

Improving Network Efficiency Through an Energy-Aware Geographic Routing Protocol

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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.

Keywords: Energy Efficiency, GF-EERP, Geographic Routing Protocol, Network Lifetime, Node Localization, Reinforcement Learning, Traffic Balancing, Wireless Sensor Networks.

INTRODUCTION

WSNs are used for real-time data collection in many fields. 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, 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].

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.

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, Karthigeysa 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. (Karthigeysan 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, which is a great computer vision issue for smart cities and security in Boujou, there are barriers to this, including the change in lighting, busy background settings, and people who are covered by others, who also have similar looks and dynamic settings. (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).

Wao 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. (Wao 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).

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, which achieve full energy play, and also have a 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].

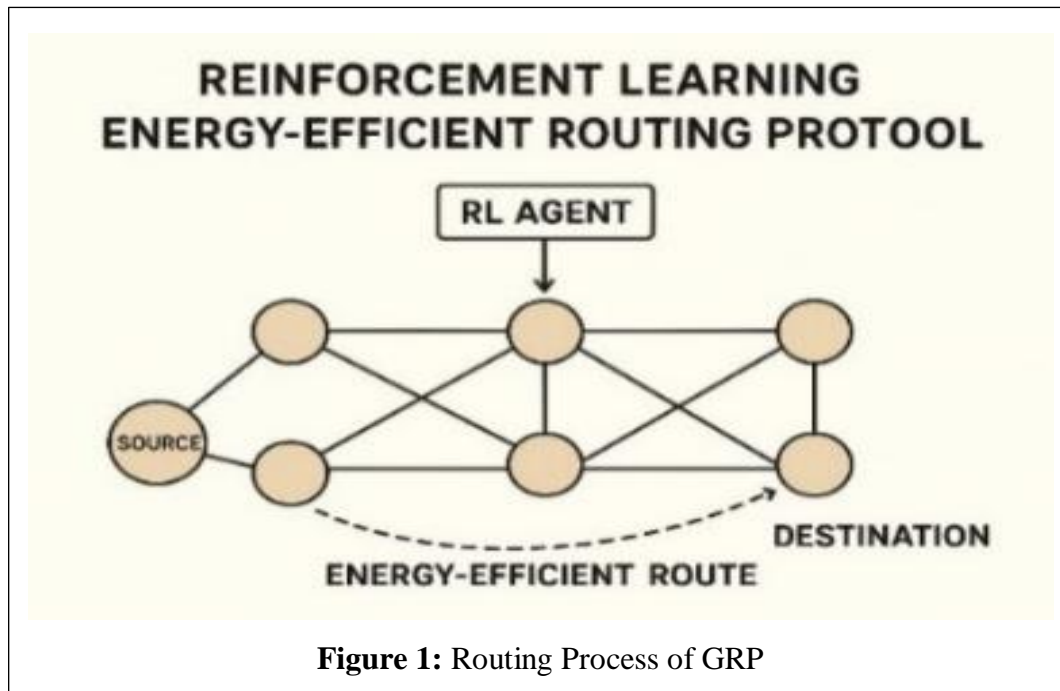


Figure 1: Routing Process of GRP

The routing process of GRP is shown in Figure 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].

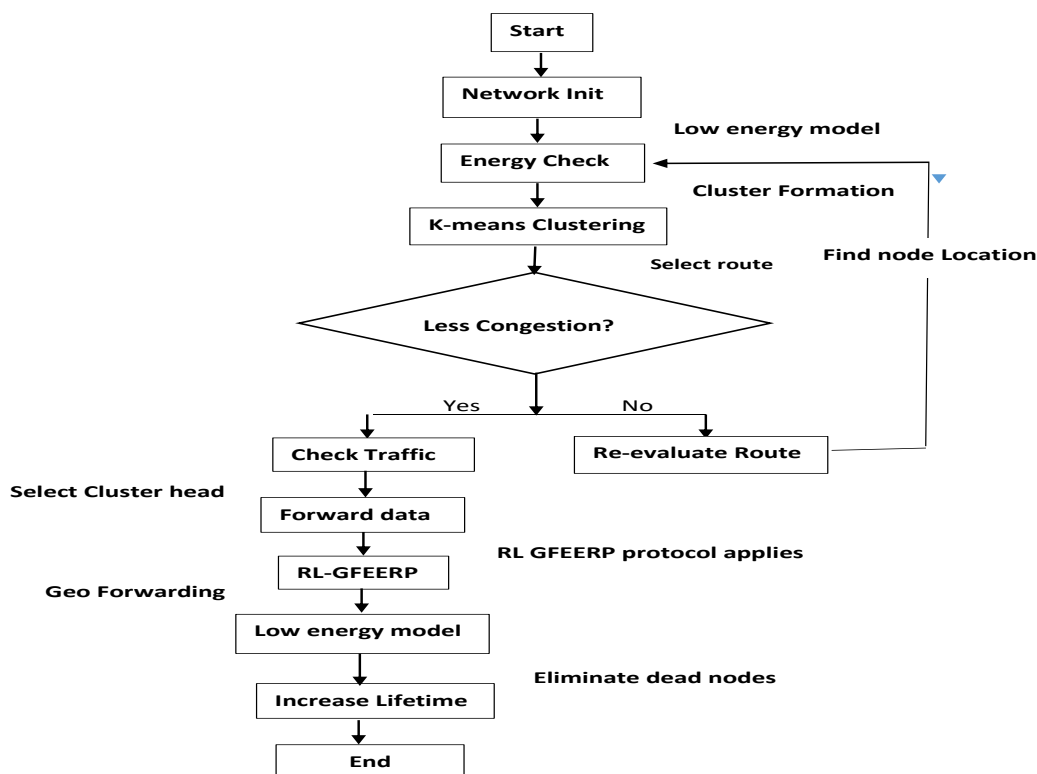


Figure 2: The Complete GD-EERP system

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 improve the GF-EERP protocol by incorporating node location and Reinforcement Learning (RL) to facilitate smart, energy-efficient routing decisions. The new method will improve 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.

Table 5: Comparison of Reviewed Work with their Methodology and Limitations.

Sr	Author/s	Methodology	Limitations
1	Bairagi et al., 2024	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	Karthigeyan 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 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 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.
3	Al-Healy and Ibrahim, 2025	Employs comparative and performance evaluation methods to analyze and optimize resource-limited Wireless Sensor Networks 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	Yajadda and Safaei, 2023	The proposed approach enhances the GF-EERP protocol by incorporating node location information using a Reinforcement Learning algorithm to make energy-efficient routing decisions.	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.
5	Abujassar, 2024	QoS, Packet Delivery Ratio (PDR), Traffic Overhead (ToH), Energy Consumption	QoS routing mechanisms like nPSIR may struggle to adjust dynamically fast enough to high network topology changes and

		(EC), distance directly to the base station, and latency, using simulations with NS2 to improve the performance of the network.	high mobility in VANETs, and thus may cause interruption of data transmission and high delay.
6.	Vinitha and 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.	Design a multi-hop routing system to achieve high performance.

CONCLUSION

This paper introduces an improved Geographic Forwarding Energy-Efficient Routing Protocol (GF-EERP) designed to boost energy efficiency and prolong the lifespan of Wireless Sensor Networks. By combining accurate node location data with adaptive routing based on reinforcement learning, the method allows for smart, context-sensitive decisions in data forwarding. The hybrid clustering and geographic routing strategy efficiently cuts down on unnecessary transmissions, balances the traffic load, and reduces early node failures. Reinforcement learning further improves routing performance by dynamically responding to network changes, traffic congestion, and remaining energy levels. A simulation-based comparison shows that the enhanced GF-EERP consistently performs better than traditional protocols like LEACH, GPSR, GEAR, and M-GEAR in terms of energy usage, packet delivery rate, latency, and overall network longevity. The findings confirm better scalability, reliability, and resilience in various network situations. By merging geographic routing with machine learning capabilities, the proposed protocol tackles major shortcomings of current energy-aware routing approaches. This research underlines the effectiveness of learning-based geographic routing for long-lasting WSN implementations. Future studies could explore real-time applications, mobility support, and deep reinforcement learning to further improve adaptability and performance in large-scale IoT environments.

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