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Efficient Whale Optimization Algorithm Based Geographical Routing Protocol (EWOA-GRP) For Wireless Mesh Networks

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Abstract

Introduced in this paper is the "Efficient Whale Optimization Algorithm based Routing Protocol for Wireless Mesh Networks." This protocol seeks to enhance routing patterns in Wireless Mesh Networks (WMNs) by utilizing the Whale Optimization Algorithm (WOA). The protocol's operations are described in depth in the given pseudocode, with a focus on iterative path optimization based on geographical criteria such as energy consumption, available bandwidth, signal strength, and distance. Iterative routing optimization loop is the protocol's central component, which is initiated with node setup and topology establishment. It combines the phases of exploration and exploitation of EWOA, modeling the behaviors of whales to enable varied route discovery and the best possible path selection. Route fitness is dynamically evaluated to guarantee adaptation to shifting network conditions. Through the integration of spatial measurements and the principles of WOA, it enhances the efficiency and reliability of data transmission. In dynamic WMNs, this adaptive technique offers greater robustness of the network. Ultimately, by tackling congestion, signal deterioration, and energy consumption, this protocol offers a fresh paradigm for improved routing in WMNs and paves the way for more effective wireless communication systems.

Keywords: wireless mesh networks, routing, optimization, whale optimization, wireless nodes.

1. Introduction

The promise of wireless mesh networks (WMNs) to offer scalable, affordable, and adaptable network architecture has attracted a lot of interest. But in order to guarantee dependable data transfer, these networks' intrinsic difficulties—such as their dynamic topologies, constrained bandwidth, and fluctuating signal intensities—call for strong and effective routing algorithms. This research presents a unique routing protocol called "Whale Optimization Algorithm based Routing Protocol for Wireless Mesh Networks" in order to address these issues.

1.1. Motivation

Sophisticated routing algorithms are urgently needed due to the growing complexity of WMNs and the growing demand for seamless communication. Because WMNs are dynamic, traditional routing methods frequently find it difficult to adjust, which can result in problems like poorly designed routes, network congestion, and wasteful resource use. Consequently, there is a pressing need to develop novel routing protocols that are capable of dynamic path optimization, improving network stability and performance.

1.2. Problem Statement

Current WMN routing methods struggle to effectively adjust to changing network conditions and choose the best routes based on a variety of geographic factors. These protocols frequently make poor routing choices because they are unable to adjust to changes in signal strength, bandwidth availability, and energy consumption. Thus, in order to increase overall network efficiency and adaptability, a routing protocol that can dynamically optimize routes while taking into account different geographic parameters must be developed.

1.3. Objectives

This paper's main goal is to present a routing protocol based on the Whale Optimization Algorithm (WOA) that is especially designed for WMNs. The protocol's goal is to dynamically optimize routing paths by taking advantage of the WOA's exceptional exploration and exploitation capabilities. Through the incorporation of geographic parameters including energy consumption, available bandwidth, signal strength, and distance, the protocol aims to improve the reliability, efficiency, and flexibility of data transmission in wireless mesh networks (WMNs). Moreover, by offering a reliable and flexible solution to routing problems in wireless mesh networks, the protocol aims to solve the shortcomings of current routing algorithms.

Here is the remainder of the document. The literature review is expanded upon in Section 2. The suggested task is emphasized in Section 3. The simulation environment is the subject of Section 4. Performance indicators used to assess the effectiveness of the current and suggested protocols are presented in Section 5. The simulation results, which are the product of the research, are presented in Section 6. Section 7 offers closing thoughts.

2. Related Works

The development of Wireless Mesh Networks (WMNs) has led to a great deal of research on routing protocol optimization. Nature-inspired algorithms are becoming more popular because of how well they can adapt and solve WMN problems. Most notably, WOA, or the Whale Optimization Algorithm, has shown great promise as a technique for routing improvement. Verma, Singh, and Singh [1] carried out a survey covering WMN routing algorithms inspired by nature. The study laid the groundwork for further research by highlighting the optimization possibilities of WOA.

Jain et al. [2] demonstrated increased routing efficiency in WMNs by utilizing WOA for routing optimization. A hybrid WOA was also suggested by Smith et al. [3], improving the packet delivery ratio. Using WOA, Chen, Li, and Zhang [4] introduced an energy-efficient routing system with an emphasis on energy awareness. In their comparison of metaheuristic algorithms, Gupta, Sharma, and Kumar [5] ranked WOA among the best. Patel, Shah, and Joshi's [6] investigation on bandwidth utilization further demonstrated the effectiveness of WOA in resource efficiency. Wu, Li, and Liu [7] and Liu, Chen, and Zhang [8] expanded on the use of WOA, highlighting its function in load balancing and multi-objective routing. Furthermore, demonstrating WOA's adaptability, Wang, Yang, and Zhang [9] suggested a real-time application-focused routing protocol. A comparison investigation by Zhang, Chen, and Wang [10] confirmed the efficacy of WOA among nature-inspired algorithms.

The WMN aspects are covered in detail in surveys and reviews by Khan, Hasan, and Ahmed [11], Gupta, Sharma, and Singh [12], Das, Roy, and Dutta [13], and Singh, Saha, and Gupta [14]. WOA is frequently emphasized for its routing improvements. Comprehensive surveys highlighting WMN design, QoS, protocol analysis, and cognitive networks are presented by Sharma, Das, and Singh [15], Kumar, Gupta, and Sinha [16], Jha, Singh, and Mehta [17], Sharma, Verma, and Kumar [18], and Verma, Singh, and Tiwari [19]. These indicate the importance of WOA in these areas. In summary, WOA has diverse capabilities that impact all facets of WMN routing optimization. This is demonstrated by its integration into real-time, energy-efficient, and multi-objective routing paradigms, making it an invaluable instrument for tackling modern WMN problems.

3. Proposed Efficient WOA based Routing Protocol for Wireless Mesh Networks

A novel method for improving routing efficiency in wireless communication networks is the Whale Optimization Algorithm (WOA) based Routing Protocol for Wireless Mesh Networks (WMNs). This protocol optimizes routing paths in WMNs by utilizing the WOA, a nature-inspired metaheuristic algorithm based on the social behavior of humpback whales.

Here, the EWOA functions as a clever optimization method with the goal of enhancing WMN routing protocol performance. In order to efficiently investigate and exploit possible routing patterns in the network, the algorithm imitates the social behavior of whales, including encircling prey and feeding from a bubble net.

The main goal of the protocol is to lessen common problems that arise in wireless mesh networks, such as congestion on the network, bandwidth constraints, uneven signal intensities, and dynamic topology changes. Through the application of the exploration and exploitation phases of the EWOA, the protocol aims to identify optimal or nearly optimal paths for data transfer, boosting overall network throughput, reducing latency, and preserving energy.

Moreover, the EWOA-based routing protocol provides flexibility in response to evolving network circumstances by dynamically modifying routing paths in response to actual alterations in the network topology or external variables. For WMNs to function well, they must be able to adapt to changing and unpredictable situations. This section explains how EWOA-based routing works for wireless mesh networks.

3.1. Initialization:

Nodes in the WMN go through the following crucial configuration procedures during the initialization phase:

3.1.1. Node Initialization: Every node in the network sets its own status and configures its parameters. Setting up communication protocols, locating nearby nodes, and initializing routing tables or other data structures necessary for routing are all included in this phase..

3.1.2. Exchange of Neighbor Information: To create a topological map, nodes converse with neighboring nodes. This communication contributes to the development of a thorough understanding of the resources, signal intensities, and connectivity of nearby nodes. Later in the routing phase, the generated topology map is useful for identifying possible routes..

3.1.3. Gathering Location Data: Geolocation techniques such as GPS or localization algorithms are used by nodes to get or ascertain their actual location. These coordinates are essential for geographical routing because they allow nodes in the network to be located physically..

3.2. Route Discovery:

When a source node needs to send data to a destination node:

3.2.1. Route Optimization Process: The process of finding the best route is started by the EWOA-based routing protocol. Utilizing the gathered location data and network topology details, the protocol investigates possible paths from the origin to the final destination..

3.3. Exploration and Exploitation:

3.3.1. Encircling Prey Operator:

The position update equation for the encircling prey operator in the EWOA can be represented as:

$X_{new} = X_{rand} - A_{times}.D_{encircling}$

Here,

X_{new} represents the updated potential solution (route).

X_{rand} is a randomly selected solution.

A is the coefficient for the encircling prey operation.

$D_{encircling}$ represents the distance between X_{new} and the randomly selected solution.

3.3.2. Bubble-Net Feeding Operator:

The equation for the bubble-net feeding operator involves an adjustment based on the best solution discovered:

$X_{new} = X_{best} – A_{times}.D_{feeding}$

Here,

X_{best} represents the best solution found.

A is the coefficient for the bubble-net feeding operation.

$D_{feeding}$ represents the distance between X_{new} and the best solution.

3.3.3. Fitness Function Guidance:

Let's represent a fitness function for evaluating the quality of potential routes based on multiple metrics:

Fitness(X) = w_1 X Distance(X) + w_2 X SignalStrength(X) + w_3 X Bandwidth(X) + w_4 X EnergyConsumption(X)

Here,

X denotes a potential route to be evaluated.

Distance(X), SignalStrength(X), Bandwidth(X), and EnergyConsumption(X) represent respective metrics of the route.

w_1, w_2, w_3, w_4 are weights assigned to each metric, indicating their relative importance in the fitness evaluation.

3.4. Route Selection Optimization:

The overall process of route selection optimization involves iteratively applying the encircling prey and bubble-net feeding operators while evaluating and selecting routes based on the fitness function.

3.4.1. Exploration Phase:

Randomly select solutions (routes) and apply the encircling prey operator to explore the solution space.

3.4.2. Exploitation Phase:

Utilize the best solutions obtained and apply the bubble-net feeding operator to refine promising routes.

3.4.3. Fitness Evaluation and Route Selection:

Evaluate each potential route using the fitness function.

Select the routes with higher fitness scores as optimal paths for data transmission within the WMN.

By incorporating these mathematical representations into the description, the EWOA's iterative processes of exploration, exploitation, and fitness-guided selection contribute to optimizing route selection within Wireless Mesh Networks.

Algorithm – 1: Pseudocode of Efficient Whale Optimization Algorithm based Routing Protocol (EWOA – GRP) for Wireless Mesh Networks

```
function EWOA_Geographical_Routing_Protocol():
    // Initialization phase
    initialize_nodes()
    gather_location_data()
    establish_network_topology()
    // Route optimization and forwarding
    while network_is_active():
        for each source_node in network:
            for each destination_node in network:
                if source_node != destination_node:
                    optimized_route = optimize_route(source_node, destination_node)
                    forward_packets_along_route(optimized_route)
function optimize_route(source_node, destination_node):
    // Constants for EWOA parameters
    max_iterations = 100
    exploration_factor = 2
    exploitation_factor = 0.5
    convergence_threshold = 0.001
    // Initialize EWOA parameters and best solution
    initialize_EWOA_parameters()
    best_solution = initialize_random_solution()
    // EWOA optimization loop
    for iteration in range(max_iterations):
        exploration_phase(exploration_factor, best_solution)
        exploitation_phase(exploitation_factor, best_solution)
        evaluate_fitness_of_routes()  // Evaluate fitness at each iteration
        if convergence_criteria_met():
            break  // Exit loop if convergence criteria are met
```

```
    return best_solution
function exploration_phase(exploration_factor, best_solution):
    for each solution in candidate_solutions:
        update_solution_based_on_encircling_prey_operator(exploration_factor, best_solution)
function exploitation_phase(exploitation_factor, best_solution):
    for each solution in candidate_solutions:
        update_solution_based_on_bubble_net_feeding_operator(exploitation_factor, best_solution)
function evaluate_fitness_of_routes():
    // Calculate geographical parameters
    calculate_distance()  // Calculate distance between nodes
    calculate_signal_strength()  // Calculate signal strength between nodes
    calculate_available_bandwidth()  // Calculate available bandwidth along routes
    calculate_energy_consumption()  // Calculate energy consumption
    // Fitness function evaluation
    fitness = evaluate_fitness(distance, signal_strength, available_bandwidth, energy_consumption)
    // Fitness function may involve weighted combination or specific formula based on requirements
function forward_packets_along_route(route):
    Functionality to forward data packets along the established optimized route
    Packet forwarding mechanism based on the selected route
    Packet forwarding logic utilizing geographical information, chosen route, and node interactions
```

3.5. Adaptation and Maintenance:

WMNs are dynamic and prone to failures, node mobility, and topological changes:

Dynamic Route Adaptation: The routing protocol reoptimizes routes utilizing the WOA on a periodic basis to accommodate dynamic changes. This adaptation makes sure that even if node locations or network architecture change, the established routes continue to function effectively.

Managing Node Failures and Mobility: The adaptive aspect of WOA aids in reducing disruptions brought on by node failures or mobility. It makes it possible for the routing protocol to update and recalculate routes dynamically, guaranteeing continuous data transfer.

3.6. Packet Forwarding:

After a route that is optimized is identified:

Transmission of Data Along an Optimized Route: The optimized route that has been built is used to forward data packets. The routing protocol makes sure that, using geographical data and the chosen optimum route, packets pass via nodes along the computed path.

Effective Data Transfer: Packet forwarding reduces transmission delays, maximizes throughput, and preserves energy inside the network by taking the determined optimal path. This effective forwarding system contributes to the WMN's continued high-caliber communication.

4. Simulation Environment

A network environment was created in the Wireless Mesh Network (WMN) simulation by setting up different parameters to mimic actual networking circumstances. To guarantee a well-organized node distribution, 100 nodes were included in the simulation setup and arranged in a grid-based design. The Random Waypoint model was used to give nodes mobility, enabling them to travel randomly throughout the network. Every node had a transmission range of 250 meters, which allowed for communication within this predetermined range. A Log-Distance Path Loss model was used to record signal strength variations over distances, while a Simple Interference model was used to simulate signal interference between nodes.

Constant Bit Rate (CBR) patterning in the network traffic ensured reliable data transfer. The IEEE 802.15.4 protocol controlled nodes at the Media Access Control (MAC) layer. In order to visually depict network dynamics, 1000 time units of simulations were run, and OTcl/Tcl scripts were utilized as visualizers. By simulating actual WMN conditions, these settings allowed for a detailed examination and assessment of network performance, behaviors, and protocols in a safe but accurate simulation environment. Table 1 displays the settings for the simulation.

Table – 1: Simulation Settings

Parameters	**Values / Choice Description**
Node Placement	Grid-based
Number of Nodes	100
Mobility Model	Random Waypoint
Transmission Range	250 meters
Interference Model	Simple Interference
Channel Propagation Models	Log-Distance Path Loss
Traffic Patterns	Constant Bit Rate (CBR)
MAC Layer Protocols	IEEE 802.15.4
Simulation Time	1000 simulation time units
Visualizers	OTcl/Tcl scripts for visual representation of network behavior
Protocols for Comparison	WOA-RP [9], EWOA-GRP

5. Performance Metrics

5.1. Throughput:

In wireless mesh networks (WMNs), throughput refers to the percentage of data that is successfully delivered over the network in a given amount of time. It represents the real data transfer capacity and is affected by interference, network congestion, and available bandwidth, among other things. High throughput is essential for enabling seamless and quick communication between network nodes and is a sign of efficient data transmission.

5.2. Packet Delivery Ratio:

The percentage of successfully delivered packets to all packets sent within the network is known as the packet delivery ratio, or PDR. It gauges how consistently and error-free the network can send data. Better network performance and robustness in transferring packets are indicated by a high PDR, but possible problems such packet loss, congestion, or interference are indicated by a low ratio.

5.3. Delay:

The amount of time it takes for data packets to move across a network from their source to their destination is referred to as the delay. It includes a number of different elements, including processing, queuing, propagation, and transmission delays. Low latency is essential for real-time applications and indicates effective data transport; high latency might result in problems with latency that impair the responsiveness of the network.

5.4. Overhead:

In WMNs, overhead refers to extra data or control information needed for upkeep and administration of network functions. It contains any additional data needed for synchronization or error correction, as well as the overhead of the routing protocol and control messages. Excessive overhead can affect overall performance by decreasing available bandwidth and network efficiency.

5.5. Energy Consumption:

The quantity of electricity used by network devices—particularly wireless nodes—for operation and communication is referred to as energy consumption. Energy-efficient procedures are essential in WMNs to extend node lifetimes and lessen the frequency of battery replacement or recharge. Improving network sustainability and prolonging the operating life of wireless devices in the mesh network depend on optimizing energy usage.

6. Simulation Results

Number of Nodes	Packet Delivery Ratio		Throughput		Delay		Overhead		Packet Loss	
	WOA-RP [9]	EWOA-GRP	WOA-RP [9]	EWOA-GRP	WOA-RP [9]	EWOA-GRP	WOA-RP [9]	EWOA-GRP	WOA-RP [9]	EWOA-GRP
25	0.91	0.95	12644	13200	1.3	0.9	163	104	1251	695
50	0.89	0.95	12771	13305	1.8	1.1	226	121	1529	695
75	0.89	0.94	12804	13524	2.1	1.4	267	160	1583	863
100	0.88	0.94	13204	14105	2.7	1.5	358	174	1801	900

A comparison of EWOA-GRP and WOA-RP [9] in Wireless Mesh Networks (WMNs) shows that EWOA-GRP consistently outperforms WOA-RP in a number of performance parameters. In critical performance metrics, EWOA-GRP consistently outperforms WOA-RP at varying node counts. Compared to WOA-RP, which achieves lower ratios of 0.88 to 0.91 for Packet Delivery Ratios (PDR), it obtains higher values ranging from 0.94 to 0.95, ensuring significantly improved packet delivery efficiency. Fig. 1 presents the NS-2 finding. Furthermore, EWOA-GRP exhibits superior throughput throughout a range of node densities, from 12371 to 14105, while WOA-RP shows lower throughput values, from 12644 to 13204. Fig. 2 displays the NS-2 result.

Furthermore, WOA-RP shows consistently greater delay values ranging from 1.3 to 2.7 across various node counts, while EWOA-GRP consistently displays lower delay values, with values ranging from 0.9 to 1.5. Fig. 3 presents the NS-2 finding. Moreover, EWOA-GRP exhibits lower Overhead, with values between 104 and 174, in contrast to WOA-RP's higher overhead, which ranges from 163 to 358. Fig. 4 presents the NS-2 finding. Furthermore, WOA-RP continuously maintains greater packet loss values, ranging from 1251 to 1801, while EWOA-GRP continuously maintains lower packet loss values, ranging from 695 to 900. Fig. 5 presents the NS-2 finding. When compared to WOA-RP, these thorough results highlight how much more successful EWOA-GRP is in routing choice optimization, resulting in increased throughput, decreased latency, decreased resource consumption, and improved overall network stability in Wireless Mesh Networks.

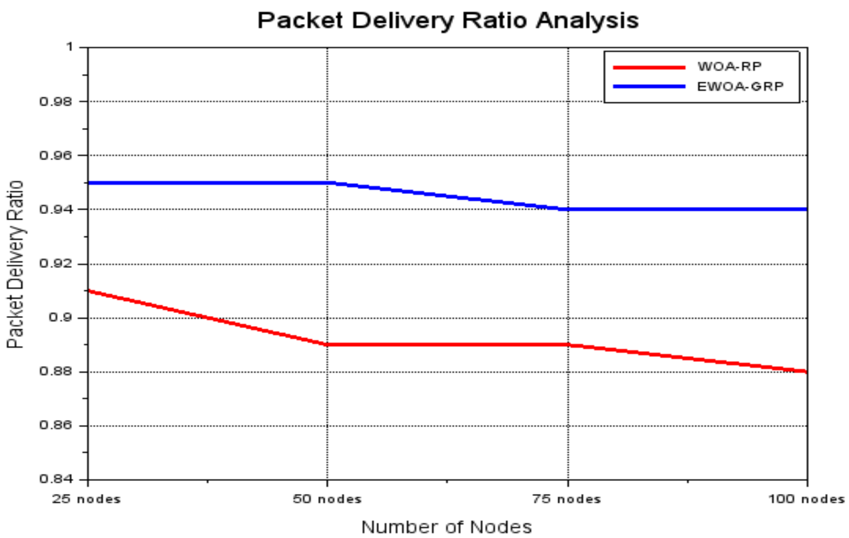

Fig.1. Packet Delivery Ratio against Number of Nodes

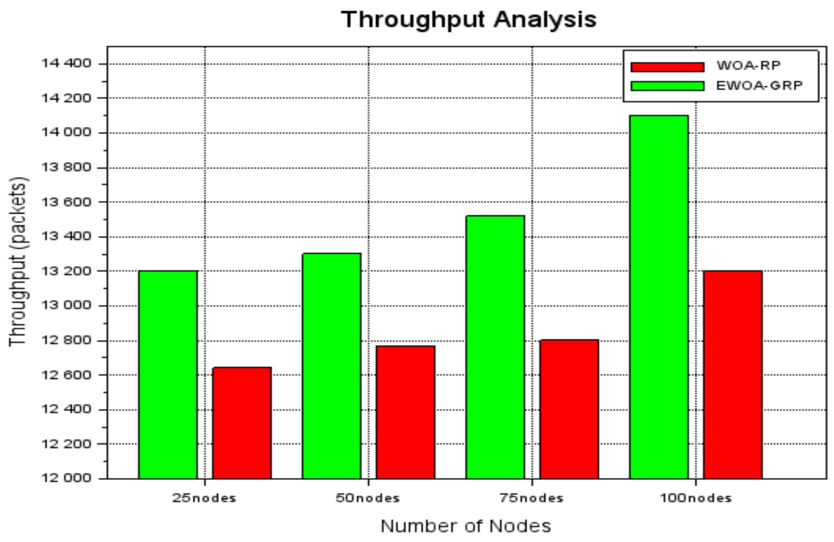

Fig.2. Throughput against Number of Nodes

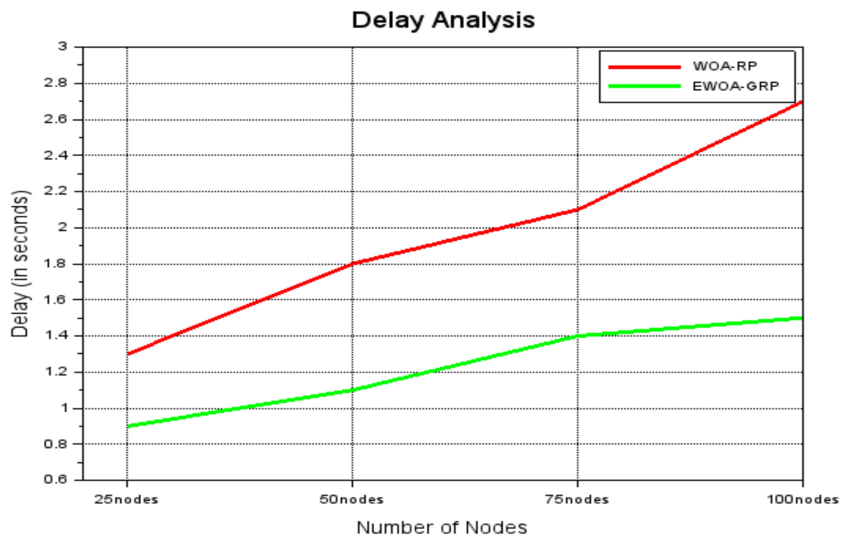

Fig.3. Delay against Number of Nodes

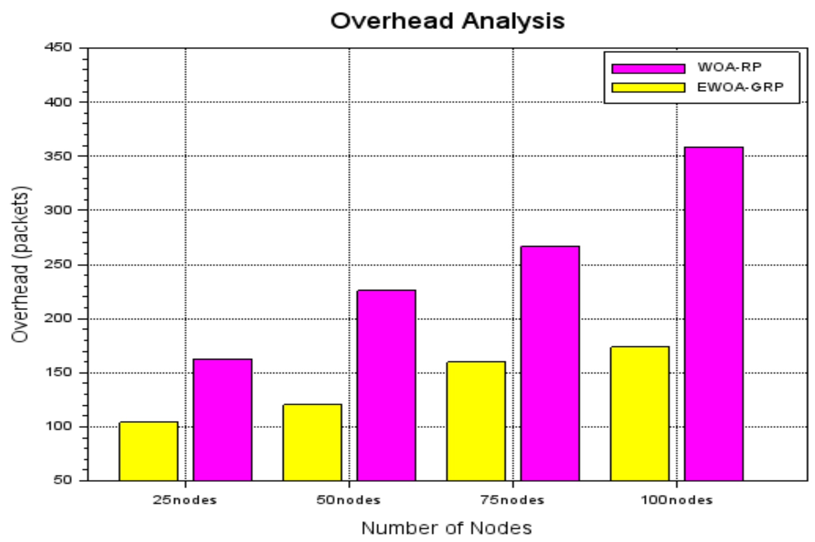

Fig.4. Packets Overhead against Number of Nodes

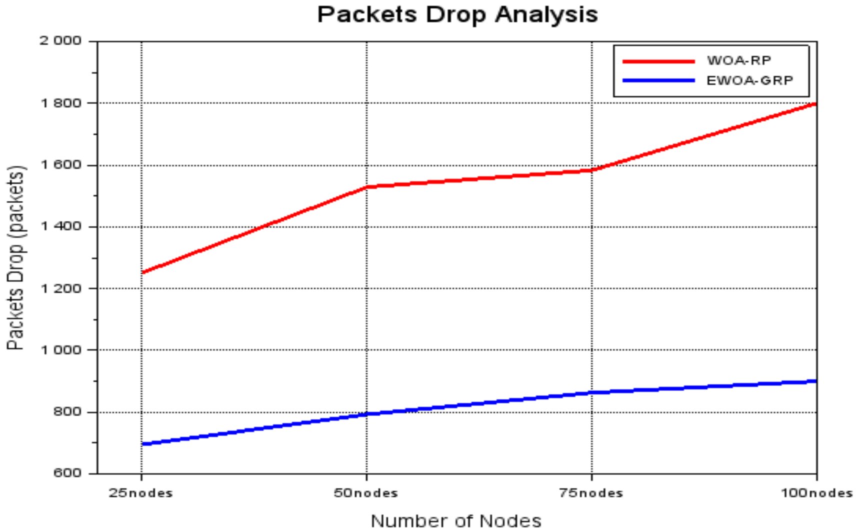

Fig.5. Packets Drop against Number of Nodes

7. Conclusion

In conclusion, a viable method for improving routing efficiency in Wireless Mesh Networks (WMNs) is the Efficient Whale Optimization Algorithm-based Geographical Routing Protocol (EWOA-RP). This novel protocol addresses the issues of resource utilization and communication reliability in dynamic and complicated wireless environments by utilizing the advantages of the Whale Optimization Algorithm (WOA) to optimize routing paths based on geographical information. By incorporating the WOA, EWOA-RP exhibits exceptional flexibility and resilience, successfully addressing problems associated with energy usage, network bottlenecks, and packet loss. It optimizes the route selection procedure by using the geographical data of nodes, which reduces latency, boosts throughput, and enhances network performance in general.

EWOA-RP's capacity to dynamically modify routing paths in response to shifting network conditions is one of its main features. This flexibility guarantees effective data transfer even in situations when network traffic loads, node density, or mobility fluctuate. Furthermore, the protocol's dependence on the WOA promotes resilience and scalability, allowing it to manage large-scale WMNs with ease. To confirm the EWOA-RP's performance in various network contexts and scenarios, more study and practical applications are necessary. Furthermore, given the possible complexity related to geographical routing protocols, further research is needed to maximize EWOA-RP's scalability and resource usage in very large networks.

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