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ORIGINAL RESEARCH

Disaster scenario optimised link state routing protocol and message prioritisation

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Abstract

Natural and artificial (human-made) disasters have been steadily increasing all over the world, signifying the importance of providing reliable and energy friendly communication network to survivors in the aftermath of a disaster. On the other hand, low-battery devices running optimised link state routing (OLSR) protocol often experience quick power failure which restricts their ability to communicate for a necessary period during rescue operations. To extend the lifespans and prioritise message delivery on low-battery devices, the authors examine disaster scenario optimised link state routing (DS-OLSR) protocol ALERT message and propose an innovative solution to prioritise messages based on the device battery energy level, leading to more energy conservation, packet delivery as well as better emotional state of survivors. An ALERT message is a novel message type added to mobile ad-hoc network's (MANET) popular OLSR protocol for energy efficiency. The proposed DS-OLSR Protocol and Message Prioritisation (DS-OLSRMP) as an extension of DS-OLSR modifies the multipoint relay mechanism and uses a prioritisation technique which classify nodes into four priority groups: Critical, High, Medium, and Low priorities. These priority groups help in prioritising both message delivery and message status notifications for devices with low battery energy. The DS-OLSRMP was implemented in a Network Simulator, version 3.29 and compared with DS-OLSR, OLSRv1 and OLSRv2. The simulation results show that DS-OLSRMP performs better than DS-OLSR, OLSRv1 and OLSRv2 in terms of energy conservation and packets delivery in the simulation of both sparse and dense network scenarios.

KEYWORDS

data communication, emergency services, energy conservation, mobile ad hoc networks, relay networks (telecommunication), routing protocols

1 | INTRODUCTION

Networks for disaster recovery and rescue operations have become a necessity for every society especially in areas with commonly occurring natural and artificial disasters for effective communication. Disasters create emergency conditions and cause physical, emotional, and social disorder. In this emergency condition, water, food, shelter, medical help, and protection are required, and the effort needed to provide disaster victims with these basic services must be quickly organised via an effective and reliable communication network. Since early 1990s, networks for emergency responses and disaster recovery operations were considered [1]. Similarly, after September 11 attacks, disaster network recovery has gained much research attention. However, most early research studies focused on the design and implementation of networks for emergency responses and disaster recovery operations based on the restoration of telecommunication infrastructure using expensive and non-flexible technologies [2, 3]. In addition, most of the proposed disaster networks are only accessible to rescue team members but not available to disaster victims and rescue volunteer workers who help rescuers with first-hand information about the disaster. Meanwhile, Nishiyama, et al. [4] and Qin, et al. [5] focused on a multi-hop D2D communication network using an Optimised Link State Routing (OLSR) protocol to route network traffic. However, these studies do not consider prioritisation techniques for message delivery and assume victims can recharge devices at their will; nonetheless, some disaster scenarios challenged this assumption, especially where power grids are crippled/impaired [6].

The authors in Ref. [7] highlight the significant need for effective communication in disaster areas, stressing the importance of providing access to all locals during and after such events. Their research focuses on planning the deployment of access points (APs) to guarantee pick coverage and high data rates for users. Their major objective is to maximise the operation of each AP while considering capacity, coverage and reducing interference between nearby Aps using Dragonfly Algorithm. Similarly, the authors in Ref. [8] address a critical need for enhancing temporary cellular networks for emergency communication in the aftermath of a disaster. They utilised a genetic algorithm (GA) to efficiently allocate users in overlapping areas to base stations, thereby improving network performance. The authors compare their scheme with a greedy algorithm, a random algorithm, and a proximity-based allocation technique and their results show that the GA significantly reduced delay as compared to the greedy techniques. However, the former mainly focuses on the optimisation of AP for effective communication for disaster recovery and rescue operation, yet they do not precisely address optimum relay selection strategies and message prioritisation as intended by our research, which are critical aspects of post disaster communication. The latter focuses on temporary deployable cellular networks, which may not fully cover some disaster scenarios and may not represent the flexibility of mobile ad-hoc networks (MANETs).

Furthermore, the authors in Refs. [9–13] employed different techniques to address the problem of multipoint relay (MPR) selection and load balancing to optimise energy consumption of OLSR nodes.

However, the above authors do not prioritise messages delivery based on device battery life and restriction of critical priority (CP) nodes from being selected as MPR to improve energy efficiency and packet delivery during disaster recovery and rescue operations. Prioritisation is a technique that cuts across different disciplines. Recently, the prioritisation schemes in the MANET routing protocol have been presented in Refs. [12–14]. The references proved that the prioritisation scheme enhances QoS in MANET. However, the studies were implemented using ad-hoc on-demand distance vector (AODV) routing protocols (nodes experience high delay) instead of a proactive routing protocol which makes it unsuitable for disaster recovery operations. In this article, the prioritisation scheme is used in a proactive disaster scenario optimised link state routing (DS-OLSR) Alert Message to prioritise message delivery based on node's battery life and restrict CP nodes from being selected as an MPR node. DS-OLSR and Message Prioritisation (DS-OLSRMP) further extends DS-OLSR's superior energy saving capabilities over classic OLSR [15] by extending the lifespan of communication devices with low battery energy and restrict CP nodes from being selected as MPR. In addition, DS-OLSRMP in disaster environment will likely improve the victim's emotional state by quickly responding to messages sent by low battery nodes and increase network collaboration in emergency management [16, 17]. Such a rapid response may include a proposed rescue time, or where such victims should gather to receive supplies or shelter. Message prioritisation requires MPR to send messages and deliver messages' status reports based on the battery life of each device.

1.1 | Research motivation

As mentioned earlier, the escalating frequency and intensity of natural and human made disasters in the recent years have underscored the critical need for robust and efficient communication networks during disaster recovery and rescue operations [17, 18]. These networks play a pivotal role in facilitating timely and coordinated responses, ensuring the safety and well-being of the affected populations. However, the energy limitations of devices involved in these networks, particularly those with low battery capacity, pose a significant challenge. The motivation for this research stems from the imperative to enhance the effectiveness and sustainability of communication networks for disaster recovery and rescue operations. Existing solutions often struggle to optimise energy usage and deliver messages efficiently, resulting in reduced network lifespan and compromised packet delivery during crucial operations [7–11]. Addressing these challenges is vital to ensure the continuous operation of devices with low battery energy, contributing to the success of disaster response efforts.

Our research focuses on the development of an innovative solution that leverages message prioritisation techniques to significantly improve energy conservation in disaster communication networks. By introducing a novel approach that prioritises messages based on the remaining battery life of devices, we aim to extend the lifespan of low-energy devices, thereby enhancing the overall resilience and sustainability of the network. A key feature of our proposed solution involves the strategic restriction of CP nodes from being selected as MPR. This approach aims to optimise energy efficiency and packet delivery by preventing high-priority nodes with critical functions from being overburdened during resource-constrained scenarios. This innovative strategy aligns with the goal of achieving a balance between effective communication and energy conservation during the demanding conditions of disaster recovery and rescue operations.

It is important to provide a reliable and energy friendly communication network to survivors in the aftermath of a disaster. Simple text message to rescue teams, loved ones, colleagues and business partners reduces anxiety over a trapped victim in a disaster zone. Such messages will allow them to deal with the situation in a better emotional state. On the other hand, the provision of a temporary OLSR protocol driven MANET for survivors to communicate often affects their device battery energy, since message routing and network flooding are prominent requirements of the OLSR protocol. Our previous work in Ref. [15] titled DS-OLSR achieved significant reduction in control messages overheads and energy consumption as compared to classic OLSR through the introduction of originator ID (holds smart phones' mobile number), ALERT message and time slices (TS). TS partition messages into their respective time. Thus, control messages such as Hello, topology control (TC), host network association (HNA) messages and ALERT (a new message type created for DS-OLSR) have their respective TS during which only a specific message type is permitted by DS-OLSR devices. However, low-battery devices often experience quick power failure which restricts their ability to communicate for longer time during rescue operations. Therefore, adding ALERT message prioritisation to DS-OLSR will further improve energy conservation, extend lifespan of low-battery energy devices and improve the emotional state of victims. This will equally prevent such victims from overwhelming the network with messages as their device battery energy dwindles as explained below:

(i) Extension of Device Lifespan:

The extension of device lifespan is a pivotal aspect addressed through innovative modifications to the MPR mechanism and the implementation of a sophisticated prioritisation technique. These adaptations are integral to mitigating the energy constraints of low battery life nodes during disaster recovery scenarios. Modification of MPR Mechanism: One of the key contributors to extending device lifespan is the modification of the MPR mechanism. Traditionally, MPR selection may not consider the energy state of individual nodes. In our proposed solution, we introduce a modification to the MPR mechanism that prevents low battery life nodes from being selected as MPR. By strategically excluding these nodes from serving as MPR, we ensure that critical devices with limited energy are not overburdened with additional responsibilities. This modification aims to optimise the energy usage of low-power nodes, thereby extending their operational lifespan during crucial disaster recovery operations.

Prioritisation Technique: A critical component of our strategy for extending device lifespan involves the implementation of a sophisticated prioritisation technique. We classify nodes into four priority groups: Critical, High, Medium, and Low. These priority groups serve as a foundation for prioritising both message delivery and message status notification for devices with low battery energy.

(ii) Improvement in Emotional State through Extended Device/network Lifespan:

One of the notable challenges faced by disaster victims is heightened emotional tension caused by the uncertainty of communication device functionality [19, 20], particularly when devices are operating on low battery life. The prospect of a device powering off before rescue or the reception of vital information, such as proposed rescue times or gathering locations for essential supplies, can significantly contribute to increased stress and anxiety among disaster affected individuals. We addressed this psychological challenge by focusing on the extension of communication device lifespan. By ensuring that devices with low battery life remain operational for an extended duration, we aim to alleviate the emotional strain experienced by disaster victims. Here is how our approach contributes to the improvement in the emotional state of individuals in crisis situations.

Certainty and Assurance: The extended lifespan of communication devices provides disaster victims with a sense of certainty and assurance. Knowing that their devices will remain operational for an extended period helps alleviate the anxiety associated with the potential abrupt loss of communication. This assurance contributes to a more stable and less stressful emotional state.

Access to Critical Information: Disaster victims heavily rely on their communication devices for critical information, such as rescue schedules, gathering points, and essential supplies distribution. The extended device lifespan ensures that individuals can consistently access this vital information, empowering them with a sense of control and reducing the stress associated with uncertainty.

Enhanced Communication with Rescuers: Extended device lifespan facilitates continuous communication between disaster victims and rescuers. This uninterrupted communication channel enables victims to receive real-time updates on rescue efforts, reducing the sense of isolation and providing a crucial psychological anchor during challenging times.

Our research recognises the profound impact that extended device lifespan can have on the emotional state of disaster victims. By addressing the uncertainty associated with low battery life and ensuring continuous access to critical information, our approach aims to provide a more stable and reassuring communication environment during disaster recovery operations. This, in turn, contributes to the overall improvement in the emotional well-being of individuals facing the challenges of a disaster.

(iii) Preventing Network Overwhelm:

One critical aspect of our research involves preventing network overwhelm during disaster recovery operations, particularly in situations where victims possess low battery energy. The strategic prioritisation of individuals with low-battery devices ensures that they receive high priority (HP), allowing them to send and receive responses promptly. This prioritisation mechanism not only facilitates timely communication for these individuals but also acts as a preventive measure against network overload, where users might otherwise flood the network with messages due to the urgency of their situations. In other words, this feature prevents victims from flooding the network with ALERT messages, especially when such victims are experiencing a dire emergency which unduly increases their panic level because their communication device battery energy is running low. Our approach effectively prevents network overwhelm through the following: Timely Response for High-Priority Nodes: By assigning HP to victims with low battery energy, our approach ensures that their messages are promptly delivered and responded to. This timely response significantly reduces the likelihood of these individuals sending multiple messages due to anxiety or urgency, as they receive the information they need without delay. Avoidance of Message Repetition: Individuals facing critical situations may tend to send repeated messages in an attempt to ensure their messages are received. However, by prioritising victims with low battery energy, our approach minimises the need for message repetition. Timely responses assure users that their messages are acknowledged, reducing the urge to resend them.

Optimal Network Resource Utilisation: Prioritising low-battery energy devices strategically distributes network resources, preventing congestion and ensuring optimal utilisation. By allowing victims with urgent needs to send and receive messages efficiently, the network operates more smoothly, minimising the risk of overload. We acknowledge the potential challenges posed by network overwhelm during disaster recovery operations. By providing HP to victims with low battery energy, our approach not only meets their urgent communication needs but also acts as a proactive strategy to prevent network congestion. This prioritisation mechanism ensures that information form critical nodes is disseminated efficiently, contributing to the overall effectiveness and sustainability of the disaster communication network.

In summary, our research is driven by the urgent need to advance the capabilities of communication networks in disaster scenarios. By introducing a message prioritisation technique that considers device battery life and strategically manages high-priority nodes, we aspire to create a more resilient and sustainable infrastructure. This work contributes not only to the field of disaster communication but also to the broader discourse on energy-efficient and robust wireless communication systems. Building on our efforts in Ref. [15], this article examines DS-OLSR ALERT message and proposes an innovative solution that will prioritise messages based on the device battery level and will restrict CP nodes from being selected as MPR to improve energy efficiency and packet delivery during disaster recovery and rescue operations as in Figure 1. Alert Message prioritisation techniques require MPR to send messages and deliver status reports based on the battery life of each device as shown in the Alert message prioritisation layer of Figure 1 (See nodes of group A through D). Each device sends an ALERT message for routing to Device F via MPR D. The Device B battery level is low; hence, the ALERT message from Device B is prioritised. On group B, MPR D equally prioritises responses from Device F to Device B for delivery. Once Device B messages are delivered, MPR D forwards the remaining messages from Devices A, C and E to Device F as shown in the nodes of group C. Finally, responses from Device F are forwarded to Devices A, C and E by MPR D as in the nodes of group D of the Alert message prioritisation layer. On the network layer, The DS-OLSR MPR selection process has

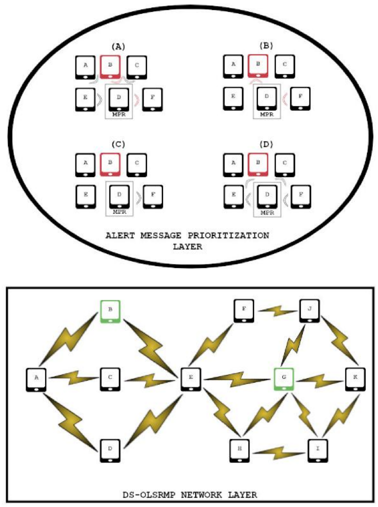

FIGURE 1 Example of DS-OLSRMP scenario architecture.

been optimised to allow only high battery life nodes to be selected as MPRs. Nodes B, C and D are potential MPR candidates for node A. However, node B has a better battery life and therefore has been selected as MPR for node A. Similarly, node G has a better battery life and has been selected as MPR to node E. Details of the techniques are presented in the implementation section of this paper.

The rest of this article is systematised as follows: Section 2 presents the related work, highlighting the key contributions and constraints of the existing literature in this domain. Section 3 presents the proposed work and prioritises energy computation. Section 4 discusses simulation setup and results analysis. Finally, Section 5 wraps up the article with conclusion and future work.

2 | RELATED WORK

The related work discussed in this Section covers the key areas of our proposed work, namely message prioritisation and energy conservation in MANETs. The provision of temporary OLSR routing protocol-driven MANETs affects device battery life, since message routing and network flooding are prominent requirements of the OLSR protocol. Most of the investigated problems in OLSR-driven MANETs focused on the creation and maintenance of routes in the network. These issues are usually attributed to the routing overhead and inefficient MPR section. To address this problem, recently, the authors in Refs. [7–11] presented different concepts to optimise the MPR selection technique in OLSR for efficient network flooding and message routing. The QG-OLSR: Quantumgeric-driven OLSR in Ref. [7] embedded the Q-Learning algorithm into OLSR techniques for optimal MPR selection. The authors in Ref. [9] presented an enhanced version of OLSR to extend the lifetime of MANET and Wireless sensor nodes known as WRE-OLSR (Weighted Reachability and energy OLSR). The WRE-OLSR introduces new criteria that utilise residual energy and reachability of nodes to determine optimal efficient MPR nodes in a network. In Ref. [8], the authors proposed a load-balancing algorithm to optimise an emergency network. The LBMRE-OLSR was developed in a software-defined model which promoted high network flexibility in an integrated heterogeneous network. In Ref. [11], the authors presented a PSO-OLSR (Particle Swarm Optimisation OLSR) deployed in a wireless mesh network to create and maintain routes for effective communication. From the references reviewed in this paragraph, we can observe that the studies only solve certain issues related to MPRs selection and routes creation in OLSR protocol-driven MANET. However, the authors do not consider prioritisation techniques as intended by this research thereby prioritising message delivery based on the device battery life and restriction of CP nodes from being selected as MPR to improve energy efficiency and packet delivery during disaster recovery and rescue operations.

Jabbar, et al. [21] presented a hybrid multi-path and multi-criteria energy and QoS-aware OLSR protocol called MEQSA-OLSRv2 to handle limited energy resources, traffic congestion and mobility of nodes in MANET and wireless sensor networks (WSN) convergence scenarios of Internet of Things (IoT) networks. MEQSA-OLSRv2 techniques combined multiple criteria including residual battery, node's lifetime, node's idle time, queue length and node's speed into a single metric for MPR selection and routing decision. Unlike existing techniques, MEQSA-OLSRv2 ranked nodes based on a multi-criteria node rank metric (MCNR) that aggregated energy and QoS-related parameters into an extensive metric to reduce multiple constrain complications and avoid routing overhead generated by broadcasting multiple parameters. However, the authors retained the main characteristics of MP-OLSRv2 and MBQA-OLSR such as residual energy and hybrid multi-path routing. The MEQSA-OLSRv2 has been implemented in an EXata simulator, and the simulation results showed that it can significantly reduce energy and improve QoS in common MANET and WSN scenarios. In MEQSA-OLSRv2, energy consumption during packet routing has been considered, and load balancing is equally achieved via multiple paths. However, message prioritisation based on the device battery level was not considered, and the complexity of multiple metrics will result to increase in routing overhead and therefore not suitable for a dense network.

Other schemes were proposed by the authors in Refs. [13, 22–27] for energy efficiency and QoS in MANET and the Wireless Sensor Network. Their studies improve some aspects of MANET and WSN performance. However, the authors ignored packets and MPRs prioritisation techniques which prioritise messages from low-energy nodes and restrict CP nodes from being selected as MPR to improve energy efficiency and packet delivery during disaster recovery and rescue operations. The techniques for message prioritisation have been presented in the literature; however, most of the work on the message prioritisation do not utilise node residual energy. In other words, the existing literature do not focus on energy as a major challenge for networks during disaster recovery and rescue operations as they mainly focused on message prioritisation based on message type, size, and context information. For example, Aggarwal and Nagrath [28] proposed Delay Tolerant Network (DTN) via message prioritisation. Their paper proposes using a device buffer and routing time-to-live (TTL) value as parameters to store and forward messages using three message levels: HP, medium priority (MP), and low priority (LP). Messages are assigned unique IDs along with a unique priority in the following order (M3, 1) or (M1, 2), or (M2, 3). Where M3 is the message ID and one is the message priority. Thus, message M3 has a priority level of high, M1 medium and M2 has a priority level of low. The researchers equally adopted TTL as a second parameter that determines message prioritisation. Thus, a HP message such as (M2, 1) can become LP if the TTL is 2, that is (M2,1) (2). This implies the message will be relegated to the second place in favour of a medium/LP message with a higher TTL value, for example, (M1, 2) (10). The authors proposed using an initial TTL value of 10, which is decreased by 2 during each update cycle. However, the paper has not considered residual battery energy of nodes for priority decision nor optimised the energy consumption of their network as they only considered the prioritisation of messages based on the buffer size and TTL value.

Zhou, et al. [18] presented a post disaster communication network called integrated satellite ground-emergency construction network (ISG-ECN). The network is divided into two parts namely satellite portable station and ground mesh network. The authors adopted a portable design that can be easily deployed by rescuers to support communication needs during disaster recovery and rescue operations. External communications are achieved using a satellite station via a local area network, while the ground mesh network is used for communication with the disaster zone. Another interesting part of their emergency communication network is the evaluation of the system in the real-life disaster environment (including flood and earthquake) which is evident that the scheme will be set quickly and support multi-user access. However, thirty (30) minutes set up time is not efficient for the post disaster communication network as such networks are required to be simple and can easily be set up by non-trained personnel in the disaster area within the shortest possible time [29], as intended by this research. Another drawback of their disaster communication network is an assumption that nodes will be equipped with unattended power source (UPS) and rechargeable energy battery to relay and maintain communication in the aftermath of a disaster. However, victims can simply use their mobile phones to connect to the energy friendly network without spending extra cash on specialised gadgets and maintain communication until they are rescued as proposed by this research.

Wang, et al. [30] proposed an optimised mobile resource deployment unit in disaster areas and the predictive population system to predict post-disaster population. This allows appropriate distributions of relay nodes to cover the entire disaster population. The main idea behind their approach is the utilisation of crowd dynamics to estimate fine-grained distribution population in the aftermath of a major disaster, thereby guiding network scheduling. Their research equally presented an approach of the post-disaster network scenario, illustrating how intellegent resources deployable networks are formed using big data. The intelligent scheme was evaluated in a real-life environment and the results showed reduction in the estimated error for population distribution by 56%–69% as compared to regressive models and that limited number of relays can efficiently cover large population. Similar to Hoque, et al. [31], the research did not optimise nor evaluate the energy consumption of their techniques, and such scheme can only be helpful when the end user device has power. In addition, most major disasters equally damage power grids which necessitate the requirement for the energy efficiency disaster network especially in places with commonly occurring natural and human-made disasters.

Lieser, et al. [32] study the impact of message prioritisation in the ad-hoc network disaster communication system. Undesirable interactions between message prioritisation in DTN and dynamic disaster scenarios were identified based on their previous field trial. Furthermore, the authors developed a message prioritisation algorithm which integrates three prioritisation schemes, namely Static, Adaptive and None, to accommodate changes in message importance and frequency over time. A generic architecture has been equally proposed to evaluate prioritised DTNs using different disaster scenarios and attributes, such as message sizes and type were assumed to be pre-assigned via mobile apps running on mobile devices. Their simulation results showed that emergency messages with HP are favoured over LP messages. However, the authors did not consider device battery life for priority computation.

Content-based filtering and prioritisation of emergency messages in the aftermath of a disaster are proposed by Bhattacharjee, et al. [33]. To achieve segregation and prioritisation of messages according to their importance, natural language processing (NLP)-based filtering has been used for filtering and prioritisation. Filtered messages were disseminated using a priority-enhanced PRoPHET routing protocol over DTN. The authors used real WhatsApp messages exchanged between rescue team members during Nepal earthquake disaster recovery and rescue operation in 2015 to classify messages based on content into five different priorities: Sentimental, Conversation, Situational, Resource Allocation and Resource Requirement. Resources Requirement and Situational messages have been allocated as priorities five (highest) and four (next highest), respectively. This is because most of the messages in both priorities are assumed to represent extreme need of resources for survival and decision-making information. ONE simulator was used to implement and evaluate the performance of their proposed techniques, and the results suggested that their protocol performed better than famous DTN routing protocols such as PRoPHET, MaxProp, Epidemic and Spay-And-wait in terms of delivery of prioritised messages and routing overhead. However, the authors did not consider device battery energy level (EL) for priority computation.

Jabbar, et al. [34] proposed Multi-path Battery-Aware routing protocol called MBA-OLSR, an enhanced energy efficient version of Multi-path OLSR (MP-OLSR) without loss of performance. MP-OLSR was proposed to address routing issues such as scalability, transmission instability and security, whereas MBA-OLSR was proposed to optimise energy consumption and QoS. MBA-OLSR uses the residual battery of devices as metrics for finding the initial cost of multiple routes. The inclusion of the device battery was achieved by the modification of HELLO and TC messages to add a type length value (TLV) mechanism for network-aware battery information. EXata 3.1 Simulation was used to evaluate the performance of the MBA-OLSR as compared to MP-OLSR. The modification to attach energy information of nodes as a metric for link cost computation enhanced energy efficiency without sacrificing QoS. It performed better than MP-OLSR in terms of end-to-end delay and packet delivery ratio (PDR). The authors developed a multi-path scheme and an efficient energy-aware routing protocol by considering devices battery energy as a metric for route selection. However, they did not prioritise message delivery based on residual battery energy nor extended the lifespan of devices with low battery energy.

In the context of optimising OLSR for energy efficiency, various related works have indeed explored different routes and message prioritisation schemes. While these efforts have contributed significantly to enhancing communication protocols, there remains a notable gap in the prioritisation techniques concerning their impact on the lifespan of low-battery devices, especially in the critical context of disaster recovery and rescue operations. Existing prioritisation schemes have primarily concentrated on factors such as message type, size, and context information. While these considerations are important for effective communication, the specific challenges posed during disaster scenarios necessitate a more nuanced approach. The proposed work recognises the imperative of extending the lifespan of low-battery devices, acknowledging that prioritising their communication is pivotal for the overall success of disaster recovery efforts. In the aftermath of a disaster, providing survivors with a reliable and energy-friendly communication network becomes paramount. Simple text messages sent to rescue teams, loved ones, colleagues, and business partners can significantly alleviate anxiety for trapped victims in disaster zones. These messages not only serve as a crucial means of communication but also contribute to fostering a better emotional state among survivors, allowing them to cope more effectively with the challenging circumstances. However, the provision of a temporary OLSR protocol-driven MANET for survivors introduces its own set of challenges, particularly concerning device battery energy. The routing of messages and network flooding, inherent requirements of the OLSR protocol, can significantly impact the energy reserves of the devices used by survivors. Hence, there is a compelling need for a prioritisation technique that not only ensures effective communication but also minimises the energy consumption of low-battery devices, ultimately contributing to their extended lifespan.

In summary, while existing related works have made valuable contributions to optimising OLSR for energy efficiency, the proposed work aims to fill a crucial gap by introducing prioritisation techniques specifically tailored to the unique challenges of disaster recovery scenarios. By extending the lifespan of low-battery devices and ensuring their communication, the proposed work strives to provide a more holistic and effective solution for communication networks in the aftermath of disasters.

3 | PROPOSED WORK

This section presents the proposed DS-OLSRMP protocol from the operational point of view. The proposed routing techniques are based on our previous scheme, namely DS-OLSR [15]. The DS-OLSRMP techniques recommend appropriate modifications to improve energy efficiency and packet delivery during disaster recovery and rescue operations. The DS-OLSRMP routing protocol retains and makes good use of some functionalities in a conventional OLSR and our previous routing techniques including the message packet format and TS. However, the developed scheme modifies other functionalities, such as the MPR willingness mechanism, and introduces message prioritisation techniques. The proposed DS-OLSRMP protocol does not introduce complexity to the conventional protocol as it only modifies the existing algorithms, thereby integrating TS and priority techniques in message delivery and MPR selection. The introduction of message specific TS which encapsulates HELLO, TC and Alert messages within their respective TS as contained in our previous research prevents nodes from flooding the network with a different message which does not belong to the current TS, hence improves link quality and reduces crosstalk and funnel problems. On the other hand, the message prioritisation scheme based on device battery life further improves energy conservation, extends the lifespan of low battery nodes, and improves the emotional state of victims with such devices in the aftermath of a disaster.

3.1 | ALERT message packet format modification

The proposed DS-OLSRMP modifies the Alert message packet format to support message prioritisation through the introduction of two new fields, namely priority and status fields as presented in Figure 2. The new fields of the ALERT message are discussed below.

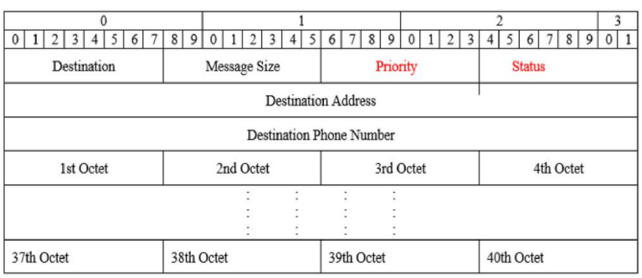

FIGURE 2 Improvement to the alert message packet format.

3.2 | Priority

Priority field stores the message priority based on a device battery life. The battery life of any device running DS-OLSR can be retrieved from a new table called the device info set [15]. The DS-OLSR messaging application periodically captures and stores the battery level of a device [15] allowing the device info set to provide an updated battery life. 3.3. Status field provides a message status to nodes that are expected to route messages between the sender and the recipient. A value of one informs nodes that the message originates from the sender and is destined to the recipient. While a value of two informs routing nodes that the message is a status notification (an acknowledgement) of an earlier message delivered to a recipient from a sender. Figure 3 presents a sample value for priority and status for the ALERT message from sender B to destination F. Device B battery life is between 1% and 33%. Hence, its ALERT message has a priority value of 1, which translates to CP. The message is routed via MPR D to the target recipient (Device F). The Device F response is captured in Figure 4. The response simply echoes back the message received, with the status field set to 2 to connote the message which is a status notification report or an acknowledgement of the previously received ALERT message.

4 | IMPLEMENTED SCENARIO

In DS-OLSRMP, nodes use different models to measure the required parameters for executing the task of send, relay, and receive. The parameters are used by DS-OLSRMP to prioritise both message delivery and message status notification for devices with low battery energy. The research initially

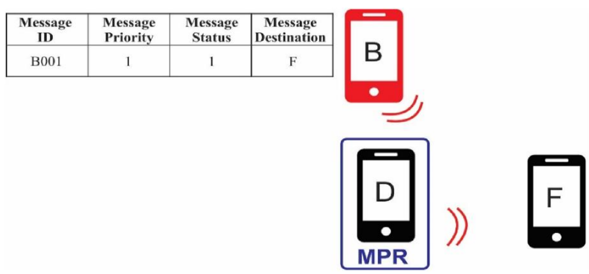

FIGURE 3 Sample values for priority and status fields for new ALERT messages from sender B to the recipient.

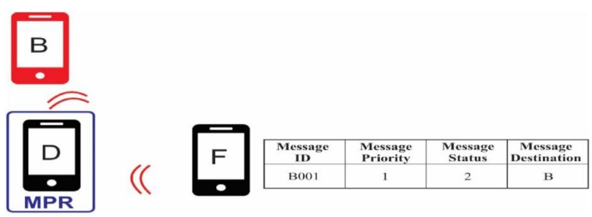

FIGURE 4 Sample values for priority and status fields for message status notification from recipient F to sender B.

implemented the proposed scheme in a simulation environment based on the disaster area model as proposed by Aschenbruck, et al. [35] and validated it by using a mathematical model. Network topology, number of nodes and other relevant metrics (such as number of packets, energy model and mobility speed) are defined in different scenarios for the implementation of the DS-OSLSMP routing protocol. A brief description of the implemented models as related to the proposed modifications is discussed in the following sub-sections.

4.1 | ALERT message prioritisation model

As mentioned earlier, Alert message prioritisation prioritises both message delivery and message status notification for devices with low battery energy. Message status notification is an integral part of the DS-OLSRMP prioritisation process for search and rescue operations. This feature prevents victims from flooding the network with ALERT messages, especially when such victims are experiencing a dire emergency which unduly increases their panic level because their communication device battery energy is running low. Alert Message prioritisation based on device battery life $P(x_i)$ is given as follows:

$$P(x_i) = \begin{cases} x_1, & \text{if } 1 \le x_1 \le 33 \\ x_2, & \text{if } 33 \le x_2 \le 67 \\ x_3, & \text{if } 67 \le x_3 \le 83 \\ x_4, & \text{if } 67 \le x_1 \le 100 \end{cases} \quad (1)$$

where x_1, x_2, x_3 and x_4 represent Critical, High, Medium, and LP nodes with the corresponding battery life percentage. Applicable priorities based on battery life are enumerated in Table 1.

The battery life of any device running DS-OLSR can be retrieved from a new table called device info set [15] In DS-OLSRMP, the remaining battery life are classified according to their respective priority and attached in the priority field of the ALERT message packet. However, the battery classification is used as an example and recommended by this research as it strikes a balance between low and CP nodes. Algorithm 1 presents the process of priority classification of nodes based on the battery life percentage. The algorithm integrates priority techniques to classify nodes based on the battery life, assigning HP to low battery nodes. This incorporation is accomplished by modifying existing algorithms rather than introducing entirely new ones. The introduction of priority techniques ensures effective energy conservation without introducing unwarranted complexities. The core algorithms inherit the fundamental structures of the conventional OLSR, maintaining simplicity while addressing the specific needs of disaster scenarios. A crucial aspect of the algorithm is the retention of the OLSR TC and Hello messages structure for one-hop/two-hop neighbour discovery and topology information. This retention ensures interoperability with existing OLSR-based networks. The protocol maintains the simplicity of message structures, making it compatible with conventional OLSR devices while enhancing energy efficiency through the introduced modifications. These adaptations, including the prioritisation of low battery nodes, do not introduce unnecessary complexities. Instead, they serve to enhance the protocol's functionality in disaster recovery and rescue operations without burdening the network with intricate mechanisms.

TABLE 1 Applicable message priorities and their values.

Priority value	Priority description	Device's battery life (%)
1	Critical	1–33
2	High	33–67
3	Medium	76–83
4	Low	83–100

Algorithm 1 Priority Decision

```
int main() { float batteryLevel = DeviceInfo.
GetBatteryLevel();
  string priority; if (batteryLevel ≥1 &
  batteryLevel ≤100)
            { if (batteryLevel <33)
                   {
        cout ≪ "Battery life is critical n";
              priority = "critical";
                   }
          else if (batteryLevel ≤67)
                   {
        cout << "Battery life is high
        priority n";
              priority = "high";
                   }
              else if (batteryLevel ≤83)
                   {
        cout ≪ "Battery life is medium
        priority n";
              priority = "medium";
                   }
                 else
                   {
        cout ≪ "Battery life is low
        prioritylow n";
              priority = "low";
                   }
                   }
                 else
                   {
    cout ≪ "Battery life must be between 1 and
    100 n";
                   }
               return 0;
                   }
```

MPRs nodes are responsible for ALERT Message prioritisation. ALERT messages collated by the MPRs are sorted based on the battery EL of each sending device. Figure 5 presents the messaging prioritisation process. Note that, MPR devices ensure that CP devices send messages and receives status notification on such messages before other priorities (high, medium, and LP nodes). This approach prevents such victims from overwhelming the network with messages as their device battery energy dwindles, thus reducing the overall traffic of the network.

Figure 6 demonstrates the message request order and priority order. Although device A is the third device to send Alert message for routing via MPR D, yet device A's Alert message is the first to be routed by MPR D to the message recipient. This is possible because device D (MPR) must sort all Alert messages according to priorities before routing to intended recipients.

The flowchart in Figure 7 is a concise representation of the message prioritisation process. As mentioned earlier, DS-OLSRMP message prioritisation technique ensures only CP nodes send and receive instant message notifications on Alert message delivery. However, the process waits for 100 ms and moves on to the next message if no feedback is received within the stipulated time (100 ms). This approach prevents the MPR from waiting indefinitely for the ALERT message status delivery report, especially when the intended recipient of such message is out of range.

4.2 | DS-OLSRMP MPR selection procedure

The DS-OLSR MPR selection process has been optimised to allow only high-battery life nodes to be selected as MPRs. This process has been achieved by modifying the concept of MPR willingness in the classical OLSR MPR selection scheme as in Algorithm 2. The mechanism selects middle and LP nodes to broadcast TC messages to the entire network rather than involving CP nodes, thereby reducing the amount of TC messages and its associated energy, subsequently increasing the lifespan of the low battery nodes. The MPR willingness is represented by four priority values of the willingness level: WILL-NEVER '1', WILL-LOW '2', WILL-DEFAULT '3', WILL-HIGH '4'. When using DS-OLSRMP, these willingness levels are ranked on the basis of nodes battery EL as used in the message prioritisation scheme. CP nodes will always set with the current EL (ELc) lower the minimum EL threshold value (ELmin). Therefore, such nodes are set to report the willingness level of WILL NEVER and will never be involved in the TC message broadcasting as a result of their critical battery life percentage. On the other hand, nodes with the EL between 33.1% and 67% (HP), 67.1% and 83% (MP), and 83.1% and 100% (LP), respectively, are set to report the willingness value based on their ranks, whereby LP nodes with ELc higher than 83% always report the maximum willingness value of WILL-ALWAYS and of course represents the best applicant for MPR as in Algorithm 2. The willingness level is broadcasted through the HELLO message and each node selects its own MPR from its one hop neighbour based on the advertised willingness.

The modification introduced to the DS-OLSRMP MPR selection mechanism within the proposed algorithm significantly impacts the complexity aspects, particularly in the context of energy conservation and network efficiency. The

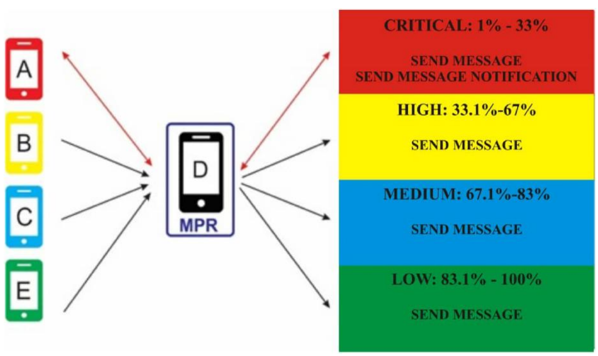

FIGURE 5 Message prioritisation process.

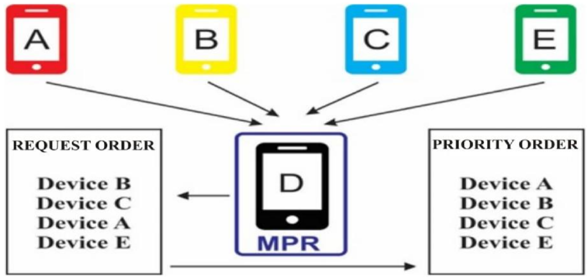

FIGURE 6 Request order and priority order.

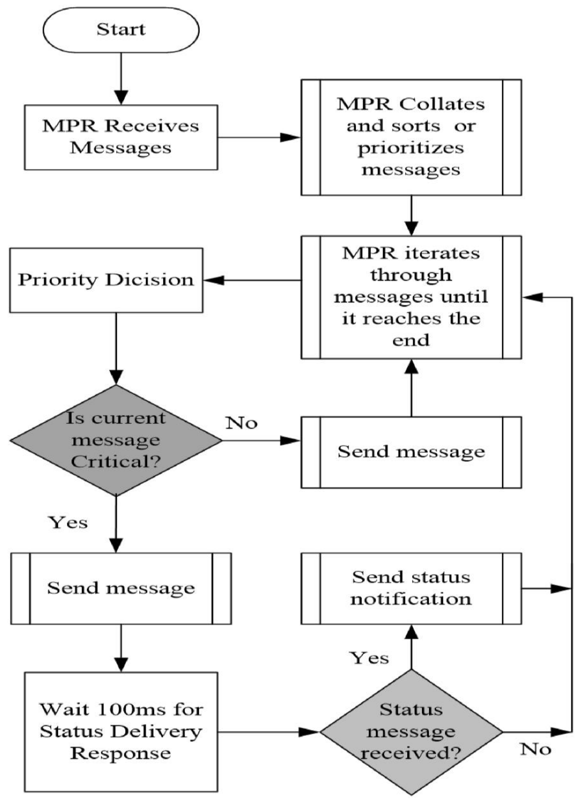

FIGURE 7 Message prioritisation process.

adjustment focuses on the willingness concept, restricting the selection of MPRs to nodes with high battery life. This modification, along with the prioritisation of nodes for broadcasting TC messages, intricately influences the algorithm's behaviour and complexity. In other words, the modification to the OLSR MPR selection mechanism within the proposed algorithm intricately manages complexity aspects to enhance energy efficiency. The prioritisation of nodes and reduction in TC messages contributes to the overarching goal of extending the lifespan of low battery nodes, making the algorithm a promising solution for disaster communication networks.

Algorithm 2 DS-OLSR MPR Willingness Process

```
Begin:
Require: Energy Level > ELmin
Ensure: Appropriate Battery life & Two-hop Nodes
ELmax the maximum energy level of node
ELmin the minimum energy level of node
ELc (i) the current energy level of node i
Wi willingness of node i ∈ v
Get ELc (i) of node i
If ELc (i) < ELmin then Wi = WILL- NEVER //1
Else if ELc (i) ≤ 67
Wi = WILL-LOW //2
Else if ELc (i) ≤ 83
Wi = WILL-DEFAULT //3
Else
Wi = WIL-HIGH //4
End if
Return Willingness level
```

The concept preventing low battery nodes from being selected as MPR in the DS-OLSRMP extends the lifetime of the low-battery nodes and reduces connection error or temporary loss of routes to other parts of the network, often caused by packet collision, thereby resulting in a massive increase in control overhead generation. The DS-OLSRMP MPR selection procedure is mathematically represented as follows: Let R_S represent the DS-OLSRMP MPR selection process, then

$$R_S = \begin{cases} 0, & \text{if } i = 1 \\ a, & \text{if } i = 2, 3, 4. \end{cases} \quad (2)$$

where $a = Max(t_i)$.

5 | MESSAGE SLICE DURATION

In DS-OLSR [15], the duration of Message TS (MTS) is 30,000 ms. However, different priority nodes have different Message Slice Durations (MSDs) when using DS-OLSRMP. This is because the priority technique prioritises the message from devices with low battery energy and allows such nodes to switch to a sleep mode after the specified time for energy conservation. The maximum battery energy percentage of each priority together with their MSD durations is used to obtain an appropriate MSD of the various priorities.

Let $t1$, $t2$, $t3$ and $t4$ represent the MSD of Critical, High, Medium, and LP nodes, respectively. Therefore, the MSD for all priorities, Ti is expressed as follows:

$$T_i \alpha t_i, \quad \text{where} \quad t_i = \frac{x_i}{100}, \quad \text{and} \quad T = \beta t_i, \quad (3)$$

where α is the proportionality symbol and β is the constant of proportionality that represents the duration of message TS.

Therefore,

$$T_i = \frac{x_i}{100}, i = 1, 2, 3, 4, \quad (4)$$

where x_i is the maximum battery energy percentage for the various priorities, and β represents the duration of MTS [15]. The MSD for the various priorities is calculated by Equation (4) and the approximated results obtained are presented in Table 2. The MSD for each priority is activated during DS-OLSR message TS (MTS) duration.

6 | BATTERY ENERGY MODEL

Many researchers have presented different models for analysing battery service life and predicting the remaining battery capacity of nodes [13, 21]. Battery provides current and voltage for the node's components including radio interface, memory cards, CPU etc. As reported by [34], the battery as storehouse of electrical charges loses its charge with the decrease of electrical current (load), and the loss rate is given as a function of the load. The total energy consumed per cycle (E_{cycle}) is the sum of the energy consumed by the various hardware components attached to a battery [34, 36] and is given as follows:

$$E_{Cycle} = E_{Trans} + E_{CPU} + E_{DC} + E_{Bat}. \quad (5)$$

where E_{Bat} denotes the efficiency loss of battery charges while $E_{Trans} + E_{CPU} + E_{DC} + E_{Bat}$ are the energy consumed by the transceiver, Processor, and converter (DC-DC), respectively. All nodes in DS-OLSRMP are provided with a simple linear battery model based on a coulomb counting technique [21] to estimate the residual battery energy of nodes at a charge monitoring interval of 1 s. However, this research deliberately

TABLE 2 Allocation of message slice duration to priorities.

Priority	Message slice duration (MSD)
Critical	10,000 ms
High	20,000 ms
Medium	25,000 ms
Low	Entire MTS (30,000 ms)

designated different initial battery capacities of nodes in *NS*—3 to account for various priority classes of message prioritisation.

7 | NETWORK MODEL AND ENERGY CONSUMPTION

MANETs are modelled using graph $G(V, E)$, where V and E represent group of mobile nodes and arcs, respectively. The arc models the intersection or wireless radio range between pairs of nodes. Every node $A \in V$ communicates directly with a set of neighbouring nodes within the range of its coverage area [21]. However, relay nodes are used for nodes that are not within the coverage area of each other. In mobility scenarios, mobile devices move arbitrarily at different speeds; consequently, the topology changes randomly and rapidly at irregular times. As the nodes move around, detects the presence of other nodes and exchange control messages among themselves, thereby creating a network dynamically. The network is established via the broadcast the of control messages from participating nodes autonomously. A typical hop length of E increases with the increase of nodes in group V, which in turn affects the performance of routing protocols. With respect to the MANET model, the network connectivity parameters of the model represent the links between normal nodes. MPR nodes and a sink node are expressed mathematically as follows:

If a node e establishes a link with an MPR node y, can be written as:

$$a_{ij}^{ey} = \begin{cases} 1, & \text{if a link on } arc(i,j) \in A_E \rightarrow My \\ 0, & \text{Otherwise.} \end{cases} \tag{6}$$

where a_{ij}^{ey} is the arc (link) between the normal node e and MPR node y, and A represents a number of links (arcs). E is the vertices of the normal node, and My is the vertices of MPR node.

If a node e establishes a link with a Sink node S, it can be expressed as follows:

$$a_{ij}^{es} = \begin{cases} 1, & \text{if a link on } arc(i,j) \in A_E \rightarrow S \\ 0, & \text{Otherwise.} \end{cases} \tag{7}$$

If an MPR node y establishes a link with a Sink node S, it can be written as follows:

$$a_{ij}^{ys} = \begin{cases} 1, & \text{if a link on } arc(i,j) \in A_{My} \rightarrow S \\ 0, & \text{Otherwise.} \end{cases} \tag{8}$$

If an MPR node y establishes a link with the other MPR node x, it can be expressed as follows:

$$a_{ij}^{yx} = \begin{cases} 1, & \text{if a link on } arc(i,j) \in A_{My} \rightarrow Mx \\ 0, & \text{Otherwise.} \end{cases} \tag{9}$$

The modifications of the OLSR module were made in two important files that contain the actual routing logic of OLSR in NS-3: these files are olsr-routing-protocol.cc and olsr-routing-protocol.h. The first file contains the full C++ source code for OLSRv1 implementation in NS-3, while the second code contains function names and their parameters. The energy function was used to compute and display the energy cost of forming and maintaining OLSR, DS-OLSR and DS-OLSRMP networks in the simulation of different disaster scenarios.

Energy consumption modelling is very critical in networks for disaster recovery and rescue operations as some disasters equally damaged power grids, and the communication nodes depend on the limited battery energy for power. The configuration setting of this energy model plays a vital role in estimating the energy consumed by nodes during transmission. Receive, Transmit, Idle and Sleep are four states of mobile nodes in a wireless communication network, and of course, every state consumes a specific amount of energy. The energy model was based on a Generic Radio Energy Model as highlighted in Refs. [13, 21], which defined the total energy consumption of a node as the sum of energy consumed in all states. Therefore, the energy consumed for each state of node is given as follows:

$$Tx_{Energy} = V \times Tx_{Current} \times Tx_{Time} \tag{10}$$

$$Rx_{Energy} = V \times Rx_{Current} \times Rx_{Time} \tag{11}$$

$$Idle_{Energy} = V \times Idle_{Current} \times Idle_{Time} \tag{12}$$

$$Sl_{Energy} = V \times Sl_{Current} \times Sl_{Time}, \tag{13}$$

where Tx_{Energy}, Rx_{Energy}, Idle_{Energy} and Sl_{Energy} are energy consumed during the states of transmit, receive, idle, and sleep, respectively. V is a default supply voltage as contained by Jabbar, et al. [7, 13, 21], and $Tx_{Current}$, $Rx_{Current}$, $Idle_{Current}$ and $Sl_{Current}$ are circuity current in amperes for each state. Tx_{Time}, Rx_{Time}, $Idle_{Time}$ and Sl_{Time} represent the time spent in each state. However, Transmit and receive energy is determined by signal transmission power from the Physical layer (PHY.SET). Therefore, due to external interference, we considered the sensitivity degradation factor as modelled in Ehiagwina, et al. [37] to account for the signal degradation or the power amplifier inefficiency factor as used in Ref. [21]. In a general term, the total energy (ET) consumed by a node to transmit and received packet is as follows:

$$E_T = S_d\left[Tx_{Energey} + Rx_{Energey} + Idle_{Energey} + Sl_{Energey} +\right], \tag{14}$$

where S_d represent the power amplifier inefficiency factor of the circuit power consumption. The energy model parameters for our study are configured based on the studies of Jabbar, et al. [21] and Ehiagwina, et al. [37]. The energy function implementation enabled this research to capture and display the energy cost of OLSR, DS-OLSR, and DS-OLSRMP networks. Replacing the terms used in Equations (14) and (4) by TC and Ti, respectively, the Total Energy (E_T) consumed by nodes to transmit and receive packet at time t can be expressed as follows:

$$E_T = \left[V * T_c \left(\frac{1}{n} \sum_{i=1}^{4} \frac{x_i \beta}{100} \right) NT \right]. \tag{15}$$

8 | SIMULATION SETUP AND RESULTS DISCUSSION

This section presents the implementation of DS-OLSRMP in the NS-3 simulation environment and evaluates the performance of the proposed routing scheme based on the disaster area network as proposed by Aschenbruck, et al. [35]. It is the same model that was used for DS-OLSR implementation as presented in our previous paper [15]. The results obtained are compared based on the selected performance criteria with DS-OLSR [15] and with two other conventional schemes: OLSRv1 and OLSRv2. Firstly, this section discusses the simulation setup and its environment and then highlights the selected performance evaluation metrics. Although, the simulation results are validated using analytical computation, but in this paper, the analysis of the simulation results of DS-OLSRMP in comparison with DS-OLSR, OLSRv1 and OLSRv2 under the same parameters wraps up the section.

8.1 | Simulation setup

As mentioned earlier, the performance of the proposed DS-OLSRMP is evaluated by simulations in NS-3.29 and validated using analytical analysis. Figure 8 presents an NS-3 python visualiser, showing the implementation of the proposed DS-OLSRMP protocol. The simulation for both static and mobility scenarios was executed and compared with DS-OLSR, OLSRv1 and OLSRv2 under different node densities: 10, 50, 100 and 200 nodes in 1000 m × 1000 m simulation environments as presented in Table 3. Different initial battery capacities of nodes were deliberately configured to account for various priority classes of message prioritisation.

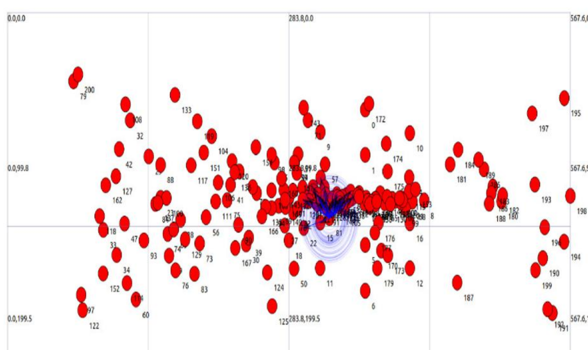

FIGURE 8 NS-3 Python Visualiser showing node placement for DS-OLSRMP.

In each DS-OLSRMP network scenario, nodes are randomly deployed into four different priority groups based on a defined battery capacity. Therefore, 20% of the deployed nodes of each simulation have been assigned as CP nodes with Battery life between 1% and 33%, while 30% of the deployed nodes as HP nodes with Battery life between 33.1% and 67%.

The remaining half of the deployed nodes have been shared between MP and LP nodes, with 30% of the nodes assigned battery life between 67.1% and 83% for the former and 20% of LP nodes assigned battery life between 83.1% and 100% for the latter. Some of these simulation parameters are from the related work and others were carefully chosen to strike a balance between realism and computational tractability, ensuring that our proposed algorithm's performance is evaluated under conditions that mirror real-world disaster recovery scenarios. For example, the energy consumption model aligns with established models in the literature and accurately reflects the dynamics of energy depletion in communication devices during disaster recovery operations.

As regards to mobility models, we considered Random Way Point (RWP) with the speed range of a pedestrian (1 m/s −2 m/s) [35]. This is because victims running at high speed during disaster recovery and rescue operation will result to high risk of injury. However, to accommodate the speed of rescuers who might be using vehicles, we also evaluate the proposed scheme with the speed range of vehicles (5 m/s–12 m/s). The

TABLE 3 Simulation parameters.

Description	Parameters
Simulation environment	1000 m × 1000 m
Number of nodes	10, 50, 100 and 200
Nodes deployment	Random positioning
Mobility model	Random way point, min speed 0, max speed 1 m/s–2 m/s, and 5 m/s–12 m/s [15], pause time 10 s
Simulation duration	180 s
Transmission range	50 m
Packet size	512 byte
Mac protocol	IEEE 802.11
Energy model	$Tx_{Current} = 0.26$ A $Rx_{Current} = 0.18$ A
	$Idle_{Current} = 0.148$ A
	$Sleep_{Current} = 0.0094$ A
	Supply voltage = 5 V
Battery model	Linear battery model
DS-OLSRMP specific parameters	
Priority classification	CP, HP, MP and LP
Battery energy level distribution	CP (1%–33%), HP (33.1%–67%), MP (67.1%–83%), LP (83.1%–100%)
Nodes distribution to priorities	CP = 20%, HP = 30%, MP = 30%, LP = 20%

simulation was generally set up according to parameters used by Jabbar, et al. [21] except those parameters that are DS-OLSR specific.

8.2 | Results discussion

The overall performance of the proposed DS-OLSRMP is thoroughly investigated and compared with DS-OLSR, OLSRv1 [15], and OLSRv2 in the disaster area model based on the simulation parameters mentioned earlier. Unlike [7], the mean values of energy dissipated in total of 10 simulations by nodes in both static and mobility scenarios were evaluated in comparison to the mean values of energy dissipated using DS-OLSR, OLSRv1 [15], and OLSRv2. The mean values of packet delivery are also evaluated to ascertain the percentage of successfully transmitted packets against the number of packets sent in the networks. Furthermore, to compare the time required for a packet to be successfully transmitted from the source to the destination, the research equally evaluated average end-to-end delay. The variation between the simulations results is insignificant and not reported in this paper. The network size of 10, 50, 100 and 200 nodes and different node speeds (Pedestrian: 1 m/s–2 m/s and Vehicles: 5 m/s–12 m/s [35]) has been selected as parameters to evaluate the proposed scheme as it is widely used to evaluate simulation studies in MANETs. When the network size and node speed increase, the scalability of the proposed routing protocol will be evaluated to prove its performance. As reported in our previous work in Ref. [15], the simulation of 200 nodes using OLSRv1 and OLSRv2 failed several times due to the generation of high control traffic that cannot be handled by the system. However, here we use a system with a better resource to compare the performance of the OLSRv1 and OLSRv2 using 10–200 nodes with DS-OLSRMP.

Figures 9–11 represent mean values of energy dissipated in total of 10 simulations by nodes using DS-OLSRMP, DS-OLSR, OLSRv1 and OLSRv2 for 10, 50, 100 and 200 nodes in both static and mobility scenarios. It is obvious from the simulation results that OLSRv1 and OLSRv2 report high energy consumption as compared to DS-OLSR and DS-OLSRMP in all scenarios, and of course, the energy consumption rate for the OLSRv1 and OLSRv2 increases exponentially with the increased number of nodes in the network. This huge energy consumption by both versions of the OLSR is attributed by the continuous generation of high control overhead traffic and constantly busy routing control messages in the background (regardless of user messages) as equally reported by Qin, et al. [5] as the major energy consumption of their experimental work. The energy conservation by DS-OLSR is attributed to TS that confines messages into their respective time [15]. It can also be observed from the simulation results of the static scenario in Figure 9 that energy saving by DS-OLSR is further enhanced by the introduction of message prioritisation techniques as DS-OLSRMP indicates reduction in energy consumption as compared to DS-OLSR, with 29.1%, 25.2%, 21.8% and 20.9% when simulating 10, 50, 100 and 200 nodes, respectively. The DS-OLSRMP using 50 nodes conserved more energy as compared to the energy reported in Ref. [13] on the same network size. The energy saving is because of the message prioritisation techniques that ensure messages from CP nodes are delivered first before messages from other priority nodes (HP, MP, and LP) and CP, and HP nodes switch to a sleep mode after 10,000 and 20,000 ms of MTS, respectively, to conserve energy.

To examine the energy conservation of the proposed routing protocol in a real-life disaster mobility scenario, the proposed techniques were evaluated under two mobility speeds: Pedestrian (1 m/s−2 m/s) and Vehicles (5 m/s−12 m/s) [35]. Figures 9 and 10 reveal that the proposed DS-OLSRMP achieves lowest energy consumption in both pedestrian and vehicle speeds irrespective of the number of nodes. This attributed to the fact that DS-OLSRMP utilises the energy-saving mechanism that is not available in other protocols. However, as reported in Ref. [15], the performance of the DS-OLSRMP is

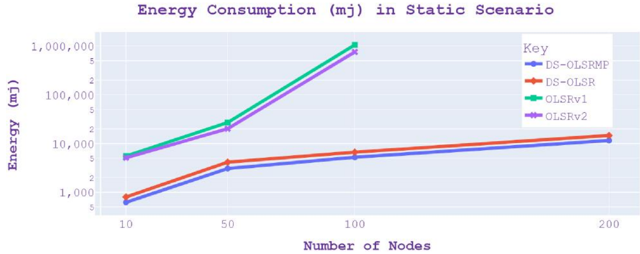

FIGURE 9 Comparison of energy consumption for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a static scenario.

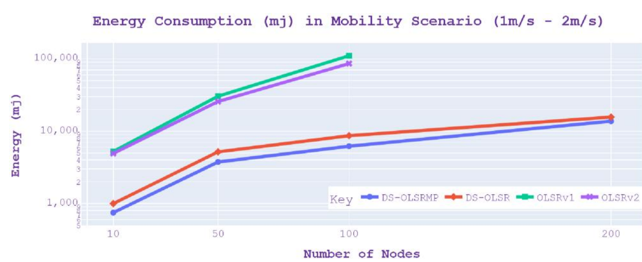

FIGURE 10 Comparison of energy consumption for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (1–2 ms).

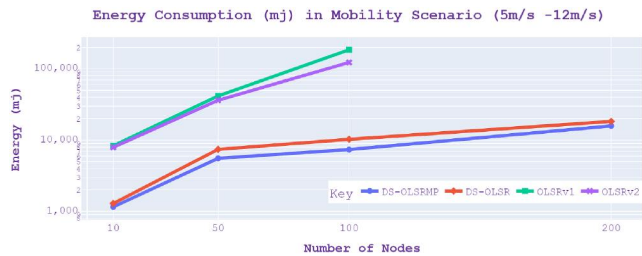

FIGURE 11 Comparison of energy consumption for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (5–12 ms).

slightly affected by the implementation of mobility metrics, particularly for 5 m/s–12 m/s speed as the energy consumption increases due to high movement of nodes in the network. Although it is still reasonable considering the number of successful transmitted packets and compared to DS-OLSR and some multi-path routing protocols [4, 13, 21, 22]. In a general term, nodes change position in mobility scenarios, and of course, their routes randomly change over time, which require further route calculation and complexity on topology sensing thereby resulting to energy expenditure. MPR nodes expend more energy than normal nodes as they forward control and data packets to the entire network on behalf of their electors. Unlike the routing concepts in Refs. [22–24, 26], DS-OLSRMP takes advantage of its prioritisation technique to prioritise messages from CP and selects only high battery life nodes (e.g. HP and MP) as MPRs. This process increases the lifetime of low-battery energy devices and reduces the total energy cost of the network.

Routing control overhead is used to analyse the cost and complexity of routing protocols in a self-organised network. Figures 12–14 represent mean values of control overhead in a total of 10 simulations for DS-OLSRMP, DS-OLSR, OLSRv1 and OLSRv2 when simulating 10, 50, 100 and 200 nodes in both static and mobility scenarios. The superiority of DS-OLSRMP can be observed in all situations as it returns the lowest control overhead in all the scenarios, regardless of nodes mobility speed and network size. While some references did not evaluate routing overhead of their OLSR-based schemes [8, 9, 11], the proposed DS-OLSRMP reported minimum overhead as compared to few similar studies that evaluated their overhead in the literature [21, 26]. This achievement of the proposed DS-OLSRMP followed by DS-OLSR became the second best routing protocol with less control overhead because both protocols share similar techniques. The results of DS-OLSRMP and DS-OLSR have illustrated the importance of using TS to encapsulate control messages such as Hello, TC, and of course, ALERT message into their respective TSs.

In addition, both protocols maintain routing information for a longer time [15], thereby reducing the delay time of packets transmission. These schemes limit message collision and the continuous rebroadcasting of control messages in both DS-OLSRMP and DS-OLSR and therefore reduce the overall routing overhead.

Figures 15–17 represent mean values of PDR in a total of 10 simulations for DS-OLSRMP, DS-OLSR, OLSRv1, and OLSRv2 with 10, 50, 100 and 200 nodes in both static and mobility scenarios. It can be observed from the simulation results that both versions of OLSR delivered fewer packets as

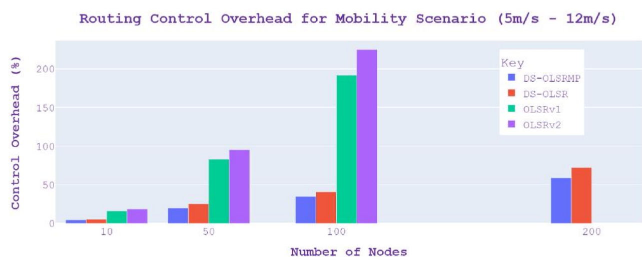

FIGURE 14 Comparison of routing control overhead for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (5–12 ms).

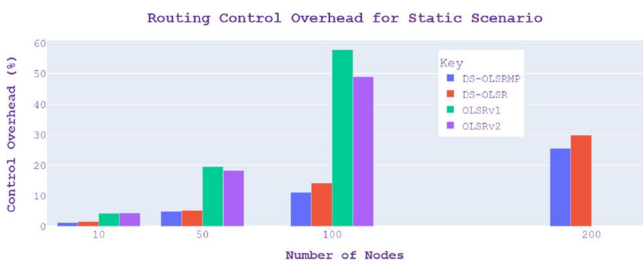

FIGURE 12 Comparison of routing control overhead for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a static scenario.

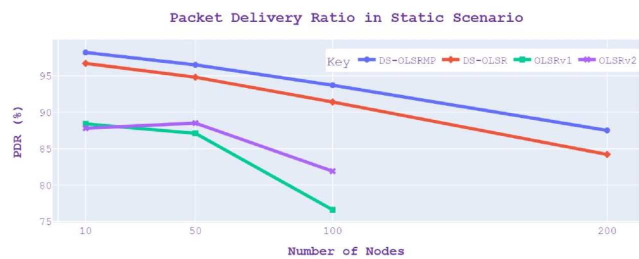

FIGURE 15 Comparison of packet delivery ratio for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a static scenario.

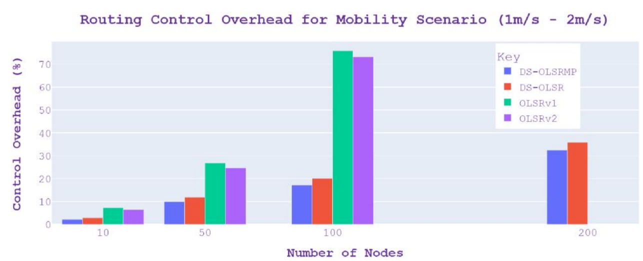

FIGURE 13 Comparison of routing control overhead for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (1–2 ms).

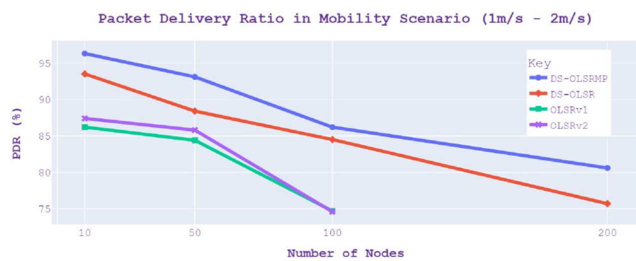

FIGURE 16 Comparison of packet delivery ratio for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (1–2 ms).

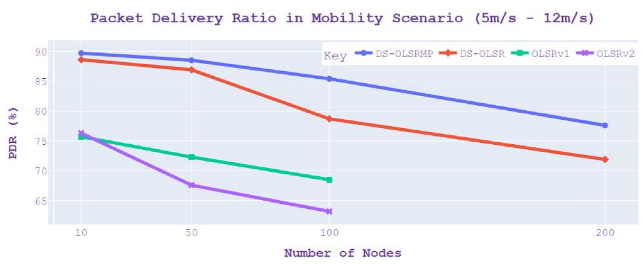

FIGURE 17 Comparison of packet delivery ratio for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (5–12 ms).

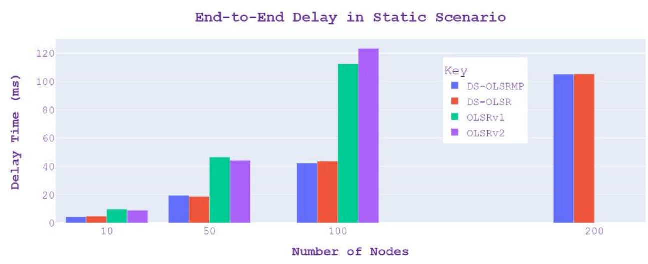

FIGURE 18 Comparison of end-to-end delay for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a static scenario.

compared to DS-OLSRMP and DS-OLSR in all scenarios. However, OLSRv2 delivered fewer packets compared to OLSRv1 in the simulations with 10 nodes due to the limited number of nodes in the network leading to a crossover in Figure 14. In addition, the PDR for OLSRv1 and OLSRv2 was drastically reduced with the introduction of high mobility (5 m/s—12 m/s) in the networks as equally reported in Refs. [7, 8, 11, 21], thereby resulting in a huge increase in their end-to-end delay and control overhead. The use of packet delivery prioritisation based on device battery life extends the lifespan of low-battery devices and allows more packets to be delivered as DS-OLSRMP shows better PDR as compared to DS-OLSR and some OLSR-based schemes in the literature [7–9, 11]. The percentage of packet delivered by DS-OLSR and DSOLSRMP protocols is similar in the simulation with 50 nodes for a static scenario as shown in Figure 15. However, in the simulation of 100 and 200 nodes for mobility scenarios, DS-OLSRMP demonstrated the capability of the proposed prioritisation scheme to prolong the lifetime of low battery nodes, thereby delivering more packets than DS-OLSR as shown in Figures 16 and 17. Although, the PDR for both protocols decreases slightly with the increase of nodes and node speeds in the network, nonetheless, the PDR is far better than what was obtained in a similar OLSR optimisation research by Prakash, et al. [38] and Jabbar, et al. [21]. The DS-OLSR and DS-OLSRMP results confirm how the concept of TSs improves link quality by eliminating crosstalk and reduces the funnel effect without compromising packets delivery in all the scenarios. Scenario (5 m/s–12 m/s) Figures 18–20 represent mean values of end-to-end delay in a total of 10 simulations for DS-OLSRMP, DS-OLSR, OLSRv1 and OLSRv2 with 10, 50, 100 and 200 nodes in both static and mobility scenarios. It is obvious from the Figures that the conventional versions of OLSR reported higher end-to-end delay in both static and mobility scenarios as compared to DS-OLSRMP and DS-OLSR.

In addition, the end-to-end delay for both OLSR versions increases exponentially with thevincreased number of nodes in the network. This is due to connection errors or temporary loss of routes to other parts of the network, often caused by packet collision [7, 21], thereby resulting in a massive increase in control packets generation, subsequently increasing end-to-

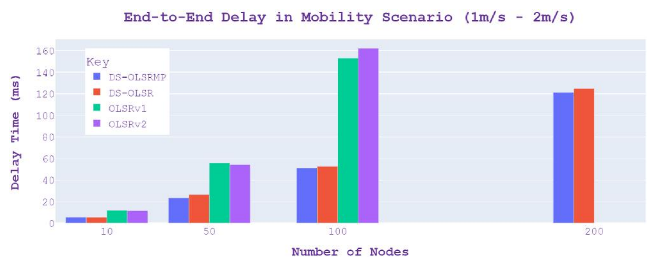

FIGURE 19 Comparison of end-to-end delay for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (1–2 ms).

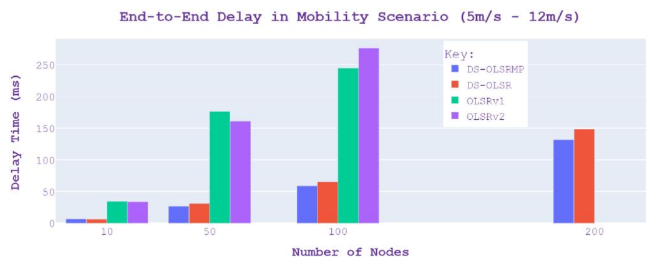

FIGURE 20 Comparison of end-to-end delay for DS-OLSRMP, disaster scenario optimised link state routing, OLSRv1 and OLSRv2 in a mobility scenario (5–12 ms).

end delay in all the simulated scenarios. The end-to-end delays for DS-OLSRMP and DS-OLSR are very similar in all scenarios. This did not come as a surprise because both schemes employed the techniques of TSs that decrease the possibility of link failure and maintain routing information for a longer time as in Ref. [15]. Therefore, data packets are not sent via unreliable routes, thereby reducing the delay time required for retransmissions. DS-OLSRMP enhances energy efficiency by extending the lifespan of low-battery energy devices without sacrificing the major quality of service metrics: PDR, average end-to-end delay, and routing control overhead. Thus, it is highly recommended for communications in disaster-related scenarios.

9 | REAL-WORLD IMPLICATIONS: ENHANCING COMMUNICATION RESILIENCE IN DISASTER RECOVERY OPERATIONS

The proposed work introduces a novel and vital dimension to the optimisation of OLSR for energy efficiency, with a specific focus on addressing the challenges associated with disaster recovery and rescue operations. The real-world impact of this research as its benefits to flood victims, aiding their communication with rescue teams such as the national emergency management authority (NEMA) and medical teams for rapid responses on, for example, a propose rescue time, or where such victims should gather to receive supplies, shelter or medical attention. Flood incidents often result in disrupted communication networks, leaving victims isolated and in need of urgent assistance. The DS-OLSRMP routing protocol presents a significant advancement in addressing communication challenges during such crises, particularly in the context of flood-stricken areas.

(1) Extended Device Lifespan:

The DS-OLSRMP's prioritisation techniques focus on extending the lifespan of low-battery devices. In flood situations where power sources may be scarce, this feature becomes crucial. Flood victims equipped with mobile devices utilising DS-OLSRMP can sustain communication for an extended duration, allowing them to reach out for help even in prolonged emergencies.

(2) Coordination with Rescue Teams:

Effective communication is paramount for coordinating rescue efforts. DS-OLSRMP's prioritised messaging ensures that flood victims can send and receive critical information, including their location, medical needs, and the severity of the situation. This information is invaluable for rescue teams, including organisations such as NEMA, to plan and execute timely and target rescue operations.

(3) Seamless Integration with Medical Teams:

In flood scenarios, medical assistance is often urgently required. DS-OLSRMP facilitates seamless communication between flood victims and medical teams. Victims can convey medical emergencies, provide information about injuries or health conditions, and receive guidance on immediate care. This real-time communication enhances the efficiency of medical teams in responding to the diverse health needs of flood-affected individuals.

(4) Network Resilience in Challenging Environments:

Flood-stricken areas may present challenging network environments. DS-OLSRMP, by emphasising network resilience and energy efficiency, ensures that the communication infrastructure remains robust even in adverse conditions. This is crucial for sustaining communication links between flood victims and rescue or medical teams, enhancing overall response effectiveness.

Furthermore, in disaster scenarios such as bushfires, for example, the recent incident in Nymboida, New South Wales, Australia, where mobile phone service was unavailable during the bushfire, the DS-OLSRMP solution, by focusing on deploying disaster communication with few steps and extending the lifespan of low-battery devices, could potentially mitigate the impact of communication outages. When traditional communication networks fail, the DS-OLSRMP's energy-efficient prioritisation techniques could enable survivors to use their mobile devices for a more extended duration, facilitating communication with rescue teams, loved ones, and support networks.

In the described incident, the inability to make phone calls during the emergency left residents vulnerable. The DS-OLSRMP's emphasis on the extended lifespan of low-battery devices could address such vulnerabilities, offering a potential solution to communication challenges during disasters such as bushfires. In summary, the DS-OLSRMP solution emerges as a vital tool in empowering flood victims to communicate effectively with rescue teams and medical professionals. By extending device lifespan, prioritising critical messages, and ensuring network resilience, DS-OLSRMP contributes to a more coordinated, timely, and efficient response to flood emergencies.

10 | CONCLUSION

The proposed DS-OLSRMP as an extension to DS-OLSR, presented in this paper, not only prioritises messages from devices with low battery energy but also extends the lifespan of communication devices with low battery energy and restricts such nodes from being selected as MPRs. It also improves overall energy conservation and packet delivery as compared to DS-OLSR, OLSRv1 and OLSRv2. In addition, DS-OLSRMP will likely improve the victim's emotional state by quickly responding to messages sent by those whose devices are low in battery energy to prevent such victims from overwhelming the network with messages as their device battery energy dwindles. The message prioritisation techniques classified mobile phones into four priority groups—Critical, High, Medium, and Low priorities, thereby prioritising both message delivery and message status notification for devices with low battery energy. The simulation results show that energy consumption and packets delivery are notably improved using the message prioritisation. The priority techniques also ensure that messages from CP nodes are delivered before messages from other priority nodes and that CP and HP nodes switch to a sleep mode after 10,000 and 20,000 ms of MTS, respectively.

10.1 | Future work

(1) Real-World Testing and Extension to Wireless Sensor Networks (WSN)-MANET-IoT Convergence: Conduct

experiments, including real Testbed scenarios, to validate the proposed DS-OLSRMP techniques in real-life environments. While simulation models have shown effectiveness, real-world testing is essential to understand practical implications and assess the impact beyond simulated assumptions. On the other hand, explore further implementations of the proposed schemes in wireless sensor networks (WSN) and scenarios involving the convergence of mobile ad-hoc networks (MANET) and internet of things (IoT) devices. Evaluate the performance of the routing protocol in diverse network settings, including devices from different manufacturers.

(2) Optimisation of Message Priority Techniques and Integration of Routing Layer Security: Address the challenge of message priority techniques, which currently may cause indefinite pauses for LP messages in the presence of higher priority messages. Develop a technique to achieve a balance, allowing a timely transmission of LP messages without undue delay. On the other hand, implement the DS-OLSRMP technique with additional routing layer security measures. Evaluate the impact of security overhead on the proposed routing schemes, considering the critical role of security in autonomous networks such as MANETs and WSN [39].

AUTHOR CONTRIBUTIONS

Umar Aliyu: Conceptualisation; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualisation; writing – original draft. **Haifa Takruri**: Funding acquisition; investigation; resources; supervision; writing – review & editing. **Martin Hope**: Investigation; resources; supervision; writing – review & editing. **Abubakar Halilu Gidado**: Data curation; investigation; project administration; writing – review & editing. **Hamid Abubakar Adamu**: Data curation; investigation; project administration; resources; validation; writing – review & editing.

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CONFLICT OF INTEREST STATEMENT

No conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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