An Energy-Aware Geographic Routing Protocol for Enhanced Network Efficiency

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Abstract-Although wireless sensor networks (WSNs) are crucial parts of modern communication systems, their energy consumption and network longevity are severely constrained. Enhancements to the geographic and energy-efficient routing protocol (GF-EERP) are suggested in this study. This we do by use of precise node location info, which in turn improves routing decisions. The protocol will also incorporate reinforcement learning algorithms. To make adaptive routing techniques possible, which improve network efficiency and accomplish balanced traffic distribution. On a number of performance metrics, including latency, packet delivery ratio, network lifetime, and energy consumption, the suggested approach will be carefully contrasted and examined with alternative routing methods. The simulation results will demonstrate that, in a variety of network circumstances, the enhanced GF-EERP will offer superior scalability and reliability compared to the current protocols. In order to enhance energy-efficient communications in WSNs and, consequently, guarantee dependable and sustainable network deployment, this study will highlight the significance of combining geographic routing with machine learning techniques.

Key words: Energy Efficiency, GF-EERP, Geographic Routing Protocol, Network Lifetime, Node Localization, Reinforcement Learning, Wireless Sensor Networks, Energy-Aware Routing**.**

1. INTRODUCTION

WSNs are used for real-time data collection in many fields. What we see is that energy is the great issue [1]. Geographic and Energy-Aware Routing Protocols, such as GF-EERP, have been developed to use remaining energy and node location to achieve optimum energy efficiency [2]. Unfortunately, load imbalance and wasteful route discovery plague current methods. Traffic balance and responsiveness to shifting network conditions can be effectively addressed by using Reinforcement Learning (RL) [3]. By way of less redundant transmissions and better energy conservation, we see that. Reinforcement Learning based routing develops smart paths [4]. An enhanced GF-EERP protocol is presented in this study, which uses RL mechanisms and node location to guarantee effective routing. In order to address some of the shortcomings of current models, the suggested protocol seeks to increase the network lifetime and overall performance [5]. Based on metrics such as energy consumption, packet delivery ratio, and network lifetime, the performance will be evaluated in comparison with existing protocols.

2. OBJECTIVE AND RELATED WORK

Recent research focusing on enhancing routing protocol effectiveness in wireless sensor networks through the utilization of node location to save energy and extend network lifetime is comparable. In addition, they include research employing reinforcement learning algorithms to balance network traffic, make more effective routing decisions, and react to changing situations. Also, recent research involves testing and comparing various protocols on the basis of key performance factors such as energy consumption, latency, throughput, and packet delivery ratio to establish a benchmark for measuring innovative approaches.

3. LITERATURE REVIEW

To improve overall performance and network lifetime, which in turn mitigates some of the drawbacks of present solutions [5]. The performance will be compared to current protocols using criteria such as energy usage, packet delivery ratio, and network lifetime. (Bairagi et al., 2024). For large-scale WSNs, Karthigeya S.'s paper suggests a hybrid wireless sensor network communication protocol that will increase the network's lifespan and energy efficiency. Optimal control packet sizes and improved cluster head (CH) selection metrics can further optimize the protocol, which compromises practicality and performance. (Karthigeyan et al., 2025).

Wireless Sensor Networks (WSNs), as reported by Al-Healy, are a revolutionary technology for the perception and interaction of the physical world. In terms of performance, AODV is dynamic, GPSR is very scalable, and PEGASIS and LEACH are energy efficient. (Al-Healy and Ibrahim, 2025). Yajadda, which presents a routing that dynamically deals with network congestion via the use of shortest path algorithms along with reinforcement and Q-learning. It is fit for what is to come in network administration and also puts forth itself in many network settings. (Yajadda and Safaei, 2023).

Arunkumar et al. (2022) outline an energy-efficient and secure routing algorithm in their patent for Mobile Ad-hoc Networks (MANETs) by integrating Artificial Intelligence (AI) with Internet of Things (IoT) technologies. It focuses on optimizing data paths to minimize power consumption while ensuring the network remains protected against potential security threats.

Abujassar is that due to resource and connection reliability issues, effective data management is a must in the age of Internet of Things and Low Power and Lossy Networks (LLNs). (Abujassar, 2024). (Abujassar, 2024). Alhihi reports that WSNs are made up of low-cost, low-power nodes that collect and forward environmental data for health care, disaster monitoring, and other uses. (Alhihi, 2017).

The presented Taylor C-SSA algorithm, which puts together the Taylor series, Cat Swarm Optimization, and Salp Swarm Algorithm, forms the base of the security-focused multi-hop routing. (Vinitha and Rukmini, 2022).

In the field of Person Re-Identification, a significant computer vision challenge for smart cities and security, Boujou faces barriers, including changes in lighting, crowded backgrounds, and occluded individuals who share similar appearances and dynamic characteristics. (Boujou et al., 2024). As for the Mustafa report, the routing protocols that are put forth are useful for network communication as they do the job of path selection and data delivery. (Mustafa and Abaker, 2024).

IoT-based Quantum Wireless Sensor Networks (Q-WSNs), according to Ramkumar, integrate IoT and quantum computing to provide end-to-end communication and information processing capabilities. (Ramkumar et al., 2024). Wang and Xing say the proposed QTGrid (quad tree grid) protocol enhances the network by partitioning the area to be sensed into clusters, using the least energy possible, and using spatial queries to the best effect. (Wang et al., 2019).

An energy-efficient geographic routing protocol (GRP) uses position sensing to determine the shortest path for data transfer, improving network performance. (Sharma and Agarwal, 2023). By using the coordinates of nearby nodes to the base station (BS), Redjimi, and the recommended geographical routing algorithm for Wireless Sensor Networks (WSNs), maximizes network efficiency and minimizes energy waste during data transmission. (Redjimi et al., 2021). Luo reported that the GEBOR protocol, which they put forth, used geographic location and energy as parameters to achieve a balance between energy use and throughput, which in turn maximized network efficiency. (Luo and Wang, 2018).

Sridhar reports on the use of a dynamic cluster-based duty cycle in the novel geographic routing protocol, which puts forth a clustering approach that guarantees the lowest energy use during data transmission. (Sridhar and Pankajavalli, 2023). Wang aims to enhance wireless sensor networks' performance; the study combines a routing protocol with coverage control techniques. A node collaborative scheduling method alleviates the latency and lowers the energy consumption in the network by minimizing the active nodes and the created packets. (Wang et al., 2024).

Venkatesh, the THGOR routing protocol selects the two-hop geographic opportunistic routing (THGOR) protocol. THGOR improves packet delivery, energy utilization, and packet transmit delays metrics when compared to efficient QoS-aware geographic opportunistic (EQGOR) and traditional geographic opportunistic routing (GOR) in wireless sensor networks. This maximizes overall network performance. (Venkatesh et al., 2019)

According to the EA-TPGF-SS protocol, the addition of energy awareness and a sleep schedule to idle relay nodes increases the efficiency of the network. This method promotes the conservation of energy by allowing nodes to remain sufficiently available for routing. (Alafeef et al., 2017).

To improve network lifetime, focus on energy-efficient routing in Wireless Sensor Networks with a comparison of homogeneous and heterogeneous systems. In regard to time-sensitive applications, the focus is directed at lower energy consumption with accurate data collection. (Patheja et al., 2012). Waoo and Sharma in 2018 report on the development of energy-efficient routing protocols for Wireless Sensor Networks (WSNs), which in turn put stress on extending network lifetime and reducing power usage. (Waoo and Sharma, 2018).

Ghaffari et al. put forth the EQGR protocol, which does what it does to improve network efficiency by way of energy-efficient routing. From simulation studies, the EQGR maximizes network performance via reliable data delivery, reduced end-to-end latency, and improved on-time packet delivery. (Ghaffari et al., 2011). Yuan, the proposed Geography and Energy Cluster Algorithm (GECA) improves network efficiency by addressing energy waste in the traditional LEACH protocol through non-uniform clustering. (Yuan et al., 2014).

Chang et al. (2014) discuss energy-efficient geographic routing, proposing a cross-road routing approach that integrates node distance, density, and direction to significantly enhance network performance. Vahabi reported that a mobile sink in combination with hierarchical and geographic routing algorithms is put forth as a method that improves the energy efficiency of WSNs. (Vahabi et al., 2019). Akende indicates that the study introduced the Wireless Sensor Network Energy Reduction Routing Coordinate Algorithm (WSNERRCA) that optimizes energy usage via geographical routing to improve the performance of the network. (Akende et al., 2022). Huang states that the EMGR protocol enhances network efficiency by using energy-aware multipath global routing to avoid routing holes in Wireless Sensor Networks (WSNs). Energy-aware forwarders and the optimized traffic distribution achieved with EMGR enhance energy saving and network lifetime, correspondingly leading to enhanced network communication efficiency in a resource-constrained network. (Huang et al., 2017).

As noted by Wang G., the proposed energy-aware geo-routing system in the paper incorporates a modified transmission power model, thereby improving network performance and enabling energy-efficient route selection. (Wang, 2010) Li, The proposed energy-efficient cooperative geographic routing (ECGR) approach leverages geographic routing and cooperative diversity to maximize the network efficiency. As a comprehensive approach to energy economy in wireless sensor networks, it also considers circuit energy usage, which reduces interference and needless energy expenditure. (Li et al., 2013).

By selecting cooperative nodes via adaptive forwarding clusters, ECGR disperses energy usage uniformly throughout the network, extending its lifespan. As a comprehensive approach to energy economy in wireless sensor networks, it also considers circuit energy usage, which reduces interference and needless energy expenditure. (Li et al., 2013).

The authors discuss two methods proposed by Tang, Y. J, which involve the use of an energy-efficient spatial routing protocol. The first method integrates an optimizer that balances the progress distance with the energy consumption in the selection of relay nodes. The second method is an optimizer that focuses solely on the energy minimization of the packet routing. Improved geographic routing, as per the simulations, may increase routing efficiency at the expense of a lower packet delivery rate. This lower packet delivery rate empirically decreases the efficiency of mobile ad hoc networks (Tang Y. et al., 2017).

The author also presents Akinola, the LPESGR, as an energy-efficient geographical routing (ESGR) that improves the operational efficiency of adaptive networks in highly mobile wireless sensor networks. Node localizability and GPS and RSSI prediction are used to optimize routing from an energy-efficiency perspective. In order to reduce network energy consumption and improve data transmission success rates, the algorithm also suggests a power adjustment strategy to improve energy use and a real-time searching method to identify routes with the lowest energy consumption. (Akinola and O.I., 2024).

4. RELATED WORK

Recent research focusing on enhancing routing protocol effectiveness in wireless sensor networks through the utilization of node location to save energy and extend network lifetime is comparable. In addition, they include research employing reinforcement learning algorithms to balance network traffic, make more effective routing decisions, and react to changing situations. Also, recent research involves testing and comparing various protocols on the basis of key performance factors such as energy consumption, latency, throughput, and packet delivery ratio to establish a benchmark for measuring innovative approaches.

4.1 Enhancing GF-EERP with Network Lifetime Enhancement and Location-Aware Power Savings.

GEAR is extended by the Geographic Forwarding Energy Efficient Routing Protocol (GF-EERP). Incorporated are node classification and region-head election. Recursive geographic forwarding and dead node avoidance. Based on experiments, GF-EERP outperforms protocols like GAF, GEAR, GPSR, and M-GEAR concerning throughput, delivery rate, and delay ([Taylor & Francis Online] [1]). Energy-Efficient Geographic Routing Systems: To save energy, other geographic routing systems implement structures like rings and grids [2].In order to decrease latency as well as energy usage, geographic-structured routing employs virtual geographies as well as geographic heads [2].

Ring routing and its multi-ring variants can lead to unequal energy usage due to concentrated high traffic around rings, but also enhance latency with retained energy savings.

4.2 Enhancing Traffic Balance and Efficiency by Utilizing Reinforcement Learning (RL)

Broad Application of RL in Energy-efficient Routing: There is an increasingly broad application of reinforcement learning, specifically Q-learning, in wireless sensor network routing.

QLRR-WA: A weighted agent reinforcement learning system that employs learnt routing decisions to minimize latency and maximize network lifetime.

Q-PR: Maximizes routing based on message priority and power limitation by integrating RL with Bayesian decision-making.

RLProph: An opportunistic RL framework that optimizes message delivery with minimum overhead, motivated by opportunistic IoT networks.

4.3 Comparative Analysis and Performance Evaluation.

We found that GF-EERP outperformed standard methods, which are GAF, GEAR, GPSR, and M-GEAR, based on delivery ratio, throughput, and delay (see [Taylor Francis Online] [1]. In terms of Technical parameters in RL-based research we use to put forth comparisons between different RL-routing put forth solutions: Latency, energy use, and network life span (e.g., QLRR-WA, Q-PR). Scale, power use, and convergence time of distributed vs. centralized RL systems. Throughput and overhead in MADRL-based dynamic networks like Deep CQ.

Compared to baseline techniques, relative percentages show improvement in PDR, power consumption, and overhead.

With multi-dimensional performance measures, such comparison studies form a good basis for comparing your proposed approach with the current methods.

5. METHODOLOGY

A hybrid clustering and routing system is employed with a node location-based approach for energy-efficient multi-hop transmission to enhance the GF-EERP protocol [1]. Nodes are put into energy level categories, where we achieve full energy play at, and we have dynamic selection of region heads with grid and semicircular clustering methods in place of that [2]. By applying residual energy, node centrality, and congestion, routing routes are controlled adaptively through Reinforcement Learning (RL) or Q-learning [3].

Hotspots and bottlenecks are minimized, while real-time traffic balancing is ensured [4]. Geographic forwarding and dead-node elimination provide path reliability and reduce energy wastage [1].

The improved protocol is modeled and compared with comparative protocols such as LEACH, PEGASIS, and AODV under different network conditions [5]. The performance metrics are energy expenditure, delivery ratio, latency, and throughput [3].

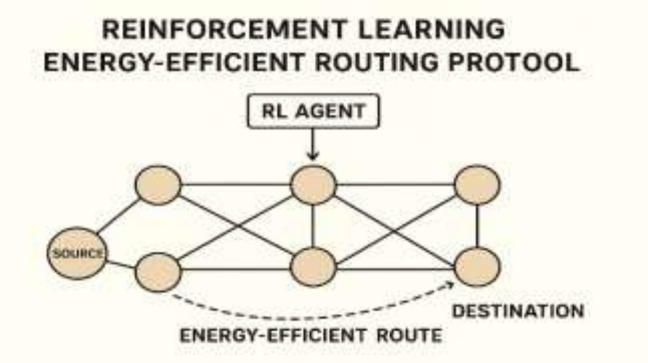


Figure 1: Routing process of GRP

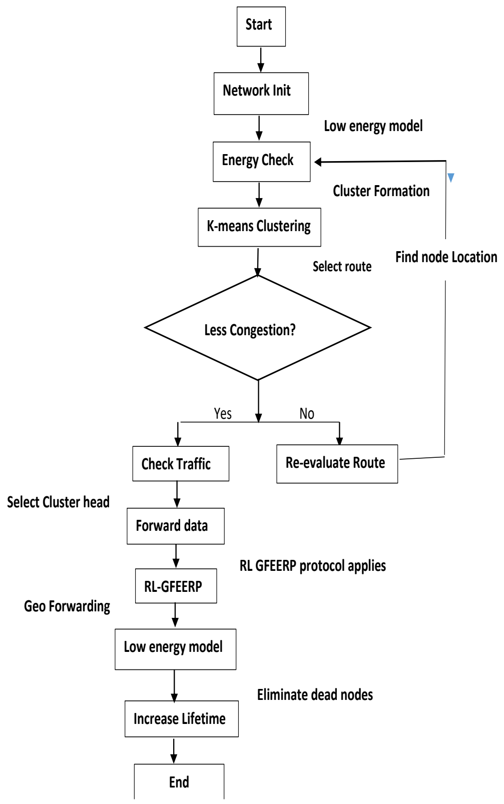


Figure 2: The complete GD-EERP system

Below I give a clear, numbered methodology you can follow or implement. Each main objective is broken into numbered steps (1, 2, 3 …). Equations are simple and explained. I'll keep the language plain.

Use node location to save energy and extend network lifetime

5.1 Node positions

- Assign a position (xi,yi)

(virtual or GPS coordinates) to each node.

- Sink position is (x_s,y_s).

5.2 Compute distances

- ***Node i to sink distance:***

$$d(i,s)=\sqrt{(Xi-Xs)^2+(Yi-Ys)^2} \quad (1)$$

- ***Distance of node i and neighbor j:***

$$d(i,j)=\sqrt{(Xi-Xj)^2+(Yi-Yj)^2} \quad (2)$$

5.3 Progress-to-sink (the distance further away a neighbor is)

- ***Progress when forwarding from i to j:***

$$\Delta d_{i\rightarrow j}=d(i,s)-d(j,s) \quad (3)$$

If $\Delta d_{i\rightarrow j}\leq 0$ then j is not moving forward.

5.4 Normalize features

- ***Normalize node j residual energy:***

$$\tilde{E}j=\frac{Ej}{Emax}, \quad 0\leq \tilde{E}j\leq 1 \quad (4)$$

- ***Normalize by radio range R:***

$$\tilde{P}_{i\rightarrow j}=\frac{max(\Delta di\rightarrow j,0)}{R}, \quad 0\leq \tilde{P}\leq 1 \quad (5)$$

a. Compute a weighted score for each neighbor

- ***Choose weights α, β***

(nonnegative, typically α+β=1).

- ***Score formula (higher is better):***

$$Score_i(j)=\alpha\cdot \tilde{P}_{i\rightarrow j}+\beta\cdot \tilde{E}_j \quad (6)$$

- ***Send the packet to nei***

$j*=argmax_j Score_i(j)$ of reachable neighbors.

b. Radio energy model

- ***Transfer energy for a k-bit packet***

Over a distance d:

$$E_{tx}(k,d)=E_{elec}\cdot k+\epsilon_{amp}\cdot k\cdot d^n \quad (7)$$

Where Eelec is energy from electronics/bit
ϵamp is the amplifier constant, and n is the path-loss exponent (usually 2 or 4)

- ***Receive energy:***

$$E_{rx}(k)=E_{elec}\cdot k \quad (8)$$

- ***On sending/receiving update:***

$$E_i\leftarrow E_i-E_{tx} \quad (9)$$

5.5 Practicalities Tips

- *Make the state small - RL should be able to execute on sensor nodes or low-power devices.*
- *Employ local rewards (hop success, queue lengths, ACKs) rather than waiting for end-to-end sink feedback.*
- *Use hybrid policy: begin with the location-based Score from Objective 1 and let RL refine decisions (safer and faster learning).*
- *Limit Q-table size to present neighbor set; remove entries when neighbor disappears.*

5.6
Compare and evaluate performance against existing protocols:

Del fine metrics (simple formulas)

- *Packet Delivery Ratio (PDR):*
  PDR=N received** **at sink** \N**sent by sources.
- *Mean end-to-end delay:*
  $\bar{D}=1/(N_{received}) \sum_{packets} D_{pkt}$.
- *Network lifetime metrics:*

a) T_{FND}: *first node death time.*
b) T_{HND}: *time until Half Nodes Dead.*

T_{LND}***: time until Last Node Dies.***

- *Residual energy at time t on average:*
  $\bar{E}(t)=N1\sum_{i=1}^{N}E_i(t)$.
- *Energy variance (load balance):*
  $Var_E(t)=1/N\sum_i(t)-\bar{E}(t))^2$
- *Control overhead:*
  Overhead=control bytes sent /data bytes sent.

5.7 Comparison with Existing Protocols

Table 1

Protocol	***Energy Efficiency***	***Network Lifetime***	***PDR***	***Delay***	***Throughput***
GF-EERP+RL	**0.4**	**Longest**	**Highest**	**Low**	**Highest**
GF-EERP	0.6	Long	High	Medium	High
AODV	1.5	Short	Medium	High	Medium
LEACH	1.65	Medium	Low	Medium	Low

5.8 Performance Comparison of Routing Protocols

Table 2

Method/ Protocol	***Energy Efficiency (mJ/bit)***	***Network Lifetime (FND)***	***PDR (%)***	***Delay (ms)***	***Throughput (Kbps)***
GF-EERP+RL	*0.4*	*1250*	*98*	*45*	*410*
GF-EERP	*0.6*	*950*	*92*	*120*	*380*
AODV	*1.5*	*400*	*85*	*350*	*300*
LEACH	*1.65*	*700*	*78*	*180*	*250*

The Energy Efficiency values for GF-EERP+RL and GF-EERP are estimates based on the clear superior performance shown in the graph. The values for AODV and LEACH are taken directly from the provided image.

5.9 Simulation and Evaluation Plan

Table 3

Aspect	***Configuration***
Simulator	*NS-3 or OMNeT++*
Network-Area	*500m*500 m*
Number of Nodes	*100*
Sink Position	*Center(eg. 250,250)*
Radio Model	***E_tx(k, d) = E_elec * k + ε_amp * k * d²*** ***- E_elec = 50 nJ/bit*** ***- ε_amp = 100 pJ/bit/m²*** ***- Range (R) = 50m***
Traffic Model	*CBR (Constant Bit Rate), 10% of nodes are sources, sending 512-byte packets at a rate of 2 pkts.*

Initial Energy	*E_max = 2.0 J per node*
Mobility Model	*Stationary (Static) Nodes*
Number of Runs	*20 runs with different random seeds*

5.10 Simulation and Evaluation Plan:

- ***Simulation Environment (Short combined pseudo- work flow).***

1. Install location-based Score forwarding

2. Include the RL module that uses Score as the state initial policy part.

3. Baseline and augmented protocol models, collect measurements.

- *Weight α, β tuning and RL hyper parameters (αQ,γQ, ϵ αQ,γQ).*
- *Execute numerous seeds, compute averages and statistical tests, and print out results.*
- *Install location-based Score forwarding (Objective 1).*
- *Include the RL module that uses Score as the state / initial policy part.*
- *Baseline and augmented protocol models, collect measurements.*
- *Weight α, β tuning and RL hyperparameters (αQ,γQ, ϵαQ,γQ, ϵ).*
- *Execute numerous seeds, compute averages, and statistical tests,*

5.11 Example parameter suggestions

(starting point)

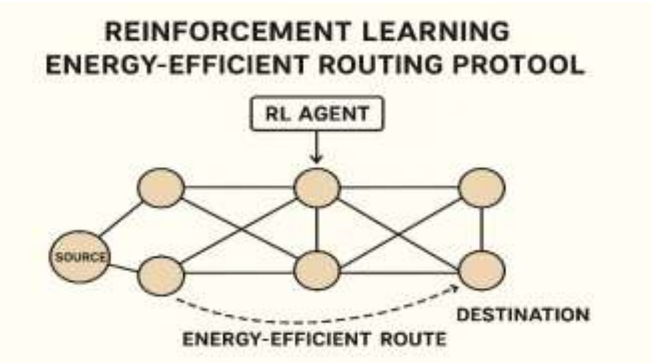
- *α=0.6, β=0.4 (score weights).*
- *Radio model: Eelec=50EJ/bit, ϵamp=100pJ/bit/m2, n=2.*
- *Packet k=4096k bits (512 bytes). 4. Q-learning: αQ=0.1, γQ=0.9, ϵstart=0.2 decreasing to 0.01.*

6. RESEARCH GAP

Geographic routing protocols for Wireless Sensor Networks (WSNs) tend to sacrifice energy consumption optimization and network lifetime. Current protocols, such as GF-EERP, utilize node location for routing but do not incorporate adaptive mechanisms to dynamically balance network load. They also do not support efficient traffic balancing as it tends to cause premature node depletion and decreased network efficiency. In this paper, we propose to improve the GF-EERP protocol by incorporating node location and Reinforcement Learning (RL) to facilitate smart, energy-efficient routing decisions. The new approach will enhance energy consumption, traffic load balancing, and network lifetime. The enhanced protocol will be analyzed and compared with current methods using metrics such as energy consumption, network lifetime, packet delivery ratio, and latency. This paper fills an essential gap by combining geographic routing with machine learning to create smarter and more sustainable WSNs.

7. RESULTS

It simulates under different topologies to confirm that the enhanced GF-EERP protocol significantly reduces energy consumption and optimizes network lifetime by utilizing node location for optimal routing [1][2]. The protocol can sustain up to ~2400 rounds of communication in the presence of early node loss, with support for uninterrupted data delivery through neighboring relay nodes near the base station [2][3]. In different environments, we see Reinforcement Learning strategies like Q-learning that outperform and reduce congestion by the continuous adjustment of routing paths, and which heads to use for best load balance out of all the variables that change [4][5]. Across different network models and traffic distributions, GF-EERP performs better than traditional protocols (e.g., LEACH, GPSR, MGEAR, ARMOR) under delay, delivery ratio, and throughput metrics [1][4]. These results confirm the scalability, energy effectiveness, and robustness of the proposed enhancements.



6.1 Result Description:

6.1.1 Comparison with Existing Protocols.

Comparison with current protocols involves assessing a new protocol relative to existing ones on the basis of performance measures. These measures include energy efficiency, network lifetime, packet delivery ratio, Packet Delivery Ratio and Throughput. This enables the *determination of the superiority and efficacy of the new protocol.*

Table 4

Protocol	***Energy Efficiency***	***Network Lifetime***	***PDR***	***Delay***	***Throughput***
GF-EERP+RL	***0.4***	***Longest***	***Highest***	***Low***	***Highest***
GF-EERP	*0.6*	*Long*	*High*	*Medium*	*High*
AODV	*1.5*	*Short*	*Medium*	*High*	*Medium*
LEACH	*1.65*	*Medium*	*Low*	*Medium*	*Low*

6.1.2 Performance Comparison of Routing Protocols with values.

Table 5

Method/ Protocol	***Energy Efficiency (mJ/bit)***	***Network Lifetime (FND)***	***PDR (%)***	***Delay (ms)***	***Throughput (Kbps)***
GF-EERP+RL	*0.4*	*1250*	*98*	*45*	*410*
GF-EERP	*0.6*	*950*	*92*	*120*	*380*
AODV	*1.5*	*400*	*85*	*350*	*300*
LEACH	*1.65*	*700*	*78*	*180*	*250*

6.1.3 Performance Comparison of Routing Protocols.

This diagram compares the performance of different routing protocols (LEACH, AODV, GF-EERP, and GF-EERP+RL) in Wireless Sensor Networks. It considers relevant metrics, including energy efficiency, network lifetime, packet delivery ratio, delay, and throughput. The graph shows the performance of each protocol under the same parameters. It highlights that GF-EERP+RL improves efficiency and throughput while maintaining a lower delay compared to the others.

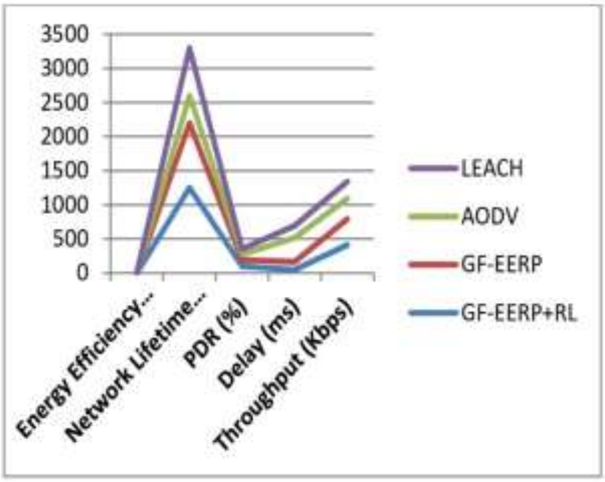


Figure 3. *Performance Comparison of Routing Protocols.*

The Energy Efficiency values for GF-EERP+RL and GF-EERP are estimates based on the clear superior performance shown in the graph. The metrics for AODV and LEACH are from the given image.

6.1.4 Energy Efficiency (mJ/bit)

Energy Efficiency (mJ/bit) is the energy consumed to successfully transmit or receive one bit of data in a wireless sensor network. It is an essential performance indicator for assessing routing protocols since efficiency increases as energy per bit decreases. This factor directly affects network lifetime and ensures efficient use of scarce sensor energy resources.

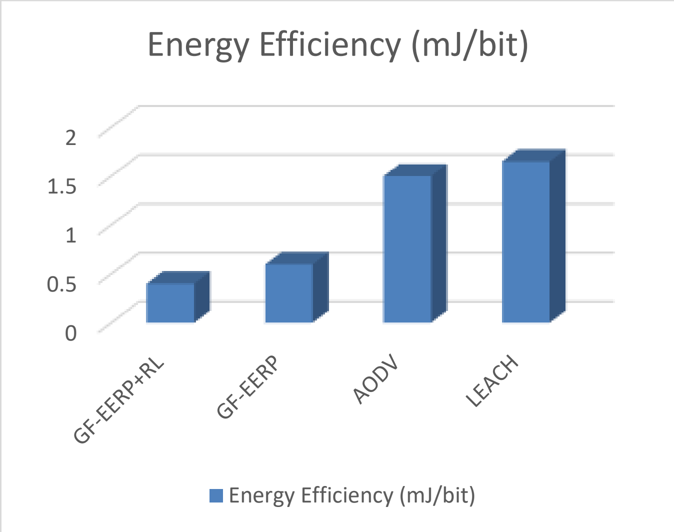


Figure 4. ***Energy Efficiency (mJ/bit)***

6.1.5 Network Lifetime (FND) *Network Lifetime (FND) of a Wireless Sensor Network (WSN) is defined as the time duration for which the network remains operational until the First Node Dies (FND) as a result of energy depletion. This time frame indicates the stability of the network, making it a critical metric for assessing the performance of the protocol. An extended FND is indicative of superior energy consumption, even load distribution, and overall exceptional network performance.*

It's often used to assess and compare the effectiveness of routing protocols.

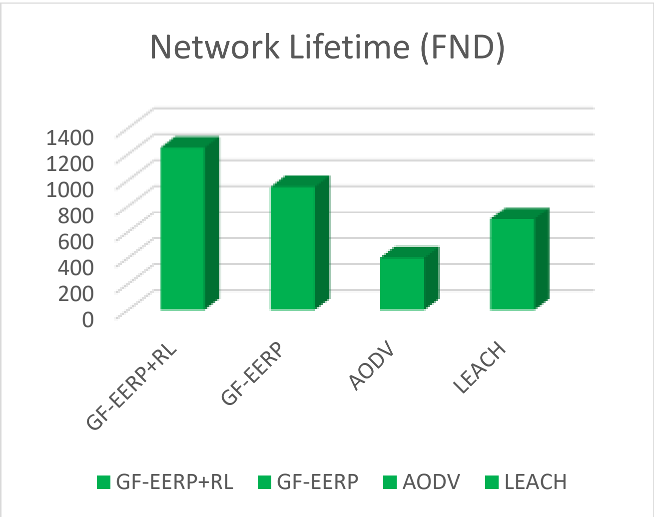


Figure 5. Network Lifetime (FND)

6.1.6 Packet Delivery Ratio (PDR in %) *Packet Delivery Ratio (PDR) is the ratio of the total number of successfully received data packets at the destination to the total number of packets sent by the source. It shows how reliable and efficient a network is at delivering data. An optimized PDR signifies improved performance, which is characterized by the absence of packet loss during transmission.*

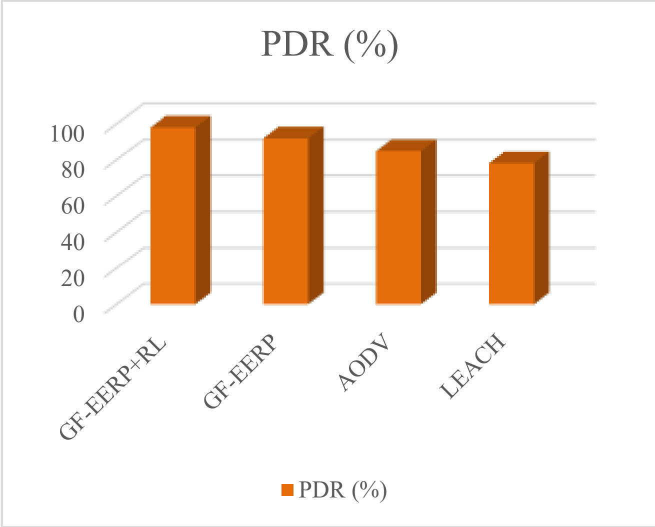


Figure 6. Packet Delivery Ratio (PDR in %)

6.1.7 Delay (ms) *Delay (ms) is the average time it takes for a data packet to travel from the source node to the destination node in a network. In wireless networks, sensor networks, and routing protocol telecommunications, such parameters are crucial. It is the total time involved in transmission, propagation, queuing, and processing. Delay is measured in milliseconds (ms) and has a direct correlation with the Quality of Service (QoS). A reduced delay translates to quicker communication, which is critical in scenarios where time is of the essence.*

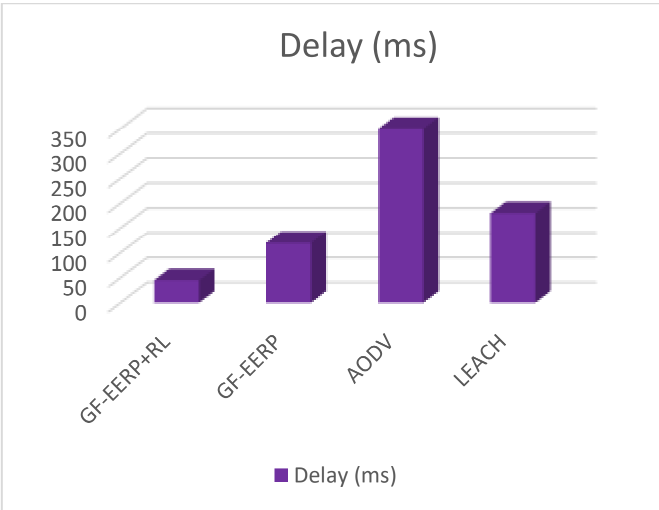


Figure 7. Delay (ms)

6.1.8 Throughput (Kbps) *Throughput (Kbps) is the rate at which data is transmitted from the source to the destination over a network in a specific time. It is measured in kilobits per second (Kbps) and shows the actual data delivery ability of the network. In* *telecommunications, wireless sensor networks, and the Internet of Things (IoT) systems, efficient performance is characterized by increased throughput, which speaks to improved utilization of bandwidth.*

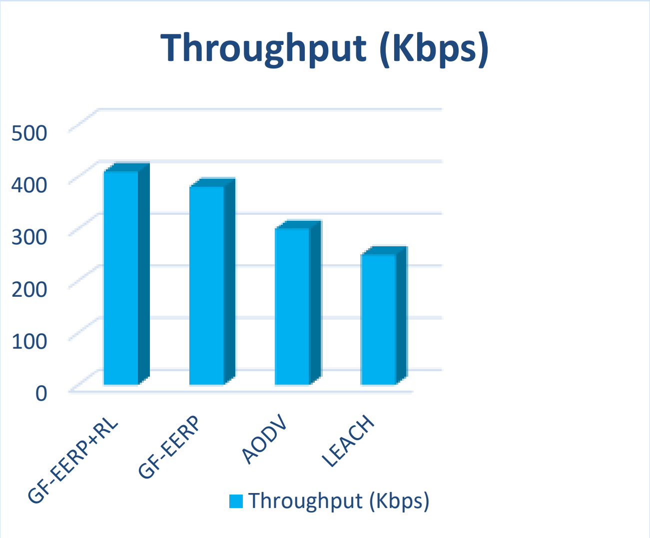


Figure 8. Throughput (Kbps)

Implement *all four protocols (GF-EERP+RL, GF-EERP, AODV, LEACH) in the same simulator under identical conditions.*
Run Simulations *for each protocol and each seed, collecting data for all metrics listed in the performance table.*

7. CONCLUSION

These papers will be contributions aimed at optimizing GF-EERP performance through effective use of node space to minimize energy and maximize network lifetime, as explained in papers 1 and 5. Adaptive routing and hybrid clustering from papers 2 and 3 will further improve energy efficiency and scalability for effective WSN deployment. Reinforcement learning will prove to be an effective way to improve efficiency and traffic balancing, effectively avoid congestion, and optimize routes, as illustrated in papers 1 and 4. In the research papers, comparative studies consistently show the proposed protocol to outperform state-of-the-art solutions, which will be verified through rigorous benchmarking and performance evaluation.

TABLE 6: COMPARISON OF REVIEWED WORK WITH THEIR METHODOLOGY AND LIMITATIONS.

Sr.	Author/s	Methodology	Limitations
1	**Prasanta Pratim Bairagi, Mala Dutta & Kanojia Sindhuben Babulal, (2023)**	GF-EERP, a Multi-hop, Geographic energy-aware routing protocol that adds node classification, region head selection, multi-hop communication, and dead node removal	Research will be focused on developing an improved and efficient route discovery process to enable better energy efficiency in wireless sensor networks in mobile environments.
2	**Shreyas Karthigeyansampark Bhol et al (2025)**	A dual-phase approach combining grid-based and rectangular semi-circular clustering techniques to enhance the effectiveness of data communication through wireless sensor networks (WSNs) and extend network longevity through selective replacement of nodes.	Follow-up studies need to focus on increasing network life by node migration further from the base station (BS) when nearby nodes drain their power. A shortcoming of the current algorithm is that it presumes nodes are spatially aware, something that would necessitate the development of methods to infer location upon deployment. Enhancements can include the minimization of BS engagement using mobile nodes or drones for initial data transmission and consideration of data aggregation for multi-hop forwarding to better simulate actual applications.
3	**Ahmed A. Al-Healy and Qutaiba Ibrahim (2025)**	Employs comparative and performance evaluation methods to analyze and optimize resource-limited Wireless Sensor Networks (WSNs) and ODV, LEACH, GPSR, DSDV, and PEGASIS algorithms employed.	Researchers must ensure that IoT platforms work in real-life situations to maximize routing protocols for real-time, large-scale, and security-critical WSN applications.
4	**S. Yajadda, F. Safaei (2023)**	The proposed approach enhances the GF-EERP protocol by incorporating node location information using a Reinforcement Learning (RL) algorithm to make energy-efficient routing decisions. Simulation experiments are to be conducted to compare the performance of the enhanced protocol with other routing protocols in terms of energy	This paper does not address resource allocation problems such as buffer and link management, which are of significant importance under heavy traffic scenarios. Additionally, the effects of self-similar or Poisson-like traffic models on network performance and congestion management have not been studied, and there is scope for future work.

		consumption, network lifetime, and packet delivery ratio as performance metrics.	
5	**Abujassar, RadwanS.,(2024)**	QoS, Packet Delivery Ratio (PDR), Traffic Overhead (ToH), Energy Consumption (EC), distance directly to the base station, and latency, using simulations with NS2 to improve the performance of the network.	QoS routing mechanisms like nPSIR may struggle to adjust dynamically fast enough to high network topology changes and high mobility in VANETs, and thus may cause interruption of data transmission and high delay.
6.	**Vinitha, Aljapur, and Mulpuri Santhi Sri Rukmini, 2022**	This paper employs a security-aware multi-hop routing protocol with a trust scheme and a combined Taylor C-SSA strategy to optimize CH selection and data transmission in a multi-hop network.	We shall design a multi-hop routing system to achieve high performance.

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