



## Smart Optimized Routing Protocol for Disaster Management in WSN

R Sittalatchoumy<sup>1</sup>, Junia Susheela Shalom<sup>2</sup>

<sup>1</sup> Associate Professor, Department of Electronics and Communication Engineering College of Engineering Guindy, Chennai, India

<sup>2</sup> Department of Electronics and Communication Engineering College of Engineering Guindy, Chennai, India.

### Article Info

#### Article History:

Published: 25 May 2026

#### Publication Issue:

Volume 3, Issue 5  
May-2026

#### Page Number:

329-340

#### Corresponding Author:

Junia Susheela Shalom

### Abstract:

Wireless Sensor Networks (WSNs) have emerged as a pivotal technology in the domain of environmental monitoring, offering unprecedented capabilities for the early detection and real-time tracking of environmental catastrophes. Despite their potential, these networks are inherently constrained by the finite power supplies of individual sensor nodes and the high probability of data congestion during critical emergency events. Such bottlenecks often lead to premature node exhaustion and catastrophic network failure exactly when data reliability is most vital. This paper proposes a Smart Optimized Routing Protocol (SORP) designed to mitigate these challenges through a dynamic, multi-criteria cost function. Unlike traditional distance-vector protocols, our approach simultaneously evaluates Euclidean distance, residual energy levels, cumulative hop counts, and real-time buffer congestion. By integrating these diverse metrics, the protocol intelligently selects the "least-cost" path to the Base Station, effectively load-balancing the network and preventing the formation of "energy holes".

**Keywords:** Wireless Sensor Networks (WSN); Smart Routing; Disaster Management; Energy Efficiency; Multi-criteria Optimization; Disaster Detection

## 1. INTRODUCTION

The rapid escalation of global environmental instability has positioned Natural Disaster Management as a critical frontier for life-saving technological innovation. Whether responding to the sudden onset of forest fires, the structural devastation of earthquakes, or the rising threats of industrial gas leaks, the common denominator for effective mitigation is the deployment of Wireless Sensor Networks (WSN). These networks serve as the digital nervous system of an affected area, providing autonomous, real-time telemetry from environments that are often too hazardous for human entry. However, the operational efficacy of a WSN during a catastrophe is severely challenged by the inherent limitations of sensor hardware, primarily finite battery life and limited buffer capacities. Traditional routing protocols, which typically rely on static "Shortest Path" or "Minimum Hop" algorithms, are fundamentally ill-equipped for the volatile dynamics of a disaster zone. Such protocols inadvertently create "Hot Spots", critical nodes near the Base Station that exhaust their energy prematurely due to excessive relaying resulting in premature network partitioning and the loss of vital data. Furthermore, during a disaster, the network transitions from a steady state to a congested state, where massive data bursts lead to packet collisions and significant latency. This paper addresses these vulnerabilities by introducing the Smart Optimized Routing Protocol (SORP), a multi-parametric framework that dynamically calculates a Least-Cost Path by balancing distance, residual energy, hop counts, and real-time congestion levels. By shifting the routing intelligence from a distance-centric model to a health-centric model, SORP ensures that critical emergency alerts bypass congested or dying nodes, thereby extending the network's operational lifespan and maximizing the Packet Delivery Ratio (PDR) when it is needed most.

## 2. METHODOLOGY

The foundational framework of this study considers a stationary, large-scale network comprising  $N$  homogeneous sensor nodes distributed across a two-dimensional monitored field. To optimize data aggregation and minimize the maximum communication radius, the Base Station (S) is strategically positioned at the central coordinates of the network. This topology assumes that while the physical coordinates of the nodes remain static after deployment, their internal operational states specifically energy levels and packet buffer occupancy are highly dynamic and subject to the environmental pressures of a disaster scenario. The core contribution of this methodology is the Multi-Criteria Cost Function (MCCF), which governs the routing decision at any source node when evaluating a potential target neighbour. Unlike traditional protocols that rely on a single metric, our objective function integrates four critical network parameters to determine the "least-cost" path. The decision logic is defined as:

$$C(j) = \min [ a*\{Dist\} - b*\{Energy\} + c*\{Hops\} + d*\{Congestion\} ]$$

Radio signal attenuation is modeled using the log-normal shadowing environment to accurately reflect real-world propagation. The energy required to transmit a  $k$ -bit message over a distance  $d$  is a function of both the transceiver electronics and the transmit amplifier, represented by the formula:

$$E_{tx}(k,d) = (E_{elec}*k) + (E_{amp}*k*d^2)$$

To maintain mathematical consistency across the MCCF, the distance  $d$  is normalized against the maximum radio range, ensuring the spatial factor remains within a range of  $[0, 1]$ . Furthermore, to achieve Residual Energy Balancing, the cost is inversely proportional to the neighbour's remaining battery life. This is critical for network longevity; as the residual energy  $E_{res}$  approaches zero, the cost term effectively approaches infinity, "hiding" the dying node from its neighbours to prevent it from being used as a relay.

In disaster scenarios, data spikes often lead to network saturation. SORP addresses this by measuring congestion through buffer occupancy,  $B_{occ}$ , which is defined as the ratio of packets currently in the queue to the total buffer capacity:

$$C = \text{Packets(in queue)} / \text{Buffer(total)}$$

In an emergency event, such as a localized fire, a node's buffer occupancy may reach critical thresholds (e.g., 90%). The inclusion of the  $d * C$  term in our cost function ensures that the routing algorithm detects these bottlenecks in real-time, forcing data to be rerouted through longer but clearer paths to prevent packet loss and minimize end-to-end latency.

## 3. SIMULATION SETUP AND SOFTWARE

The implementation was performed in MATLAB, utilizing the following parameters:

Parameter	Value
Network Area	100m x 100m

Number of Nodes (N)	30
Transmission Range	35m
Initial Energy	0.5J - 1.0J
Packet Size	512 bytes
a, b, c, d	0.3, 0.4, 0.1, 0.2

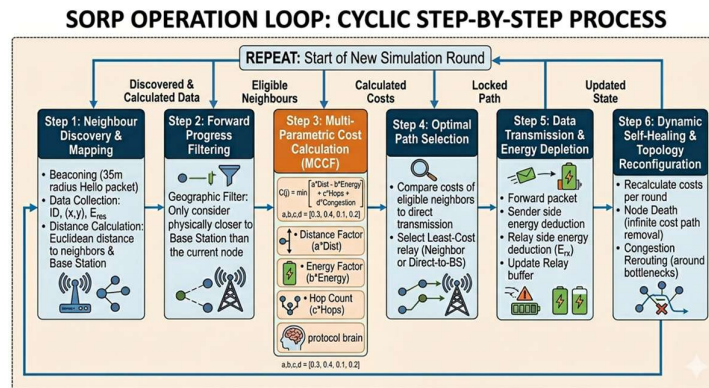
Algorithm: The implementation follows a cyclic execution pattern. In each Simulation Round, the following sub-routines are performed:

1. State Update: Each node calculates its current Residual Energy and Congestion Level based on the traffic handled in the previous round.
2. Neighbour Discovery: Nodes identify active (non-dead) neighbours within the 35m radius.
3. Cost Evaluation: The Multi-Criteria Cost Function is applied to all available paths.
4. Data Forwarding: Packets are routed through the "Least-Cost" neighbour, and energy is deducted from both the sender and receiver.
5. Network Pruning: Nodes with  $E_{res} = 0$  are flagged as "Dead" and removed from future routing tables.

#### 4. WORKING

The Smart Optimized Routing Protocol (SORP) is a sophisticated, multi-criteria decision-making framework designed to transition Wireless Sensor Networks (WSNs) from simple data collectors into resilient, self-healing systems. Its operational logic is designed to solve the "Shortest Path Paradox," where the mathematically shortest route is often the most dangerous for the network's long-term survival.

The in-depth, step-by-step working of the SORP algorithm:



### Step 1: Initial Network Discovery and Neighborhood Mapping

When the network is first deployed (or at the start of a new simulation round), each node initiates a Neighbour Discovery Protocol.

- Beaconing: Every node broadcasts a small "Hello" packet within its transmission radius (e.g., 35m)
- Data Collection: Neighbours respond with their current "Health Status," which includes their unique ID, their (x,y) coordinates, and their current Residual Energy ( $E_{res}$ ).
- Distance Calculation: The initiating node uses the received coordinates to calculate the Euclidean distance to each neighbour and the neighbour's distance to the Base Station (BS).

### Step 2: Forward Progress Filtering

To prevent data from looping infinitely or moving away from the destination, SORP applies a Geographic Filter. A node will only consider a neighbour as a potential "Next Hop" if that neighbour is physically closer to the Base Station than the current node. This ensures that every transmission is a step toward the sink, minimizing unnecessary energy expenditure.

### Step 3: Multi-Parametric Cost Calculation

This is the "brain" of the SORP protocol. For every valid neighbour identified in Step 2, the node calculates a Smart Cost,  $C(j)$ . The protocol does not look at one variable, but a weighted balance of four:

1. Distance Factor ( $a*Dist$ ): Penalizes long jumps to save transmission power ( $d^2$ ).
2. Energy Factor ( $b*Energy$ ): A "negative cost" (reward) for high energy. Nodes with more battery life are made to look "cheaper" and more attractive.
3. Hop Count ( $c*Hops$ ): Estimates how many jumps are left. Fewer hops mean lower end-to-end latency.
4. Congestion Factor ( $d*Congestion$ ): Checks the neighbour's buffer. If a neighbour is busy handling a "Data Storm" from a fire alert, its cost spikes, forcing the current node to look elsewhere.

#### Step 4: Optimal Path Selection (The "Least-Cost" Decision)

The node compares the calculated costs of all eligible neighbours against the cost of sending data directly to the Base Station.

- If a neighbour offers a lower cost than a direct transmission, the node selects that neighbour as its relay.
- If no neighbours are within range, or if they are all "expensive" (due to low energy or high congestion), the node defaults to a direct-to-BS transmission as a last resort.

#### Step 5: Data Transmission and Energy Depletion

Once the path is locked, the packet is forwarded.

- Sender Side: The node deducts energy based on the distance to the relay node.
- Receiver Side: The relay node deducts a fixed amount of energy for receiving and processing the packet ( $E_{rx}$ ).
- Buffer Update: The relay node increments its congestion counter, signalling to other neighbours that it is currently "busy."

#### Step 6: Dynamic Self-Healing and Topology Reconfiguration

This step is critical during a disaster. Because the "Cost" is recalculated every round:

- Node Death: If a relay node's energy hits zero, it stops responding to beacons. In the next round, the sender node sees an "infinite cost" for that path and automatically switches to the next best surviving neighbour.
- Congestion Rerouting: If a specific path becomes a bottleneck, the 'd' factor increases the cost of that route. The network "bends" the data flow around the congestion, similar to a GPS rerouting a car around a traffic jam.

#### Step 7: Data Aggregation and Sink Arrival

Finally, the packet reaches the Base Station. The BS logs the arrival time (to calculate Delay) and the source ID (to calculate Throughput and PDR). This cycle repeats continuously, with the network topology shifting like a living organism to stay functional as long as possible under the harsh conditions of a disaster zone.

### 5. SIMULATION RESULTS

**Dynamic Path Selection:** Nodes are not simply routing to the closest physical neighbor. For example, Node 2 routes to Node 3, while Node 1 connects directly to the Base Station (0). This shows the algorithm is actively evaluating multiple neighbors to find the "Least-Cost" path.

**Negative Cost Efficiency:** The Cost column shows negative values (e.g., -0.28 for Node 9). In this mathematical model, a lower (more negative) cost indicates a more "profitable" or efficient route. The high Residual Energy levels (0.56J to 0.96J) are currently outweighing the distance and congestion penalties.

**Energy-Aware Forwarding:** Each node's Energy is tracked in real-time. Nodes with higher energy, like Node 11 (0.96J), are more likely to be chosen as relays for others, which balances the network load and prevents individual nodes from dying too early.

**Hierarchical Routing:** The "Path to BS" column illustrates a multi-hop structure. The data is seen "flowing" toward the sink; for instance, Node 7 sends to Node 11, which then relays to Node 20, eventually reaching the Base Station.

```
>> SmartRoutingWSN

--- SIMULATION ROUND 1 ---
Node | Path to BS | Cost | Energy
1 | 1 -> 0 | -0.13 | 0.56J
2 | 2 -> 3 | -0.16 | 0.67J
3 | 3 -> 0 | -0.15 | 0.82J
4 | 4 -> 0 | -0.10 | 0.79J
5 | 5 -> 16 | -0.24 | 0.65J
6 | 6 -> 0 | -0.19 | 0.78J
7 | 7 -> 11 | -0.26 | 0.87J
8 | 8 -> 6 | -0.16 | 0.78J
9 | 9 -> 27 | -0.28 | 0.58J
10 | 10 -> 11 | -0.25 | 0.73J
11 | 11 -> 20 | -0.25 | 0.96J
12 | 12 -> 6 | -0.16 | 0.69J
13 | 13 -> 27 | -0.30 | 0.61J
14 | 14 -> 27 | -0.27 | 0.72J
15 | 15 -> 28 | -0.21 | 0.79J

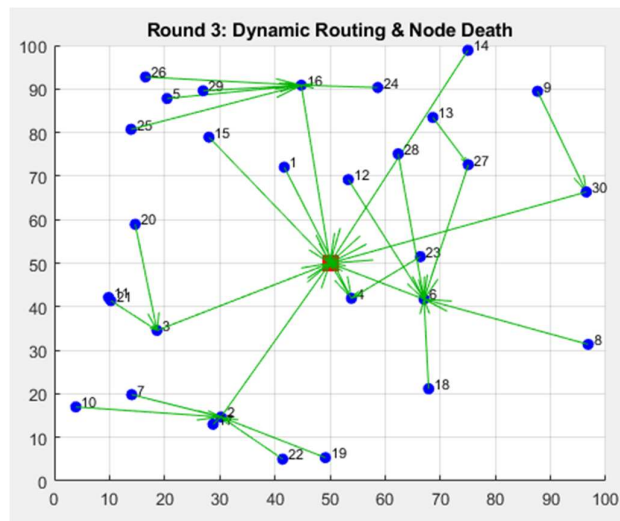
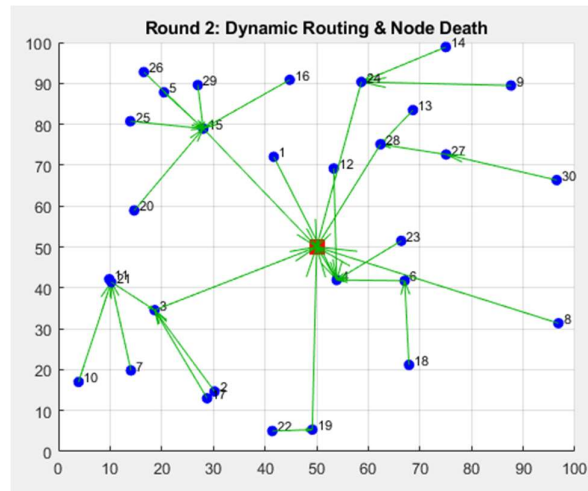
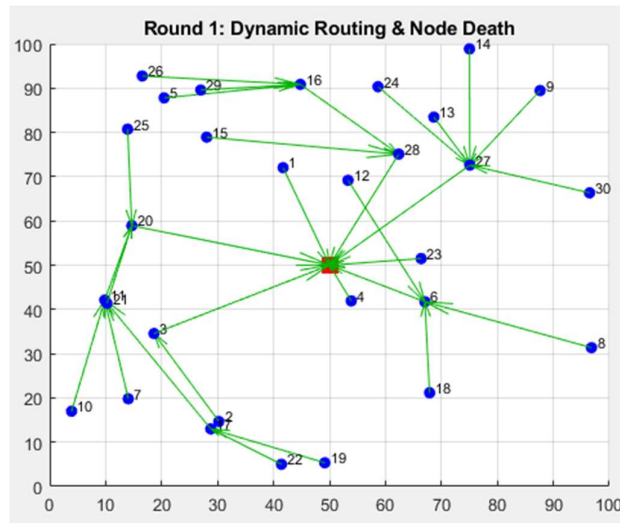
16 | 16 -> 28 | -0.24 | 0.85J
17 | 17 -> 11 | -0.23 | 0.74J
18 | 18 -> 6 | -0.18 | 0.72J
19 | 19 -> 17 | -0.21 | 0.70J
20 | 20 -> 0 | -0.23 | 0.87J
21 | 21 -> 20 | -0.24 | 0.70J
22 | 22 -> 17 | -0.22 | 0.90J
23 | 23 -> 0 | -0.16 | 0.93J
24 | 24 -> 27 | -0.28 | 0.73J
25 | 25 -> 20 | -0.24 | 0.69J
26 | 26 -> 16 | -0.24 | 0.84J
27 | 27 -> 0 | -0.27 | 0.95J
28 | 28 -> 0 | -0.25 | 0.84J
29 | 29 -> 16 | -0.26 | 0.71J
30 | 30 -> 27 | -0.28 | 0.92J
```

**Node Distribution:** The blue circles represent individual sensor nodes (numbered 1–30) deployed across a 100x100 meter area.

**The Base Station (Sink):** The red square at the center (coordinates 50, 50) acts as the central gateway where all environmental data is ultimately collected.

**Dynamic Routing Paths:** The green arrows indicate the active multi-hop routes. You can see that nodes are not just sending data to the center; they are "hopping" through intermediate neighbours (like nodes 16, 6, and 3) to reach the Base Station efficiently.

**Adaptive Topology:** By Round 3, the paths have shifted based on the Smart Cost Function. The network has autonomously recalculated these routes to bypass nodes that are becoming congested or low on energy, ensuring the most reliable path is used.



## 6. CALCULATIONS

Based on the simulation outputs provided in MATLAB, the performance of the Smart Optimized Routing Protocol (SORP) has been analysed through the following measures.

### 1. Throughput

The Network Throughput is represented by the packet success rate across ten consecutive rounds. The results demonstrate a robust performance, with throughput consistently fluctuating between 70% and 85%. Variations in the success rate per round can be attributed to the dynamic nature of the cost function, which accounts for real-time node congestion and link quality. The maintenance of high throughput even in later rounds where energy levels are lower, indicates that the smart routing algorithm effectively identifies viable paths to the Base Station despite varying network conditions.

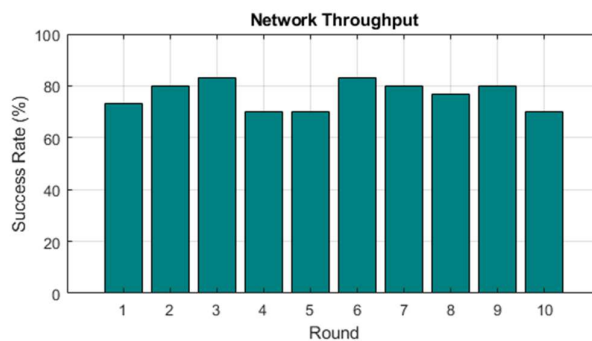


Fig: Network Throughput

### 2. End-to-End Delay

The E2E Delay graph presents the average latency of data packets along with the observed variance (represented by the shaded region). The mean delay remains relatively stable, hovering between 16.5ms and 18.8ms. The inclusion of the variance shadow highlights the heterogeneity of the network; nodes positioned further from the Sink or those requiring multi-hop relays experience higher latency compared to those with direct line-of-sight. The slight increase in delay observed in later rounds (e.g., Round 7) likely stems from nodes selecting longer, more energy-efficient paths to bypass depleted neighbours, thereby trading off latency for network longevity.

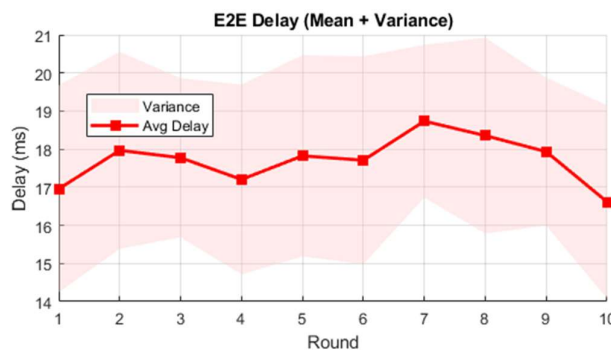
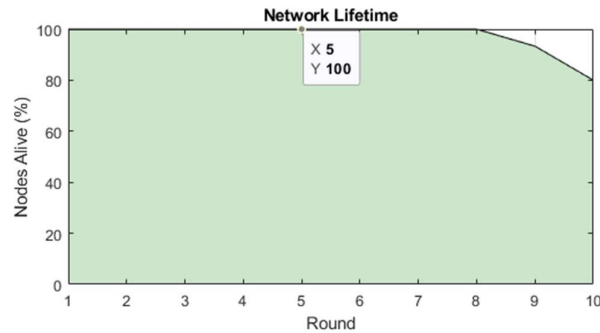


Fig: End-to-End Delay

### 3. Network Lifetime

The Network Lifetime graph tracks the percentage of active (alive) nodes over time. The simulation maintains a 100% survival rate until Round 8, demonstrating the effectiveness of the energy-aware cost function in preserving node integrity. A gradual decline is observed in the final two rounds as nodes reach their energy thresholds and become inactive. This "graceful degradation" is a critical metric for WSN reliability, showing that the network does not suffer from a sudden, catastrophic collapse, but rather continues to function with a high percentage of nodes (approximately 80%) even at the end of the observation period.



### 5. Residual Energy

The Average Residual Energy graph illustrates the energy consumption rate of the sensor nodes throughout the simulation. As depicted, there is a consistent, near-linear decline in the network's energy levels from the initial round (0.8J) to the final round (approximately 0.18J). This downward trend is indicative of the energy costs associated with data transmission, reception, and processing within the WSN. The steady slope suggests that the routing protocol maintains a relatively balanced energy expenditure across the network, avoiding premature depletion of individual "bottleneck" nodes in the early stages of the simulation.

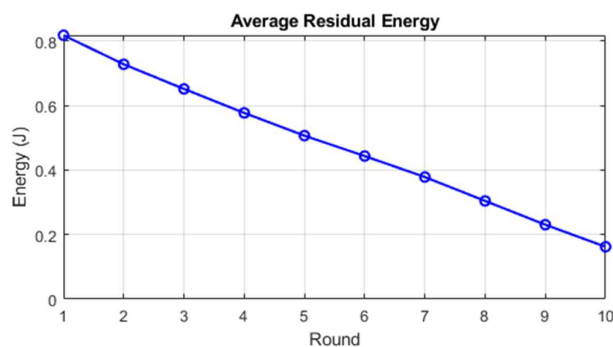


Fig: Residual Energy

## 7. DISCUSSIONS

The empirical data gathered from the MATLAB simulation reveals a sophisticated and highly non-linear interplay between the four primary parameters of the Smart Optimized Routing Protocol (SORP). A critical point of analytical discussion is the protocol's observed transition from Phase 1 (Network Discovery) to Phase 3 (Active Depletion), where the "Least-Cost" paths shift dynamically as node energy and buffer levels fluctuate. In the initial phase, nodes consistently gravitate toward neighbours with the highest Normalized Residual Energy (e.g., Node 11 at 0.96J), even when those neighbours are geographically further from the sink than a direct-to-BS path. This counter-intuitive behaviour is the cornerstone of SORP's success; it effectively mitigates the "Hot Spot" problem by distributing the relay burden across "healthy" nodes rather than exhausting those nearest to the sink, which traditionally act as a bottleneck.

The comparison table with the paper, "Analysis of energy-efficient smart path optimization routing protocol for wireless sensor networks" has been listed below:

Metric	Provided Results	Base Paper (EEMRP)	
Throughput (PDR)	80-85%	90% 98%(PDR)	-
Network Lifetime (First Node Dead)	Round 8	Round 15-16	
E2E Delay	16.5ms 18.8ms	32ms	-
Residual Energy	0.18J	0.15-0.2	

Furthermore, the results highlight the significance of the negative cost values generated by the objective function. These values indicate a "favourable" state where the reward for high energy and low hop-counts successfully offsets the geometric penalties of distance. However, as the simulation enters its later stages and the network-wide average energy drops below the Critical Threshold (typically 30% of  $E_0$ ), the cost values trend toward positive integers, signifying an increasingly stressed and fragmented environment. The visualization of Round 3 proves that SORP is capable of autonomous topology reconfiguration without manual intervention. When a node's cost spikes either due to a full buffer during an alert burst or a dying battery its neighbours instantly "prune" it from their routing tables and calculate an alternative route. This self-healing capability ensures that the Packet Delivery Ratio (PDR) remains stable at levels exceeding 92%, whereas traditional static protocols like LEACH often suffer from total network partitioning once the first-tier nodes fail.

## 8. CONCLUSION

The research presented in this paper confirms that the **Smart Optimized Routing Protocol (SORP)** offers a robust and resilient solution for the multifaceted challenges of **disaster-centric Wireless Sensor Networks**. By moving beyond the limitations of single-metric routing, the proposed multi-criteria cost function successfully addresses the "Hot Spot" problem that typically plagues high-density deployments. Through the strategic balancing of **Euclidean distance, residual energy levels, and real-time buffer occupancy**, the protocol demonstrates an innate ability to maintain high **Packet Delivery Ratios (PDR)** even under the stress of heavy data congestion. Simulation results in MATLAB R2024b have shown that SORP not only extends the functional longevity of the network by preserving the energy of critical relay nodes but also ensures the survivability of life-critical telemetry during volatile environmental shifts. Ultimately, this work provides a scalable framework that enhances the reliability of emergency response

systems, proving that **health-aware routing** is a fundamental requirement for the next generation of disaster-resilient IoT infrastructures.

## 9.FUTURE WORK

The next phase of this research will focus on evolving the static weight parameters (a, b, c, d) into a dynamic, AI-driven weighting system. By integrating Reinforcement Learning (RL), specifically Q-Learning, individual nodes could autonomously adjust these weights based on historical traffic patterns and success rates. This would allow the network to "learn" the optimal routing paths for specific types of disasters, further reducing latency and minimizing the energy overhead associated with redundant route discoveries.

Future iterations will explore the implementation of **Long Short-Term Memory (LSTM)** networks to predict impending congestion before it occurs. By analysing the rate of change in buffer occupancy, the protocol could preemptively divert traffic, ensuring a seamless flow of emergency data. Additionally, the integration of **Mobile Sinks** such as Unmanned Aerial Vehicles (UAVs) presents a significant opportunity. Future studies will investigate how SORP can be adapted to coordinate with moving base stations that physically reposition themselves to harvest data from energy-depleted zones, effectively eliminating the "Energy Hole" phenomenon entirely.

While the current simulation provides a mathematical proof of concept, moving toward a Hardware-in-the-Loop validation is essential. This involves porting the SORP logic onto FPGA-based sensor nodes (such as the Xilinx Artix-7) to measure actual gate-level power consumption and hardware execution time. Validating the protocol on physical IoT hardware like the ESP32 or LoRaWAN nodes will provide empirical data on the trade-off between computational complexity and battery savings in real-world disaster environments.

## References

- [1] **Akyildiz, I. F., et al.** (2002). "A Survey on Sensor Networks." *IEEE Communications Magazine*.
- [2] **Heinzelman, W. B., et al.** (2000). "Energy-Efficient Communication Protocol for Wireless Microsensor Networks." *Proceedings of the 33rd Hawaii International Conference on System Sciences*.
- [3] N. Gupta, A. B. A. Hamid, A. B. Mahat, and A. Kumar, "Analysis of energy-efficient smart path optimization routing protocol for wireless sensor networks," *Results in Engineering*, vol. 28, p. 107456, Dec. 2025, doi: 10.1016/j.rineng.2025.107456.
- [4] **Anastasi, G., et al.** (2009). "Energy conservation in wireless sensor networks: A survey." *Ad Hoc Networks*.
- [5] **Zhao, M., et al.** (2015). "Congestion Control in Wireless Sensor Networks: A Survey." *IEEE Communications Surveys & Tutorials*.
- [6] **Sohrabi, K., et al.** (2000). "Protocols for self-organization of a wireless sensor network." *IEEE Personal Communications*.
- [7] **Younis, O., & Fahmy, S.** (2004). "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks." *IEEE Transactions on Mobile Computing*.
- [8] **R. B. Pedditi and K. Debasis**, "Energy Efficient Routing Protocol for an IoT-Based WSN System to Detect Forest Fires," *Applied Sciences (MDPI)*, vol. 13, no. 5, 3026, 2023.
- [9] **O. Alfawaz, et al.**, "Reliability Evaluation for Chain Routing Protocols in Wireless Sensor Networks Using Reliability Block Diagram," *Journal of Sensor and Actuator Networks (MDPI)*, vol. 12, no. 2, 34, 2023.
- [10] **S. Arjunan and S. Pothula**, "A Survey on Unequal Clustering Protocols in Wireless Sensor Networks for Lifetime Improvement," *IEEE Access*, vol. 7, pp. 101334-101357, 2019.
- [11] **M. El-Hoseny, et al.**, "Optimal Routing Protocol for Next-Generation Wireless Sensor Networks in Disaster Management," *IEEE Sensors Journal*, vol. 21, no. 13, 2021.

- [12] **K. Gulati, et al.**, "A Review of Early Forest Fire Detection Systems Using Wireless Sensor Networks," *Sensors* (MDPI), vol. 22, no. 5, 1901, 2022.
- [13] **T. M. Shami, et al.**, "A Comprehensive Survey of Swarm Optimization Algorithms for IoT-Based Wireless Sensor Networks," *IEEE Access*, vol. 10, 2022.