] Saraereh, Omar A., Amer Alsaraira, Imran Khan, and Peerapong Uthansakul. "Performance evaluation of UAV-enabled LoRa networks for disaster management applications." *Sensors* 20, no. 8 (2020): 2396. https://doi.org/10.3390/s20082396
[23] Sardi, Mohamad Fazli, and Khamarrul Azahari Razak. "Assessment of effectiveness of emergency response time during landslide event in Malaysia." *ASM Sci. J* 12 (2019): 1-19. https://doi.org/10.32802/ASMSCJ.2019.360
[24] Sciullo, Luca, Federico Fossemo, Angelo Trotta, and Marco Di Felice. "Locate: A lora-based mobile emergency management system." In *2018 IEEE global communications conference (GLOBECOM)*, pp. 1-7. IEEE, 2018.
[25] Sciullo, Luca, Angelo Trotta, and Marco Di Felice. "Design and performance evaluation of a LoRa-based mobile emergency management system (LOCATE)." *Ad Hoc Networks* 96 (2020): 101993. https://doi.org/10.1016/j.adhoc.2019.101993
[26] Shih, Yuan-Yao, Ai-Chun Pang, and Pi-Cheng Hsiu. "A doppler effect based framework for wi-fi signal tracking in search and rescue operations." *IEEE Transactions on Vehicular Technology* 67, no. 5 (2017): 3924-3936. https://doi.org/10.1109/TVT.2017.2752766
[27] Son, Hoang Hai, Vo Phuc Tinh, Duc Ngoc Minh Dang, Bui Thi Duyen, Duy-Dong Le, Thai-Thinh Dang, Quoc-Hung Nguyen et al. "A novel solution for energy-saving and lifetime-maximizing of LoRa wireless mesh networks." *Journal of Information and Telecommunication* (2023): 1-17. https://doi.org/10.1080/24751839.2023.2235114
[28] Vithayathil, Aishwarya, Afaf Mohamed, Ann Jacob, Chinju Merin Raju, and Jaison Jacob. "LoRa Based Wireless Network for Disaster Rescue Operations." In *2021 International Conference on Advances in Computing and Communications (ICACC)*, pp. 1-7. IEEE, 2021. https://doi.org/10.1109/ICACC-202152719.2021.9708218
[29] Wu, Yuting, Yigang He, and Luqiang Shi. "Energy-saving measurement in LoRaWAN-based wireless sensor networks by using compressed sensing." *IEEE Access* 8 (2020): 49477-49486. https://doi.org/10.1109/ACCESS.2020.2974879
[30] Yang, Zhuorui, James Schafer, and Aura Ganz. "Disaster response: Victims' localization using bluetooth low energy sensors." In *2017 IEEE International Symposium on Technologies for Homeland Security (HST)*, pp. 1-4. IEEE, 2017.
[31] Yuan, Yue, Lei Wu, Weiwei Song, and Zhihui Jiang. "Collaborative control of microgrid for emergency response and disaster relief." In *2009 international conference on sustainable power generation and supply*, pp. 1-5. IEEE, 2009.