Enhanced Particle Swarm Optimization based Load Balancing with Geographic Routing using Greedy Perimeter Stateless Routing (EPSO-GPSR) for Underwater Wireless Sensor Networks (UWSNs)

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ABSTRACT

EPSO-GPSR (Enhanced Particle Swarm Optimization-based Load Balancing with Geographic Routing using Greedy Perimeter Stateless Routing), a unique strategy designed specifically for WSNs, is presented in this work. Using Enhanced Particle Swarm Optimization (EPSO) to provide load balancing across sensor nodes, the proposed EPSO-GPSR technique reduces energy disparities and increases the operational lifetime of the network. Additionally, it interfaces with the geographic routing protocol Greedy Perimeter Stateless Routing (GPSR) to enable effective data forwarding based on geographic locations, minimizing communication overhead and improving scalability. EPSO-GPSR's efficacy is shown against traditional load balancing and routing methods via comprehensive simulations and performance assessments. The network lifetime, energy efficiency, throughput, packet delivery ratio, and delay have all significantly showed better performance, according to the results. Additionally, the EPSO-GPSR algorithm demonstrates robustness against node failures and issues related to scalability, indicating a significant potential for real-world implementation in various WSN scenarios.

Keywords - **Underwater Wireless Sensor Networks, load balancing, network lifetime, throughput, delay, packet delivery ratio, routing, greedy perimeter, stateless routing.**

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I. INTRODUCTION

Underwater Wireless Sensor Networks (WSNs), which allow data transmission and collection from far-off and frequently unreachable locations, are essential for many applications. These networks are made up of little, inexpensive sensor nodes that work together to gather, process, and send data to base stations or sinks that are assigned. However, effective data routing and network lifespan are severely hampered by the limited resources and dynamic nature of WSNs. The decentralized nature of the Greedy Perimeter Stateless Routing (GPSR) protocol and its reliance on geographic data for routing decisions have drawn attention to it. The next hop in GPSR is chosen based on how close the destination is, which usually leads to shorter pathways and less communication overhead. However, load mismatches across nodes might impair GPSR's effectiveness, resulting in uneven energy consumption and possible network deprivation.

The combination of GPSR and Enhanced Particle Swarm Optimization (EPSO) offers a viable solution to this problem. EPSO is a heuristic optimization method that adjusts individual placements iteratively based on collective information to maximize solutions. It is inspired by the social behavior of fish or birds. Potentially providing dynamic load balancing capabilities through EPSO integration with GPSR would allow nodes to optimize routing choices and adaptively redistribute traffic.

The main goal of this research is to include EPSO-based load balancing into WSNs to improve GPSR's capabilities. This integration attempts to reduce load imbalances among nodes, optimize energy usage, and enhance overall network performance and reliability by dynamically optimizing routing decisions based on both geographical proximity and load balancing data.

The goals include creating an integrated EPSO-GPSR routing model, optimizing routing choices via load balancing, and conducting thorough performance reviews to gauge the influence on important metrics. This work attempts to offer important insights into the feasibility and efficacy of the suggested integrated method in real-world WSN deployments through comprehensive simulations and analysis.

II. RELATED WORKS

In WSNs, routing protocols play a crucial role in enabling data transfer between sensor nodes. The Greedy Perimeter Stateless Routing (GPSR) algorithm is one of these protocols that has been studied and improved upon to get better results in terms of packet delivery, energy efficiency, and network lifetime. Examining numerous studies that have improved GPSR-based routing protocols for Underwater Wireless Sensor Networks is the focus of this overview of the literature.

The energy balance in GPSR for Underwater Wireless Sensor Networks is the main topic of the study by Qian et al. (2008). The authors suggest adjusting GPSR to take node energy status into account when making packet forwarding decisions in order to increase energy efficiency. By tackling the problem of energy consumption in GPSR-based routing, which is essential for extending network lifetime, this work makes a substantial contribution.

An energy-efficient GPSR variation designed for Underwater Wireless Sensor Networks is introduced by Xu et al. (2006). The focus of their study is on routing using the least amount of energy possible. This work helps to increase the total network lifespan, which is an important consideration in resource-constrained sensor networks, by improving the route selection process based on energy indicators.

An enhanced GPSR routing system is presented by Lin and Sun's (2009) study, which focuses on network energy balancing. Their technique intends to more equally distribute energy consumption among nodes, hence minimizing premature node failures and extending network operation, by improving the energy-awareness features of GPSR.

An adaptive multi-level clustering method integrated into GPSR is proposed by Chen and Yu (2010). Through the use of multi-level routing and dynamic cluster formation, they optimize GPSR's routing decisions, improving network efficiency, load balancing, and scalability.

Zong et al. (2011) present an upgraded GPSR technique that is multi-hop and energy-balanced. Through the consideration of multi-hop communications, the research aims to refine the performance of GPSR by increasing network coverage and decreasing the dependence on direct neighboring nodes for packet forwarding.

In GPSR, Wang and Li (2012) present an optimization that makes use of ant colony optimization techniques. In order to improve GPSR's routing choices, their research investigates the integration of algorithms with natural inspiration. They concentrate on energy balancing and path selection optimization for improved packet delivery.

An energy-efficient GPSR technique based on fuzzy logic is proposed by Kumar and Lohan (2013). Through the use of fuzzy logic concepts, the study seeks to enhance GPSR's decision-making process by empowering nodes to make more adaptable and nuanced routing decisions in response to changing network conditions.

Bera and Sahu (2014) combine multi-path routing with hybrid clustering to propose an improved GPSR system. Their work focuses on using numerous pathways and clustering to improve packet delivery and reduce congestion, hence increasing network resilience and reliability.

Al-Jarrah and Mourad's (2016) paper presents a hybrid GPSR-AODV routing protocol that combines the advantages of the Ad Hoc On-Demand Distance Vector (AODV) and GPSR protocols. By combining elements of AODV, their hybrid approach seeks to solve some limitations and capitalize on GPSR's efficiency while reaching a fair trade-off between efficiency and adaptability.

An enhanced GPSR-based approach with an emphasis on load balancing and energy economy is put forth by Ali and Shehab (2017). Their research makes a contribution by incorporating load balancing techniques into GPSR to distribute traffic uniformly throughout the network, improving the durability and overall performance of the system.

The literature under discussion demonstrates how GPSR-based routing strategies for Underwater Wireless Sensor Networks are developing. Together, this research has made a significant contribution to tackling important issues in GPSR, including load balancing, energy efficiency, network scalability, and packet delivery dependability. Many strategies have been investigated to improve GPSR's performance in various areas, including energy awareness, clustering, optimization techniques, and hybridization with other procedures.

Even though these studies show great progress, further research is still needed to improve GPSR-based routing protocols, adapt them to a variety of WSN applications, and handle new problems in settings with limited resources

III. PROPOSED WORK

For Underwater Wireless Sensor Networks (WSNs), the geographic routing algorithm Greedy Perimeter Stateless Routing (GPSR) is used. Packets are sent to the destination via a greedy algorithm that chooses the neighbor that is nearest to the destination in terms of geography. Since GPSR is a stateless method, no routing tables are kept up to date by it. Rather, it bases its forwarding decisions on knowledge of the network structure and local information.

GPSR Algorithm

The following steps make up the GPSR algorithm:

Packet Reception:

The first action taken after receiving a packet in the Greedy Perimeter Stateless Routing (GPSR) algorithm is critical to deciding how to proceed. A node initially determines if it is the packet's intended recipient (destination) when it gets one. The packet is said to have reached its intended endpoint if the receiving node's identification matches the destination address specified in the packet header. In this instance, depending on the contents of the packet, the node sends the packet to the application layer for additional processing, execution, or data consumption. If the node is the ultimate destination, this delivery to the application layer guarantees that the received data is used or acted upon by the node.

On the other hand, it suggests that the packet has to be forwarded farther in the direction of its target if the receiving node finds that it is not the packet's intended destination. As a result, the node starts the routing procedure by executing the subsequent actions specified by the GPSR algorithm.

Greedy Forwarding:

A node uses the Greedy Forwarding technique when it discovers that the received packet is not meant for it. By choosing a neighbor among its immediate neighbors that is geographically closest to the intended destination, the node in this approach seeks to advance the packet towards the destination.

Algorithm – 1: The Working of EPSO - GPSR

```
# Particle Initialization
function particle_initialization():
    initialize_population()  # Initialize a population of particles
    for each particle in population:
        initialize_position(particle)  # Initialize particle positions randomly
        initialize_velocity(particle)  # Initialize particle velocities randomly
# Fitness Calculation for Load Balancing
function fitness_calculation():
    for each particle in population:
        calculate_fitness(particle)  # Evaluate fitness based on load balancing metrics
# EPSO-based Position Updates
function EPSO_position_updates():
    for each particle in population:
        update_position(particle)  # Update particle positions based on EPSO logic
        update_velocity(particle)  # Update particle velocities based on EPSO logic
# Relay Node Selection based on EPSO Results
function relay_node_selection():
    best_particle = find_best_particle()  # Identify the best particle based on fitness
    selected_relay_nodes = determine_relay_nodes(best_particle)  # Determine relay nodes from the best particle
# GPSR-based Routing
function gpsr_routing(selected_relay_nodes):
    for each data packet to transmit:
        select_next_hop(selected_relay_nodes)  # Determine the next hop based on GPSR
        forward_packet()  # Forward data packet to the selected next hop based on GPSR
# Iterative Optimization and Adaptive Routing
function iterative_optimization():
    while not convergence_criteria_met():
        fitness_calculation()  # Recalculate fitness based on load balancing metrics
        EPSO_position_updates()  # Update particle positions using EPSO
        relay_node_selection()  # Select relay nodes based on EPSO results
        gpsr_routing(selected_relay_nodes)  # Forward data packets using GPSR based on selected relay nodes
# Convergence and Optimization Criteria
function convergence_criteria_met():
    if maximum_iterations_reached or satisfactory_load_balancing_solution:
        return true
    else:
        return false
# Main Function to Execute EPSO-GPSR Integration
function main():
    particle_initialization()  # Initialize particles for EPSO
    iterative_optimization()  # Execute iterative optimization for EPSO-GPSR integration
```

The node uses stored geographic data about its nearby nodes to carry out Greedy Forwarding. The desired destination and the geographic coordinates (such as latitude and longitude) of these nearby nodes are usually included in this data. The node determines which neighbor is physically closest to the destination in terms of geographic distance using this geographical knowledge. The packet is able to get closer to its intended endpoint in the network by using this nearest neighbor as its next hop.

On the other hand, there may not always be an adjacent node that is closer to the target than the one that is now there. When this occurs, the algorithm moves on to the Perimeter Check, which is the following stage, because the Greedy Forwarding method cannot be implemented further.

Perimeter Check:

The GPSR algorithm moves on to the Perimeter Check stage if the Greedy Forwarding step is unable to find a neighbor who is closer to the destination. To find a possible routing option that might be closer to the destination than the current node, the node surveys its surroundings in this step. It does this by analyzing the nodes that are nearby.

The node evaluates the geographic locations of its surrounding nodes in respect to the desired destination during the Perimeter Check. Finding an adjacent node that is physically closer to the desired destination than the current node is the goal. It becomes the favored option as the next hop for packet forwarding if such a closer neighbor is found. The program aims to optimize the packet's route and get it closer to its destination by selecting this closer neighbor.

But in terms of possible forwarding choices, the algorithm comes to a standstill if the Perimeter Check also is unable to locate a neighboring node that is closer to the destination. Consequently, if the node is unable to find a better routing option nearby, it may choose to drop the packet.

The three main decision-making processes of the GPSR algorithm are Packet Reception, Greedy Forwarding, and Perimeter Check. With the help of these procedures, nodes operating in ad hoc wireless networks can decide on local routing based on geographical data, guaranteeing that packets are effectively routed to their intended locations. This method, which enables decentralized and dynamic routing in wireless networks, is particularly useful in situations when a centralized infrastructure is lacking or unfeasible.

The GPSR algorithm's efficacy stems from its capacity to utilize spatial information and nodes' local decision-making to direct packets to their intended locations. On the other hand, difficulties like erratic network topologies, impediments, or untrustworthy GPS systems can affect how effective the algorithm is, which could result in packet drops or less-than-ideal routing choices.3.1. EPSO-based Load Balancing with GPSR for Underwater Wireless Sensor Networks

3.1.1. EPSO Initialization:

First, a population of particles is initialized, each of which represents a possible set of relay nodes in the WSN. Similar to the possible relay node locations and motions, these particles are initialized with coordinates and velocities. The basis for later iterations, in which particles evolve according to their fitness, is laid by this initialization step, which is very important.

3.1.2. Fitness Calculation for Load Balancing:

Using load balancing metrics, the fitness evaluation phase determines whether the relay node set for each particle is appropriate. Calculations are made on metrics including energy consumption, traffic distribution, and node use. Fitness evaluation facilitates the identification of relay node sets that optimize data routing, improving network load balancing.

3.1.3. Position Update via EPSO Optimization:

The fundamental idea behind EPSO is the iterative updating of particle locations. Particle positions are updated during this procedure according to the global best-known position (gbest) among all particles as well as each particle's unique best-known position (pbest). By simulating the adaptive behavior of relay node selection in GPSR, these position updates guarantee that relay nodes adjust dynamically to fitness assessments.

3.1.4. Relay Node Selection based on EPSO Results:

The optimal particle or particle set with the most appropriate relay node configuration is determined based on the updated positions attained during the EPSO process. In order to identify the relay node sets that provide the most effective data routing paths, this selection takes into account the load balancing metrics that were previously assessed.

3.1.5. Leveraging GPSR for Data Packet Forwarding:

The GPSR routing technique is used for effective data packet forwarding after the relay nodes are chosen based on the EPSO's findings. GPSR leverages the placements of the relay nodes chosen by EPSO to inform packet forwarding decisions based on geographic information. This stage makes sure that data packets move through the network effectively by using routing based on geographic proximity.

3.1.6. Iterative Optimization and Adaptive Routing:

Iterations are used in the integration process. EPSO optimization is used to update particle positions throughout each iteration, and relay node selections are refined depending on fitness evaluations. Because iterative processes provide adaptive routing behavior, the network may adjust dynamically to changing traffic loads, node characteristics, and network conditions.

3.1.7. Convergence and Optimization Criteria:

When predetermined optimization requirements are satisfied, the EPSO-GPSR integration converges. Achieving convergence to a workable load balancing solution or reaching a maximum number of repetitions are two examples of these criteria. Convergence makes ensuring that the integrated system takes real-time flexibility and computing overhead into account while optimizing routing.

The seven procedures that are specified for integrating EPSO into GPSR for load balancing and effective routing in Underwater Wireless Sensor Networks (WSNs) are the exact emphasis of this comprehensive discussion. In dynamic WSN contexts, every step is critical to improving load balancing, selecting relay nodes optimally, and guaranteeing adaptive routing behavior—all of which increase network performance and resource consumption.

The Working Mechanism of EPSO – GPSR is presented in Algorithm 1.

IV. SIMULATION SETTINGS AND PERFORMANCE METRICS

The actual space where the sensor nodes are installed is indicated by the WSN, which spans an area of 1050 by 1100 meters. Twenty-five, fifty, seventy-five, and one hundred nodes are the different numbers of nodes used to analyze the existing and proposed protocols performance under various metrics. The performance, coverage, and resource usage of the network can be affected by this fluctuating node count. The power required by the sensor nodes to wirelessly send data packets to other nodes or the base station is 0.780 watts, or transmission power. The nodes' receiving power, which indicates how much power they need to receive data from other nodes or the base station, is 0.495 watts.

The quantity of data transported from one node to another or to the base station is 155 bytes, which is the size of a data packet transmitted inside the network. Compared to data packets, control packets, which are used for routing, synchronization, and network management, are smaller—only 40 bytes. The degree of data aggregation or compression utilized to lower the volume of transmitted data and aid in energy conservation is indicated by the aggregation ratio, which is set at 16%. Two joules are the starting energy level that each sensor node has, signifying the beginning energy reserve that is accessible for functions like processing, sensing, and communication.

These characteristics are essential to the architecture and functionality of WSNs. They are essential in deciding how well the network functions, how much energy it uses, how well it communicates, and how long the network will last in the designated region with the available number of nodes and energy limitations. Analyzing the network's performance in these various scenarios can reveal the best setups and tactics for effective WSN operation. Table 1 displays the settings for the simulation.

Table – 1: Simulation Settings

Area (n x m)	1050 X 1100
Number of Nodes	25, 50, 75, 100
Transmission power (W)	0.780
Receiving power (W)	0.495

Data packet size	155 bytes
Control packet size	40 bytes
Aggregation ratio	16%
Initial energy	2 joules

V. RESULTS AND DISCUSSIONS

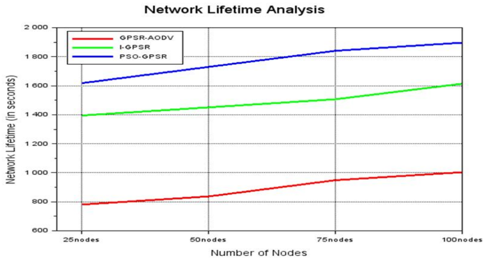

Fig.1. Number of Nodes Vs Network Lifetime

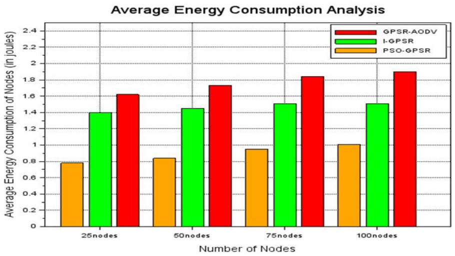

Fig.2. Number of Nodes Vs Average Energy Consumption of Nodes

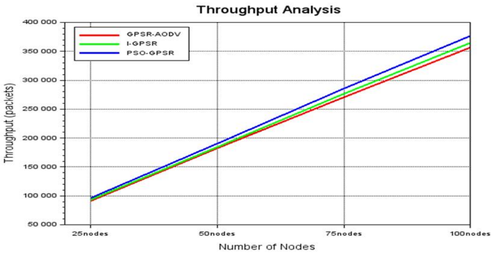

Fig.3. Number of Nodes Vs Throughput

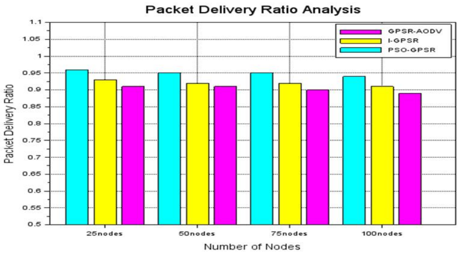

Fig.4. Number of Nodes Vs Packet Delivery Ratio

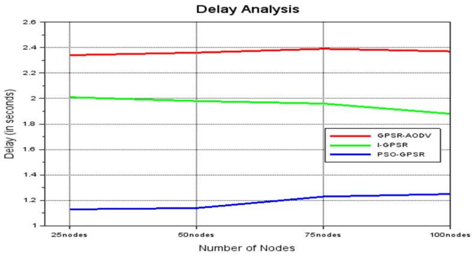

Fig.5. Number of Nodes Vs Delay

Table – 2: Overall Performance Analysis

Number of Nodes	Network Lifetime			Average Energy Conservation of Nodes			Throughput			Packet Delivery Ratio			Delay		
	GPSR-AODV [9]	I-GPSR [10]	EPSO-GPSR	GPSR-AODV [9]	I-GPSR [10]	EPSO-GPSR	GPSR-AODV [9]	I-GPSR [10]	EPSO-GPSR	GPSR-AODV [9]	I-GPSR [10]	EPSO-GPSR	GPSR-AODV [9]	I-GPSR [10]	EPSO-GPSR
25	781	1395	1619	1.62	1.40	0.79	91182	93186	96199	0.91	0.93	0.96	2.34	2.01	1.12
50	837	1451	1732	1.73	1.45	0.83	182364	184368	190388	0.91	0.92	0.96	2.36	1.98	1.13
75	949	1507	1844	1.84	1.51	0.94	270540	276552	285574	0.90	0.92	0.95	2.39	1.96	1.22
100	1004	1614	1899	1.90	1.51	1.02	356712	364728	376757	0.89	0.91	0.95	2.37	1.88	1.25

Fig.1. portrays the performance analysis in terms of network lifetime. The proposed EPSO-GPSR extended the network lifetime up to 25% when compared with the existing routing schemes / protocols. Fig.2. presents the performance analysis in terms of average energy consumption of nodes. It is evident that around 29% of energy consumption is reduced by the proposed EPSO-GPSR. Fig.3. depicts performance analysis in terms of throughput. It is obvious to notice that the throughput is consistently increased even while increasing the number of nodes in the wireless sensor network terrain region. Fig.4. shows the performance analysis in terms of packet delivery ratio. It can be easily understood that when the throughput increases obviously packet delivery ratio will also increase. By that way, the proposed EPSO-GPSR obtained better packet delivery ratio. Fig.5. presents delay analysis performance. In general, delay will be caused by several reasons including packet lifetime, network lifetime, efficacy of the protocol. Likewise, the proposed EPSO-GPSR incurred lesser delay and it reduces up to 39% when compared to the existing routing schemes / protocols. The overall numerical data of the obtained results are presented in Table 2.

VI. CONCLUSION

In conclusion, a potential method for load balancing and effective data transmission in Underwater Wireless Sensor Networks (WSNs) is the combination of Enhanced Particle Swarm Optimization (EPSO) and Greedy Perimeter Stateless Routing (GPSR). This combination makes use of EPSO's optimization powers to dynamically adjust network load and improve routing, while GPSR's geographic routing reduces overhead and efficiently makes use of node position data.

The network's performance is greatly increased in terms of decreased energy consumption, minimized latency, higher packet delivery ratio, and improved scalability by using this hybrid EPSO-GPSR technique. By dispersing traffic loads throughout the network and optimizing the choice of relay nodes, the EPSO algorithm not only reduces congestion but also increases the lifetime of the network by more evenly dividing energy consumption among the nodes.

Additionally, the use of GPSR for geographic routing guarantees effective packet forwarding based on location data, which lessens the requirement for large routing tables and control overhead. This makes it possible for the network to adjust to sudden changes in topology and outside factors, guaranteeing dependable and effective data transfer

VII. FUTURE SCOPE OF RESEARCH

To examine and address potential constraints or obstacles, such as scalability issues in bigger networks, adaptability to various environmental conditions, and the influence of node failures on the overall operation of the network, more investigation and testing are necessary. However, the EPSO-GPSR technique offers significant gains in effectiveness, dependability, and network performance, making it a viable option for load balancing and geographic routing in Underwater Wireless Sensor Networks.

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