PrioriNet: An Energy-Efficient Emergency Priority Protocol for Sustainable Communication in Disaster Scenarios

Original Scientific Paper

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Abstract *– During disaster scenarios, effective communication systems are essential for coordinating emergency response efforts and ensuring the safety of affected individuals. However, existing communication protocols often face challenges in providing reliable and efficient communication in these highly dynamic and resource-constrained environments. To overcome these challenges a novel energy-efficient emergency priority protocol namely PrioriNet technique which specifically tailored for urban earthquake scenarios. The protocol focuses on prioritizing the transmission of emergency data packets to ensure their prompt and reliable delivery, while appropriately managing normal data packets. The PrioriNet prioritizes the emergency messages as high and low priority messages and allocate them to energy efficient nodes efficiently. The experimental results indicates that the suggested protocol performs better than the existing LEACH technique in terms of energy consumption, network coverage, packet delivery ratio, and throughput. In emergency data scenarios, the LEACH protocol demonstrates throughputs between 0.3 Mbps and 1.2 Mbps, whereas the proposed method consistently outperforms the LEACH protocol with throughputs ranging from 0.7 Mbps to 1.8 Mbps respectively.*

Keywords*:* *PrioriNet, LEACH, earthquake, emergency priority protocol, energy, MATLAB*

1. INTRODUCTION

A natural disaster is an unforeseen and catastrophic event that can strike anywhere in the world, disrupting societies and causing significant loss of life, rationality, and economic impact [1]. In such dire situations, disaster management plays a crucial role in providing support to those at risk and managing emergencies efficiently [2]. To recover and improve communications in post-disaster scenarios, various technologies have been proposed to facilitate faster and more reliable communication [3]. Earthquakes, tsunamis, and storms are among the disasters that necessitate low-power operating systems and devices for the people in disaster places to communicate with the outside world for help. Rescue efforts by the rescue teams are prioritized using rescue urgency degrees (RUDs), which are based on the seismic intensity measured by the seismographs from the impacted locations [4]. RUD will demonstrate the reverse effects caused by the earthquake and the urgency level for rescuing the persons affected in the disaster zone. Therefore, for sharing emergency-related information among first responders and their supervisors, a robust, reactive, and energy-efficient routing protocol is crucial. Prioritizing limited resources becomes critical to saving lives and minimizing further damage [5-8]. Existing protocols, such as LEACH, partially address these limitations but fail to fully meet the specific requirements of disaster scenarios [9-10]. They lack efficient prioritization of emergency messages, leading to potential delays and compromised situational awareness. Additionally, energy resources are often inefficiently utilized, resulting in premature depletion of node energy and reduced network lifetime [11]. To overcome these limitations, a novel emergency priority protocol is proposed. The research contribution of this study has been outlined as follows:

- The proposed PrioriNet protocol effectively differentiates emergency and non-emergency data and ensures the prompt transmission of critical information. Priorities are assigned according to predefined criteria.
- The generated emergency calls are then received and processed by the PrioriNet, based on urgency levels, ensuring swift attention to critical information.
- The effectiveness of the proposed PrioriNet protocol has been assessed on the basis of network coverage, packet delivery ratio, energy consumption and throughput.

The remaining sections of the paper are organised as follows: The literature review is described in Section II. The proposed technique is described in Section III. The experimental results are described in Section IV, and the study concludes including some suggestions for further investigation in Section V.

2. LITERATURE REVIEW

To address the seamless mobilization of rescue teams for providing emergency services during disasters, various strategies have been explored in the existing literature. Among those, some of the literature has been reviewed in this section.

Araghipour and Mostafavi [11] proposed a new emergency routing protocol based on ERGID. To accomplish these objectives, a mechanism for prioritizing urgent data was created. Shreyas et al [12] proposed the Energy Efficient Emergency Response System (EEER). During emergencies, the suggested EEER efficiently and quickly distributes crucial data. Abdellatif et al. [13] suggested using IoT devices and LTE device-to-device ProSe (D2D ProSe) technology to create an effective emergency communication network during a disaster.

Campioni et al. [14] proposed a novel Aceso - Proof-of-Concept smart city middleware technique. It offers location- and context-aware services to completely support Humanitarian Assistance and Disaster Relief (HADR) operations. Zhao et al. [15] presented a directional-area-forwarding-based energy-efficient opportunistic routing (DEOR) approach for the post-disaster MioT. Mohammadiounotikandi et al. [16] proposed a hybrid nature-inspired optimization approach, Emperor Penguin Colony, and Particle Swarm Optimization (EPC-PSO). Tang et al. [17] proposed an optimal solution according to observable workloads and communication channel connectivity.

Olatinwo et al. [18] proposed a coordinated superframe duty cycle hybrid MAC (SDC-HYMAC) protocol to enhance energy efficiency and to prolong the devices' lifetime. Al-Hady et al. [19] proposed an IoT-based automated emergency response website that leverages IoT technology to gather real-time data from various sensors installed in the site and uses machine learning algorithms to predict and prevent potential fire incidents.

The reviewed literature has various advantages in prioritizing emergency messages during disasters, however, they possess some drawbacks which is given in Table 1.

Table 1. Comparison of existing techniques

Reference	Method	Result	Advantage	Disadvantage
Araghipour and Mostafavi [11]	emergency routing protocol based on ERGID	performs better than ERGID by 60% and 35%, for end-to-end time and packet loss rate respectively.	speeds up the transmission of emergency data	high complexity
J Shreyas et al. [12]	EEER	improvements in power consumption, packet delivery speed, and end-to-end latency of 5%, 6%, and 7%, respectively.	the suggested EEER efficiently and quickly distributes crucial data.	did not consider resource allocation
Abdellatif et al. [13]	D2D ProSe technology	significantly outperforms others suggested in the literature	effective communication during disaster	Very low throughput
Campioni et al. [14]	novel Aceso - Proof-of-Concept smart city middleware technique	Aceso's value in prioritizing the processing and routing of crucial information.	offers location- and context-aware services to support HADR operations	Less efficiency
Zhao et al. [15]	DEOR approach	outperforms existing methods in terms of energy consumption, and network lifetime	Less energy consumption	Limited capacity
Mohammadiounotikandi, et al. [16]	EPC-PSO	decreased the execution time and cost by 10.41% and 25% compared to other algorithms.	achieve a sustainable system and less energy consumption	Low scalability
Tang et al. [17]	cooperative learning-based solution	superior in terms of service quality and energy conservation in diverse environments	optimal solution according to observable communication channel connectivity	Higher delay
Olatinwoet al. [18]	SDC-HYMAC protocol	performed better convergence speed, energy efficiency, and devices' lifetime.	enhance energy efficiency and prolong the devices' lifetime	Deployment Cost is high
Al-Hady, S.M.Z., et al [19]	IoT-based automated emergency response website	reduce the impact of fire disasters by providing accurate and timely information.	machine learning algorithm for preventing potential fire incidents	Lower throughput

3. PRIORINET TECHNIQUE FOR URBAN EARTHQUAKE SCENARIOS

We have considered a scenario in a densely populated urban area, a devastating earthquake strikes, causing widespread destruction and chaos. For reliable communication, the energy-efficient PrioriNet protocol in emergency disaster situations is implemented in this section. These nodes can be wireless devices, such as sensors or communication devices, strategically placed to provide coverage and enable communication within the disaster-affected region. The overall block diagram of the proposed PrioriNet protocol is given in Fig. 1.

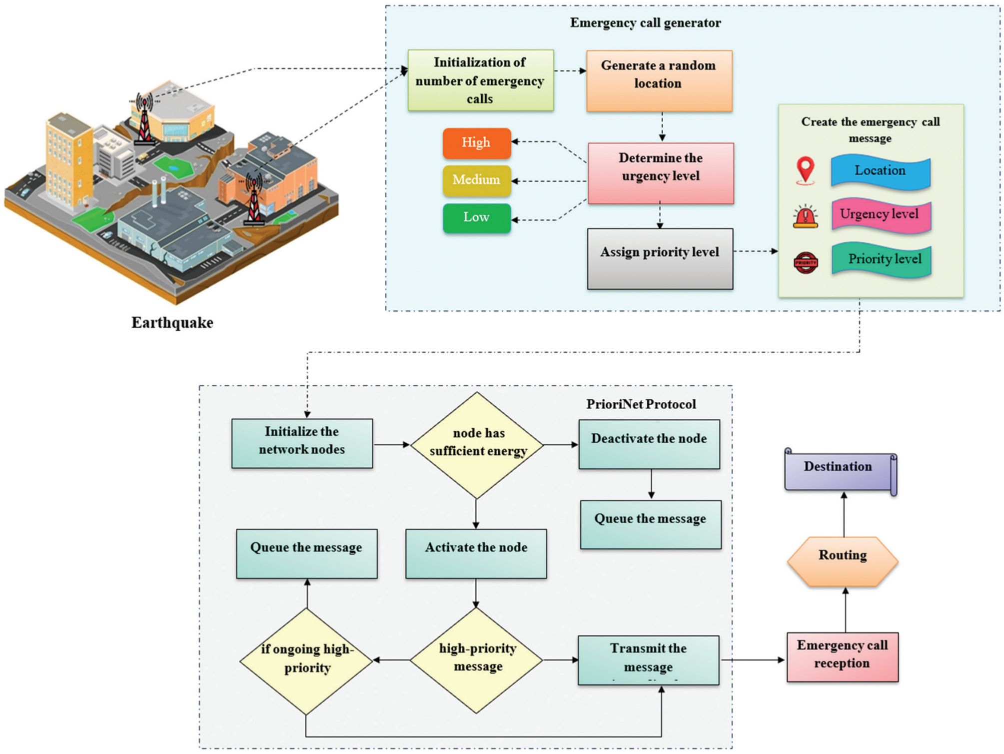

Fig. 1. Proposed PrioriNet technique

3.1. EMERGENCY CALL GENERATION

The process initiates with the generation of emergency calls, simulating distress signals from affected individuals or devices reflecting the urgent need for assistance, while the emergency call generator module simulates the generation of calls with varying urgency levels and assigns priorities based on predefined criteria vital signs of a person, the battery level, or the location. The algorithm 1 uses a loop to generate multiple emergency calls based on the specified number of calls (numCalls). Each call is assigned a random location, urgency level, and priority level. The generated emergency call messages are then queued for transmission based on higher priority calls that are given precedence.

Algorithm.1: On emergency call generation

1. Initialize the number of emergency calls to be generated (numCalls).
2. Set the loop counter (i) to 1.
3. Start the loop to generate emergency calls:
   a. Generate a random location within the affected area for the emergency call.
   b. Determine the urgency level for the emergency call (e.g., high, medium, low).
   c. Assign a priority level to the emergency call based on its urgency.
   d. Create the emergency call message with the location, urgency level, and priority level.
   e. Queue the emergency call message for transmission based on its priority.
   f. Increment the loop counter (i) by 1 and check if the loop counter (i) ≤ the number of emergency calls (numCalls).
   g. If true, repeat steps a-f.
4. End the loop.

3.2. ASSIGN PRIORITY LEVEL

The proposed protocol uses scheduling algorithm which considers both the priority of the data packet and the remaining level of energy of the sensor node, which can be formulated using the following equation:

$$S(i) = P(i) * E(i) \quad (1)$$

where $S(i)$ represents the scheduling score for data packet i, $P(i)$ and $E(i)$ denotes the priority assigned, remaining energy level to the packet i. In this equation, a higher $P(i)$ signifies the urgency and criticality of the data packet, while a higher $E(i)$ indicates the available energy resources of the transmitting node.

3.2.1. PrioriNet protocol

In PrioriNet, data packets providing critical details are all assigned to the higher priority queue, whereas packets containing regular sensed data are placed in the lower priority queue.

Algorithm.2: PrioriNet Protocol

1. Initialize the network nodes and their parameters.
2. Set simulation parameters, such as simulation time and message generation rate.
3. Start the simulation loop:
   a. Generate messages based on the specified rate.
   b. Determine the priority of each message based on its type and urgency.
   c. Check the network nodes for available energy:
      i. **if** a node has sufficient energy {
         // **Activate the node**
         Check the priority of the message:
            if it is a high-priority message {
               // **Handle high-priority message**

Transmit the message immediately.

Update energy consumption for the transmitted message.

            }
            else {
               // **Handle low-priority message**

Check if there is ongoing high-priority communication:

If yes, queue the message for later transmission.

If no, transmit the message immediately.

Update energy consumption for the transmitted message.

            }
         }
      ii. **if** a node has low energy or is unable to transmit {
         // **Deactivate the node to conserve energy**
         Queue the message for later transmission.
         }
   d. Update the energy levels of active nodes based on their transmission and reception activities.
   e. Repeat steps a-d until the simulation time is reached.
4. Calculate and display the performance metrics (e.g., energy consumption, message delivery ratio).

End

3.3. EMERGENCY CALL RECEPTION

During a disaster scenario, timely response to emergency calls is critical for effective disaster management and saving lives. Algorithm 3 optimizes resource allocation and energy consumption by activating nodes with sufficient energy and considering the urgency and priority levels of each call. By considering population density and building types, the protocol prioritizes areas with a higher concentration of people and critical infrastructure, ensuring a more targeted response. The features of PrioriNet are flexibility, adaptability, interagency collaboration and clear communication of prioritization. An effective emergency call protocol for earthquake scenarios integrates technology, prioritization criteria, and community engagement to ensure a rapid, targeted, and coordinated response.

Algorithm.3: On receiving an emergency call:

if (node's energy >= threshold_energy):

Activate the node for emergency call processing.

Determine the priority level of the emergency call.

if (priority level is high):

Allocate necessary resources for high-priority emergency call processing.

Transmit an acknowledgement message to the sender.

else if (priority level is medium or low):

Check ongoing high-priority emergency calls.

if (no ongoing high-priority calls):

Allocate resources for medium or low-priority emergency call processing.

Queue the emergency call for processing.

else:

Delay the processing of the emergency call until ongoing high-priority calls are completed.

else:

Deactivate the node due to insufficient energy.

End

4. PERFORMANCE AND EVALUATION

To assess the efficiency of the developed emergency priority protocol a comprehensive simulation has been conducted in contrast to the well-known existing protocol, LEACH. LEACH has been chosen for comparison in the context of emergency priority protocols due to its widespread use and recognition. By comparing new protocols against LEACH, researchers and practitioners can assess the efficacy of proposed in the context of energy efficiency, scalability, and adaptability, providing valuable insights into the advancements made in addressing the challenges posed by emergency scenarios in these highly dynamic and resource-constrained environments.

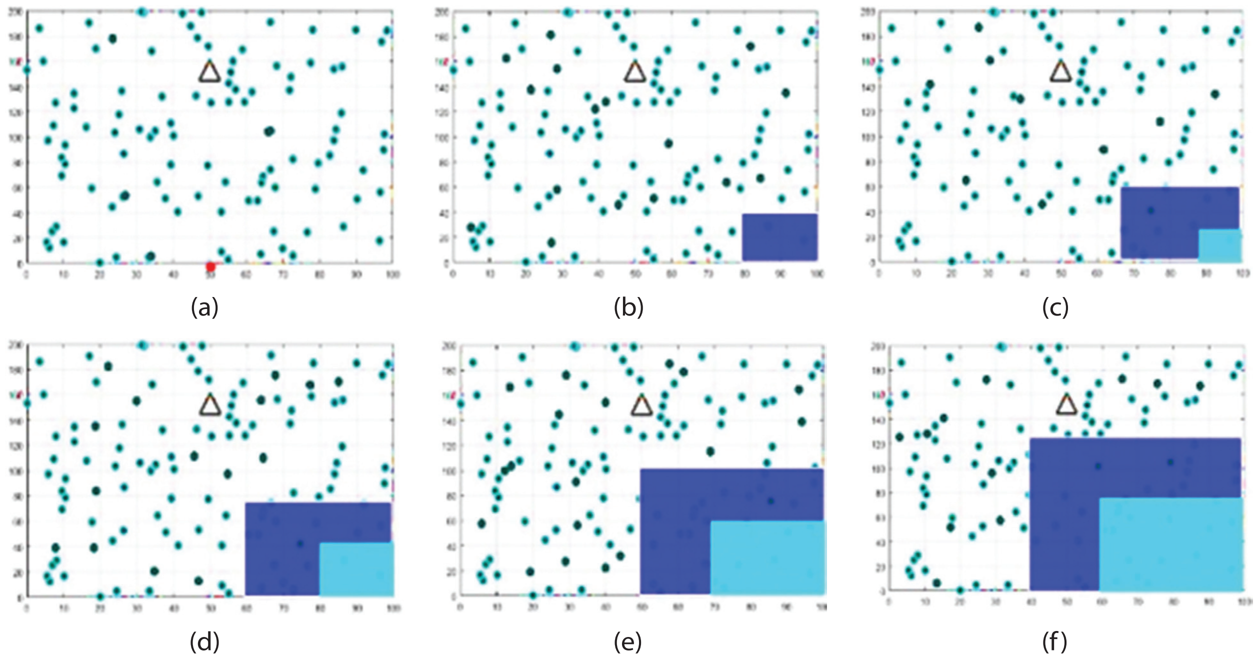

Fig. 2. Simulation scenarios: (**a**) with a certain number of nodes, representing the initial phase of the communication network. (**b**) As the disaster intensifies, resulting in potential damage and communication disruptions. (**c**) the escalation of the disaster's intensity and impact on communication. (**d**) the situation worsens, depicting the growing challenges in establishing effective communication. (**e**) the communication system faces critical failures and disruptions. (**f**) the disaster reaches its peak impact, resulting in a significant number of non-functional nodes and communication dead zones throughout the urban area.

4.1. SIMULATION SETUP

The simulation was conducted using MATLAB 2017a on a computer system with Windows 10 Enterprise-64bit as the operating system, an Intel Core i7 processor, and 8 GB of memory. Node movement is modeled using the Random Waypoint model, simulating realistic mobility patterns in situations of disaster. Table 2 presents the simulation parameters.

Table 2. Parameters for simulation

Parameter	Value
Size of Network	100
Size of Area	1000m * 1000m
Node Density	0.1 nodes/m^2
Mobility pattern	realistic mobility patterns
Communication Range	100m
Transmission Power	0.5 Watts
Initial Energy	1 Joule
Emergency Packet Size	1000 bytes
Normal Packet Size	500 bytes
Normal Transmission Rate	10 Kbps
Residual Energy Threshold	0.3 Joules
Simulation Time	3600 seconds
Traffic Pattern	Dynamic
Node Movement Model	Random Waypoint

To ensure the practicality and realism of our research, it is crucial that the simulation environment closely reflects the real-world situation.

Fig. 2 shows the simulation scenario that unfolds in different stages: (a) with a certain number of nodes, representing the initial phase of the communication network. (b) As the disaster intensifies, resulting in potential damage and communication disruptions. (c) the escalation of the disaster's intensity and impact on communication (d) the situation worsens, depicting the growing challenges in establishing effective communication; (e) the communication system faces critical failures and disruptions; (f) the disaster reaches its peak impact, resulting in a significant number of non-functional nodes and communication dead zones throughout the urban area.

4.2. PERFORMANCE METRICS

We concentrate on analyzing and contrasting a number of performance metrics in this phase of our research to determine the PrioriNet performs in disaster scenarios. The criteria for comparison and analysis include the following variables:

Energy Consumption

The amount of energy utilized by all of the network's sensor nodes during the simulation is measured as energy consumption which is given in equation 2.

$$EC=N\times (ET_{active} * P_{active} + ET_{sleep} * P\_sleep) \quad (2)$$

Where, N is the network's total number of nodes, ET_{active}, P_{active} is the energy consumed per unit time, percentage of time nodes spend in active mode, ET_{sleep}, P_{sleep} is the energy consumed and the percentage of time nodes spend in sleep mode.

Network Lifetime: A crucial metric to evaluate the sustainability and longevity of the network during the disaster scenario is Network lifetime.

Packet Delivery Ratio (PDR): The measure of proportion of packets that are successfully delivered to all of the packets that a source node has sent is known as PDR.

Network Throughput: Throughput refers to the amount of data successfully transmitted within a given time frame.

Network Coverage: Network coverage measures the extent of the network's geographical area that is effectively covered by sensor nodes.

4.3. COMPARISON ANALYSIS

A comparative evaluation is performed between the proposed model and the existing LEACH method to assess the performance of the proposed method.

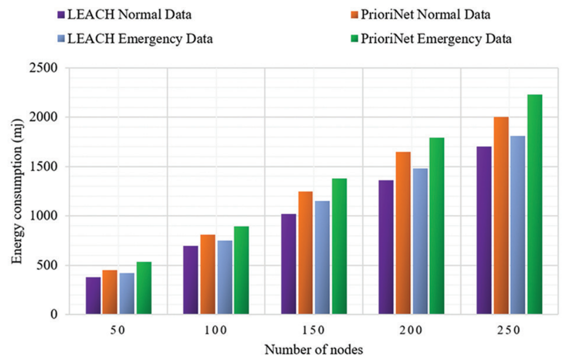

Fig. 3. Energy consumption vs Number of Nodes

Fig. 3 represents the energy consumption of the proposed PrioriNet protocol in comparison with the existing LEACH technique. In normal data scenarios, with increase in number of nodes, the LEACH protocol displays energy consumption ranging from 520 units to 2230 units, while the proposed method demonstrates lower energy consumption, ranging from 420 units to 1810 units. Similarly, for emergency data, the LEACH protocol's energy consumption varies between 450 units and 2000 units, whereas the proposed method consistently achieves reduced energy consumption, ranging from 380 units to 1700 units, even with increasing numbers of nodes.

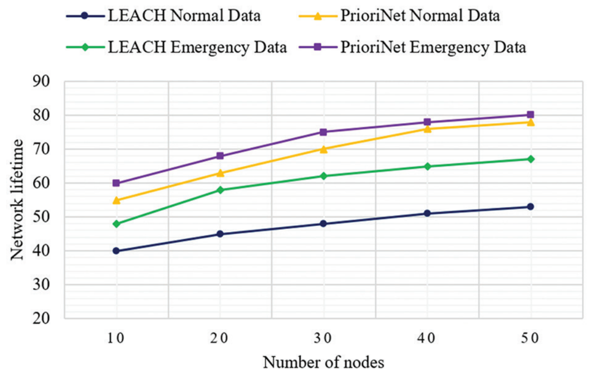

Fig. 4. Network Lifetime vs Energy Threshold

Fig. 4 represents the network lifetime of the proposed PrioriNet protocol in comparison with the existing LEACH technique. From fig. 4, it is observed that the proposed method consistently achieves longer network lifetimes compared to the LEACH protocol for both normal and emergency data scenarios. The proposed method outperforms the LEACH protocol in terms of network lifetimes, with durations ranging from 55 to 78 hours compared to LEACH's range of 40 to 53 hours. In emergency data scenarios, the PrioriNet consistently surpasses the efficiency of the LEACH protocol, exhibiting network lifetimes ranging from 60 to 80 hours.

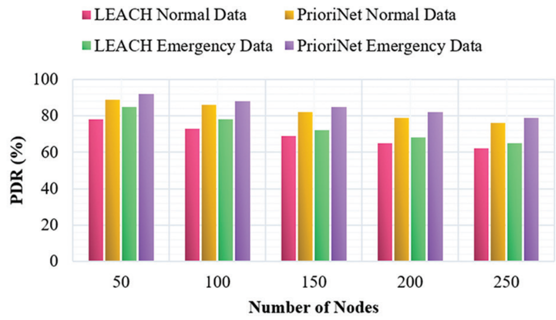

Fig. 5. PDR vs Number of Nodes

Fig. 5 represents the PDR of the proposed PrioriNet protocol in comparison with the existing LEACH technique. According to fig. 5, the proposed method consistently outperforms the LEACH protocol, achieving higher packet delivery ratios in both normal and emergency data scenarios. By assigning priorities to emergency messages and optimizing resource utilization, the proposed method ensures that critical information is given precedence, resulting in improved message delivery and overall system performance. Fig. 6 represents the Network throughput of the proposed PrioriNet protocol in comparison with the existing LEACH technique. In normal data scenarios, the LEACH protocol achieves throughputs ranging from 0.2 Mbps to 0.9 Mbps with increase in nodes, while the proposed method consistently attains higher throughputs, ranging from 0.5 Mbps to 1.6 Mbps, with an increasing number of nodes. Similarly, in emergency data scenarios, the LEACH protocol demonstrates throughputs between 0.3 Mbps and 1.2 Mbps, whereas the proposed method consistently outperforms the LEACH protocol with throughputs ranging from 0.7 Mbps to 1.8 Mbps.

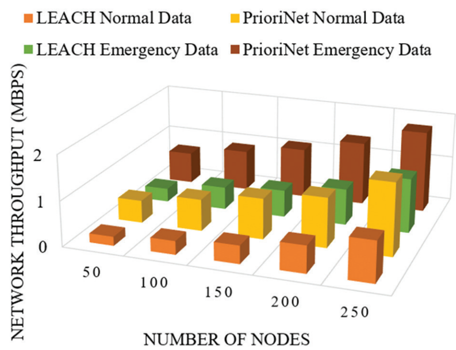

Fig. 6. Network throughput vs number of nodes

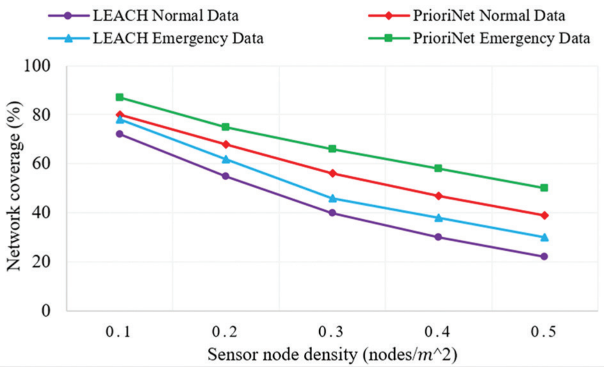

Fig. 7. Network Coverage vs Node Density

Fig. 7 represents the Network Coverage of the proposed PrioriNet protocol in comparison with the existing LEACH technique in terms of spatial area. From fig. 7, it is evident that the proposed method consistently achieves higher network coverage compared to the LEACH protocol for both normal and emergency data scenarios. The proposed method achieves a higher network coverage of 30.8% than existing LEACH technique.

5. CONCLUSION

In this paper, a novel PrioriNet protocol was developed to enhance communication efficiency, and improve emergency response coordination. The experimental results indicates that the suggested protocol performs better than the existing LEACH technique in terms of energy consumption, network coverage, packet delivery ratio, and throughput. In emergency data scenarios, the LEACH protocol demonstrates throughputs between 0.3 Mbps and 1.2 Mbps, whereas the proposed method consistently outperforms the LEACH protocol with throughputs ranging from 0.7 Mbps to 1.8 Mbps. The proposed method achieves a higher network coverage of 30.8% than existing LEACH technique. The future development of the proposed work will focus on enhancing the security of sustainable devices to ensure uninterrupted services.

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