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Enhanced Whale Optimization Algorithm for Multi-Objective Node Disjoint Routing

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Abstract

Objectives: The research goal is to identify node-disjoint pathways maximizing path lifetime, delivery ratio, etc. while establishing several node-disjoint paths to optimize routing and enhance interference reduction and PDR efficiency. **Methods:** In the MANET, the Enhanced Whale Optimization Algorithm (EWOA) is utilized to discover the most secure routing path. The dataset used in this research comprises simulated scenarios representing various network conditions and configurations, allowing for a comprehensive evaluation of the proposed work. The software employed for simulation and analysis includes an NS-3 network simulation tool, allowing the model to evaluate the performance of the proposed routing protocol in diverse MANET scenarios. The parameters considered during the evaluation include throughput, end-to-end delay, packet delivery ratio (PDR), and routing overhead. The modifications involve enhancing the routing algorithm to prioritize node-disjoint pathways, thus improving interference reduction, energy efficiency, and overall network performance. **Findings:** The EWOA for Multi-Objective Node Disjoint Routing demonstrates superior performance compared to existing routing protocols such as SRABC and OLSR across various key metrics. Specifically, in terms of end-to-end delay, EWOA consistently outperforms SRABC and OLSR by reducing delay by 1.3% and 4.7%, respectively. Additionally, EWOA achieves a higher packet delivery ratio, surpassing SRABC and OLSR by 4.3% and 0.4%, respectively. Moreover, EWOA exhibits higher throughput, with a throughput increase of 11.3% compared to SRABC and 6.2% compared to OLSR. Furthermore, EWOA demonstrates lower routing overhead, reducing overhead by 9.6% compared to SRABC and 3.1% compared to OLSR. These findings highlight the efficacy of EWOA in optimizing multi-objective routing in MANETs, offering improved network performance and efficiency compared to existing protocols. **Novelty:** The Multi-Objective Node Disjoint Routing Protocol with Enhanced Whale Optimization is utilized in MANET to choose the best route, reducing latency resulting from link failure and distributing traffic loads across multiple paths.

Keywords: Optimization; Whale Optimization Algorithm (WOA); Optimized Link State Routing (OLSR); Secure Routing Algorithm Blockchain Technology (SRABC)); MANET

1 Introduction

Mobile Ad hoc Networks (MANETs) have emerged as critical tools for disaster and emergency communication management, offering unparalleled utility in scenarios where traditional infrastructure networks, such as telecom networks, are compromised or unavailable due to natural disasters like earthquakes, floods, cyclones, landslides, or conflict situations. MANETs provide a resilient solution by enabling the establishment of ad hoc networks that facilitate uninterrupted data collection, thereby ensuring the reliability of crucial information during rescue operations. Unlike traditional networks, MANETs operate without centralized administration, consisting of mobile nodes capable of dynamically forming connections among themselves [1]. These nodes, equipped with wireless communication capabilities, create a self-organizing network where communication is established through direct wireless links. Nodes within proximity communicate directly, while communication beyond their range is facilitated through intermediate nodes, forming a hop-by-hop path to relay information effectively [2]. This inherent flexibility and adaptability make MANETs a practical and indispensable solution for disaster scenarios, where rapid deployment and reliable communication are paramount for effective response and coordination efforts.

Developing efficient MANET routing protocols presents a significant challenge due to the inherent limitation of energy resources in mobile nodes. These protocols play a crucial role in optimizing energy consumption while ensuring reliable real-time communication in MANETs. Mobile nodes within MANETs face heightened power consumption and rapid battery drainage, exacerbated by factors such as decentralized coordination and the dynamic nature of the network environment [3]. Thus, achieving energy-efficient routing in MANETs is imperative, even amidst frequent changes induced by node mobility, interference, hidden terminal issues, and node failures. In a MANET, each mobile node establishes communication through multi-hop wireless connections with other nodes, with every node serving as a relay for data transmission. However, this decentralized routing paradigm can lead to network congestion and overload, particularly when intermediate nodes are unable to handle traffic beyond their capacity [4,5]. Consequently, optimizing routing strategies to alleviate congestion and efficiently manage energy consumption becomes paramount for the seamless operation of MANETs, especially in resource-constrained environments.

The research in routing protocols for MANETs has witnessed notable advancements, yet certain shortcomings persist, particularly in optimizing node-disjoint pathways for improved energy efficiency, network durability, and overall performance. Existing routing algorithms often fall short in at the same time enhancing multiple objectives such as path-lifetime, delivery ratio, and interference reduction. The existing works in the field have limited capability of routing protocols to consider multiple objectives simultaneously, resulting in suboptimal trade-offs and compromised network performance. Current challenges include the need for routing solutions that address energy consumption, latency, packet delivery ratio, and route longevity comprehensively. The evolving nature of MANETs and their increasing role in various applications underscore the urgency for a robust routing algorithm capable of handling these complex, multifaceted challenges.

The Whale Optimization Algorithm (WOA) is gaining increasing attention from the scientific community as an outstanding remedy to numerous optimization problems. The optimal way to solve complicated issues is increasingly being found by using meta-heuristic algorithms. To accurately mimic these operators, the Whale Algorithm makes use of three directed operators, a collection of random variables, and a variety of humpback whale hunting strategies. Finding answers to issues with route longevity during data transmission from source to destination is the main objective of this endeavor. The challenges of source-to-destination route lifetime consideration have not been effectively addressed by any method in the recent past. If the route lifetime is ignored, congestion and packet loss will occur. Whale Optimization, a meta-heuristic technique, is proposed as a solution to this problem. The suggested method accounts for connection failures by using the node-disjoint route. Figure 1 illustrates the workflow of the proposed system. All the abbreviations used in this work are mentioned in Table 1.

Contributions made by the work are:

- The work proposed Enhanced Whale Optimization Algorithm (WOA) to addresses the critical challenge of multi-objective optimization in MANETs, particularly focusing on node-disjoint routing. By enhancing the traditional WOA with novel strategies, the algorithm effectively balances multiple conflicting objectives such as network lifetime, path longevity, and end-to-end latency simultaneously, thereby improving the overall efficiency and adaptability of communication in dynamic ad hoc networks.
- The enhanced WOA introduces robust mechanisms to handle the dynamic nature of MANETs, ensuring resilience against network fluctuations and node failures. By incorporating adaptive features, the algorithm dynamically adjusts routing decisions based on real-time network conditions, thus improving the reliability and adaptability of node-disjoint routing in varying environments.
- In addition to its efficacy in optimizing routing objectives, the Enhanced WOA offers computational efficiency, making it suitable for practical implementation in resource-constrained MANETs. By leveraging optimized search strategies and fine-tuned parameters, the algorithm achieves optimal routing solutions with reduced computational overhead, facilitating seamless integration into existing MANET infrastructures.

2 Literature Review

In recent years, the optimization of Mobile Ad hoc Networks (MANETs) has been the subject of intense research due to their dynamic and resource-constrained nature. Various algorithms and techniques have been proposed to address challenges such as energy efficiency, routing efficiency, and network security. This literature review synthesizes key contributions in this field, focusing on recent advancements and their implications.

[6] Introduced a blockchain-assisted secure swarm intelligence routing protocol for MANETs, addressing the challenges of node supervision and security in decentralized communication environments. The protocol integrates multiple processes including BLAKE-3 hashing for authentication, rewards-optimized deep Q-learning for clustering, particle-swarm optimization for priority-based routing, and blockchain-based SALSA 20 encryption for packet sensitivity calculation. However, the method's performance is constrained by limited resources and bandwidth.[7] Proposed an efficient video transmission method in MANETs utilizing clustering and optimization techniques. The study employed Discrete Wavelet Transform (DWT) for frame decomposition and Stream Control Transmission Protocol (SCTP) multi-streaming for video transmission. Clustering was executed using the Enhanced Fuzzy C-Means (EFCM) algorithm, while the Enhanced Cuckoo Search (ECS) optimization algorithm facilitated optimal path selection for video stream transmission. Simulation analysis demonstrated improved performance metrics such as delivery ratio, delay, energy consumption, throughput, and overhead, with varying node numbers and transmission rates.

[8] Introduced an enhanced routing protocol by integrating an optimized multi-protocol router (MPR) and DYDOG for secure video transmission in MANETs. This hybrid approach optimizes energy utilization and reduces delays in the Optimized Link State Routing (OLSR) protocol, ensuring secure video streaming. By analyzing various malicious attack nodes and employing encryption techniques like digital signature and AES, the protocol enhances node mobility and promotes security. Simulation results demonstrate the effectiveness of these enhancements in securing video transmission in MANETs.[9] Presents a novel multipath routing approach based on Multi-Hop Routing (MHR), crucial for successful data transmission in MANETs. The research comprises three phases: Priority Dynamic Routing (PBDR) aims to mitigate Node Link Failures (NLF) by dynamically considering node mobility parameters, outperforming traditional protocols. Improved Multi-Path Dynamic Routing (IMPDR) focuses on enhancing Quality of Service (QoS) by introducing QoS timers and considering distance, linkability, trust, and QoS for next-hop selection.

A fuzzified Particle Swarm Optimization oriented Routing (FPSOR) algorithm is proposed,[10] aiming to minimize data loss and maximize MANET lifetime by optimizing energy-efficient routes. By integrating fuzzification techniques with Particle Swarm Optimization, FPSOR selects paths with lower energy consumption, evaluated through fitness values, enhancing overall routing efficiency in IoT-enabled MANETs. Performance evaluation is conducted using the NS2 simulator. The proposed algorithm's performance heavily relies on accurate energy level estimations and may suffer from inaccuracies in assessing node energy states, especially in large-scale networks.[11] Introduced F-CAPSO (Fuzzy Chaos Adaptive Particle Swarm Optimization), a novel method designed to improve energy efficiency and data transmission security in MANETs. By integrating routing and clustering processes, F-CAPSO selects optimal Cluster Heads (CH) using the Fuzzy-based CAPSO algorithm and employs SSARM-SCA (Salp Swarm Algorithm with Replacement Method and Sine Cosine algorithm) for routing optimization and data security. Despite promising results in performance metrics like throughput and network lifetime, the approach's limitations lie in scalability concerns and potential overhead associated with trust-based encryption strategies. Further validation in real-world scenarios is necessary to assess its practical applicability.[12] Introduced a Hybrid Whale Optimization Algorithm tailored for enhancing the routing efficiency of limited capacity vehicles in supply chain management, aiming to optimize transportation logistics. While this approach shows promise in improving routing efficiency, it may encounter limitations in scalability when dealing with a large number of vehicles or complex supply chain networks. Additionally, the algorithm's effectiveness may be impacted by the variability and unpredictability inherent in real-world supply chain environments.[13] Proposed a Dynamic Spiral Updating Whale Optimization Algorithm specifically designed for solving the optimal power flow problem, contributing to the optimization of power systems. Despite its potential benefits in optimizing power flow, this algorithm may face challenges in accurately modeling and adapting to dynamic changes in power grid conditions. Furthermore, its applicability to large-scale power systems with diverse generation sources and demand patterns remains to be fully explored.[14] Investigated the application of Whale Optimization and Lion Optimization algorithms for optimal routing in Wireless Sensor Networks (WSNs), focusing on improving communication efficiency and network performance. While this research highlights the potential of nature-inspired algorithms in WSN routing, there may be limitations in the scalability and adaptability of these algorithms to dynamic WSN environments. The use of the Guided Whale Optimization Algorithm (GWOA) to enhance network security in MANETs, addressing multiobjective optimization challenges[15], shows promise in improving security in MANETs. However, its effectiveness may be limited by the need for accurate guidance mechanisms and the potential vulnerability to sophisticated security threats. Multi-Objective Energy Efficient Adaptive Whale Optimization Based Routing for Wireless Sensor Networks[16] aims to optimize energy consumption and enhance routing efficiency in sensor networks. While this approach offers potential benefits in prolonging network lifetime and improving energy efficiency, it may face challenges in balancing multiple conflicting objectives and adapting to dynamic network conditions. Additionally, the overhead associated with multi-objective optimization may impact the scalability and practicality of the proposed routing scheme.[17] Presents an Improved Whale Optimization Algorithm for solving constrained optimization problems, demonstrating the algorithm's efficacy in solving complex optimization tasks. While this algorithm shows promise in addressing constrained optimization problems, its performance may be influenced by the choice of constraint handling mechanisms and parameter settings.

Research Gap

While several routing protocols have been proposed to optimize individual aspects such as network lifetime, path longevity, or latency reduction, a holistic approach that integrates these objectives is noticeably lacking. Existing protocols often prioritize one objective at the expense of others, resulting in suboptimal network performance and limited adaptability to diverse MANET scenarios[9]. The purpose of this study is to bridge this research gap by introducing and evaluating the Multi-Objective Node-disjoint Multipath Routing protocol. This protocol is specifically designed to overcome the limitations of existing solutions and provide a comprehensive framework that considers the interplay between network lifetime, path longevity, and end-to-end latency. The study aims to contribute to the advancement of routing protocols in MANETs by offering a nuanced solution that addresses the multi-objective optimization challenge, thereby enhancing the overall efficiency and adaptability of communication in dynamic ad hoc networks.

Background

The Whale Optimization Algorithm (WOA) has emerged as a promising metaheuristic optimization technique inspired by the social behavior of whales. Initially proposed by[18], WOA simulates the hunting behavior of humpback whales to iteratively search for optimal solutions in optimization problems. The algorithm leverages two main mechanisms: exploration, where whales move randomly in search space, and exploitation, where whales converge towards promising regions based on their prey's location. Despite its effectiveness in solving various optimization problems, the basic WOA suffers from certain limitations. These include premature convergence, lack of diversity in exploration, and susceptibility to local optima. Additionally, the original WOA formulation may not adequately address specific requirements and constraints of certain optimization domains, such as multi-objective optimization or constrained optimization problems.

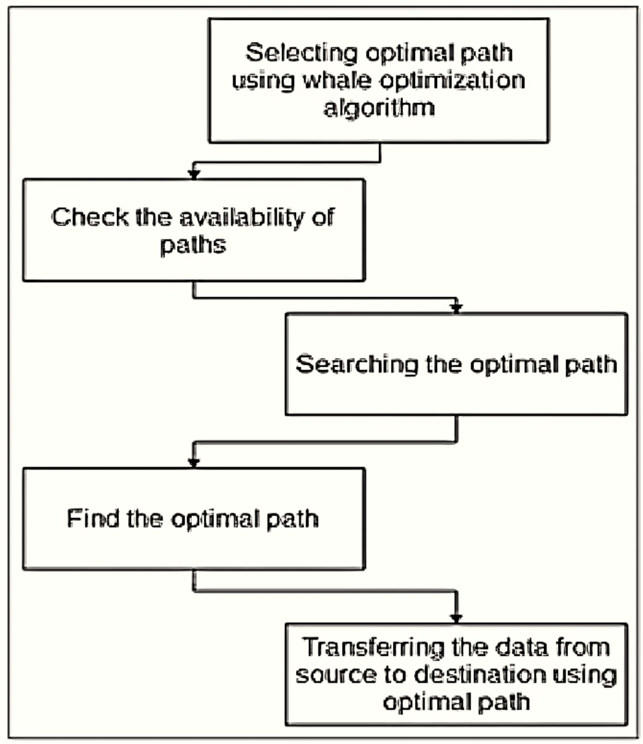

Fig 1. Illustrates the workflow of the proposed system

Table 1. Variable or Symbol used

Variable/Symbol	Description
f(x)	Objective function representing the fitness of a solution in the optimization problem
ϒ1,ϒ2	Weight parameters used to balance multiple objectives in the objective function
P(x)	Total path lifetime, also referred to as overall hop count, representing the duration of a route from origin to endpoint
h(x)	Maximum energy expenditure per hop
t(x)	Energy consumption factor for a given traffic load
RREQ	Route Request message
RREP	Route Reply message
ec	Energy consumption
ec_I, ec_J	Energy consumption at nodes I and J, respectively
e(x)	Energy consumption for a route consisting of n - 1 links
$nd_{(I*J)}$	Node-disjoint matrix element representing paths between nodes I and J

3 Methodology

3.1 Enhanced Whale Optimization Algorithm for Multi-Objective Node Disjoint Routing Protocol

To address the limitations of the existing WOA and enhance its effectiveness in solving complex optimization problems, a novel EWOA is suggested. The enhanced version incorporates several pointer modifications and extensions aimed at improving algorithm performance, convergence speed, and solution quality across diverse optimization scenarios. The proposed EWOA is specifically customized for Multi-Objective Node Disjoint Routing in MANETs. EWOA builds upon the principles of WOA while incorporating enhancements to address the challenges of multi-objective optimization. The key enhancements include:

Objective Function Adaptation(OFA): EWOA utilizes an adaptive objective function that incorporates multiple metrics such as network lifetime, path longevity, and end-to-end latency. This allows EWOA to balance competing objectives and adapt to changing network conditions.

Dynamic Parameter Adjustment(DPA): EWOA dynamically adjusts its parameters based on the network topology and traffic patterns, ensuring robust performance across diverse MANET scenarios.

Node Disjoint Routing Strategy(NDRS): EWOA employs a node disjoint routing strategy to enhance fault tolerance and resilience in MANETs, ensuring that alternative paths are available in case of node failures or network partitions.

3.2 Optimal path finding using enhanced whale optimization

Enhanced WOA is employed to find optimal paths in MANETs by considering various factors such as node mobility, link quality, and energy constraints. The algorithm iteratively searches for the best path based on predefined fitness functions, balancing the trade-off between energy efficiency and packet delivery performance. By dynamically adapting to changing network conditions, the proposed approach aims to improve the reliability and efficiency of data transmission in MANETs.

To equalize the three distinct parameters, Υ_1 and $\Upsilon_2$are weights, and a normalization coefficient is added and produced by averaging the three values $\frac{\Upsilon_1 \; and \; \Upsilon_2}{2}$ separately. The specified weight value determines the ideal value for f(x). P(x) is the total path lifetime (ms) in the route from the point of origin and the endpoint. It is sometimes referred to as the overall hop. The maximum energy expenditure per hop (h) and h(x) combine to form the word 1. For a given traffic load (t), the product of the highest energy consumption is (tx).

$$f(x) = min\left(\Upsilon_1 \Upsilon_2 \frac{p(x)}{\alpha} + (1-\Upsilon_1)\Upsilon_2 h(x) + (1-\Upsilon_2)t(x)\right) \tag{1}$$

$0 \leq \Upsilon_1,\ \Upsilon_2 \leq 1$

To improve performance, a multi-objective function-based routing system is incorporated in the suggested study. The multi-objective idea lengthens the path life span, which strengthens the network's resilience. To avoid delays in finding the node-disjoint path at the destinations, a time limit for receiving the RREQ (Route Request) is set. RREQ messages that have reached their target are deleted before being examined when their duration limit has elapsed. A routes preservation plan is created to stop network division, which starts identifying pathways as soon as the route cache fills up.

3.3 Computation of Energy Consumption for Paths Finding

In the computation of energy consumption for path finding, the focus lies on accurately estimating the energy requirements associated with each potential route in MANETs. This process involves considering various factors such as transmission distance, packet size, node mobility, and transmission power levels. By integrating mathematical models and empirical data, the energy consumption for each hop along the path is calculated, accounting for energy expenditure during transmission, reception, and idle periods. The computed energy consumption for paths serves as a crucial metric for routing algorithms, guiding the selection of energy-efficient routes that minimize power consumption and enhance overall network performance in MANETs. This section considered the energy usage of the travel to efficiently determine the optimum route. We first determine the Energy Consumption (EC) in a connection made up of two nodes, J and I $(ec_{I,J})$, according to equation's description.

$$ec_{IJ} = ec_I + ec_J \tag{2}$$

Equation (3) illustrates how to compute the amount of power used by a route involving the starting location and an endpoint for each of the n -1 links denoted by (e(x)). The letter (n) stands for the entire number of connections in a single route.

$$e(x) = \sum_{n=1}^{n-1} ec_t(n) \tag{3}$$

3.3.1 Encircling Path

Generating node-disjoint paths to meet the specified target value for secure data transfer, as expressed in Equation (1), involves identifying multiple information-transmission paths. To ensure the integrity of these paths, the endpoint initiates a process wherein it sends a Route Reply (RREP) message to a designated node responsible for supplying the data once the stipulated duration limit has elapsed. Upon receiving a response from the designated node, indicating the availability of a route, the endpoint disseminates all node-disjoint paths back to the originating point. Each path is uniquely identified, enabling the starting node to retrieve the corresponding RREP message for the target destination. To maintain data integrity, the starting node discards any RREPs received from intermediate nodes along the transmission paths. The total number of identified paths is depicted in Figure 2, providing a visual representation of the network's robustness and redundancy in ensuring secure data transmission.

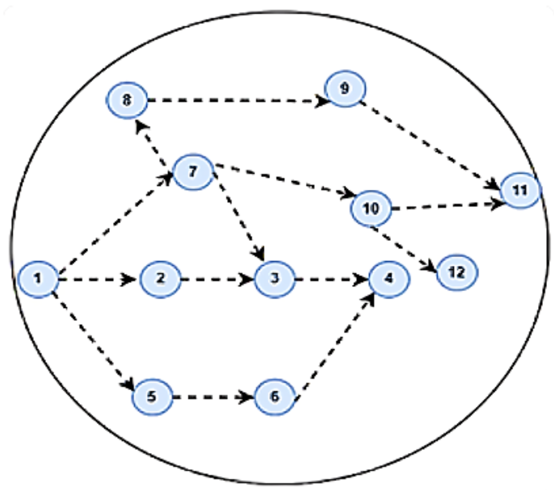

Fig 2. Number of Paths

3.3.2 Paths searching

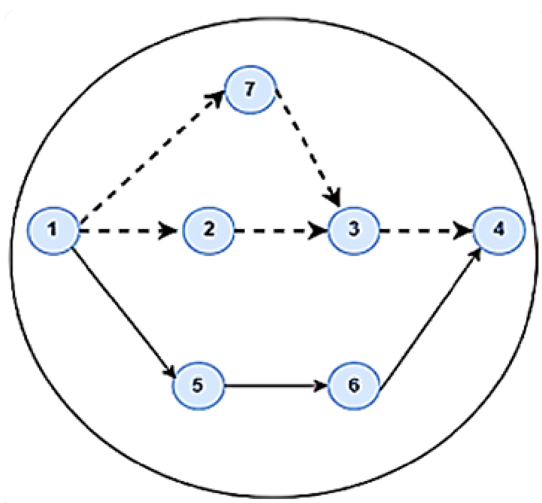

Fig 3. A list of the best routes

Node 1 represents the starting place and node 7 represents the goal in Figure 3. The total number of available routes to reach Nodes 1 and 7 is three. Consequently, the dimension of the node-disjoint matrix is determined by the number of pathways, resulting in a 3x3 matrix. Creating the elements of the node-disjoint matrix involves examining the existing pathways. To generate the entries for the initial row of the matrix, each path is evaluated in conjunction with the other two paths. Similarly, for subsequent rows, each path is examined alongside the other paths to ensure node-disjointness. This process ensures that no two routes share common intermediate nodes, guaranteeing redundancy in case of node failures or network disruptions. The creation of each node-disjoint matrix element is depicted by the following equations:

$$nd_{I*J}\,[111213212223313233] = nd_{I*J}\,[011100000] \tag{3}$$

3.3.3 Paths hunting

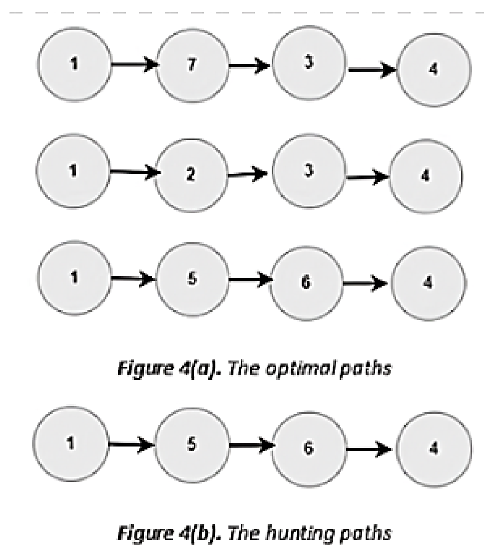

Fig 4. (a) The optimal paths, (b) The hunting paths

Figure 4**(a)** shows the optimal paths. As a result, Path 3 (node 1 node 5 node 6 node 4) is used to transmit data from the origin to the endpoint which is shown in Figure 4 **(b)**. To reduce the number of nodes, node interchange has to be suspended along the provided path. Greater node lifespans and minimal route breaks are anticipated consequences of node swapping. When node-disjoint paths are anticipated by the destination node, the path response is sent posterior to the initial node. The initial node subsequently selects several routes according to Equation (1)'s objective function. The objective function's value determines which of the several created paths is attained. Three different paths are used to deliver data at any one moment. A new path search is started if three consolidated paths are observed overall or if no node-disjoint routes are discovered.

4 Results and Discussion

The experimental setup for the research study utilized a computing system equipped with an Intel® Core™ i3-3245 CPU clocked at 3.40 GHz. The system was equipped with 4.00 GB of installed memory (RAM), with 3.83 GB usable for the experiments. Operating on a 64-bit operating system, the experimental environment provided the necessary computational power for conducting simulations and analyses. For the simulation tasks, a combination of software tools and frameworks was employed to facilitate the evaluation of proposed algorithms and protocols. Specifically, simulation software such as NS-3 (Network Simulator 3) and MATLAB (Matrix Laboratory) were utilized for modeling and simulating MANETs. NS-3, a widely used discrete-event network simulator, provided a platform for implementing and evaluating the performance of routing protocols and optimization algorithms like optimized link state routing (OLSR) [19] and secure routing algorithm blockchain technology (SRABC) [20] in MANET scenarios. The integration of NS-3 allowed for comprehensive experimentation, enabling the assessment of various performance metrics such as Routing overhead, Ratio of Packet delivery, End-to-end delay, and Throughput. Moreover, the experimental setup facilitated the comparison of proposed approaches with existing state-of-the-art techniques, thereby providing insights into the effectiveness and efficiency of the developed algorithms in MANET environments. The simulation parameters of the proposed method are depicted in Table 2.

Table 2. Simulation parameters

Parameter	Typical Value
Number of nodes	150
Packet ratio	98.5
Node speed	20 m/s
Maximum node speed	1–25 m/s
Data size	8 MB
Pause time	120 s
Size of packets	1024 bytes
Topology dimensions	1000 m × 1200 m

End to End delay

Measuring end-to-end delay involves tracking the time taken for a data packet to traverse the network from the source node to the destination node. Figure 5 shows a comparison of end-to-end latency. This information is then used to evaluate the performance of routing protocols and optimization techniques, with lower end-to-end delay indicating better network efficiency and responsiveness.

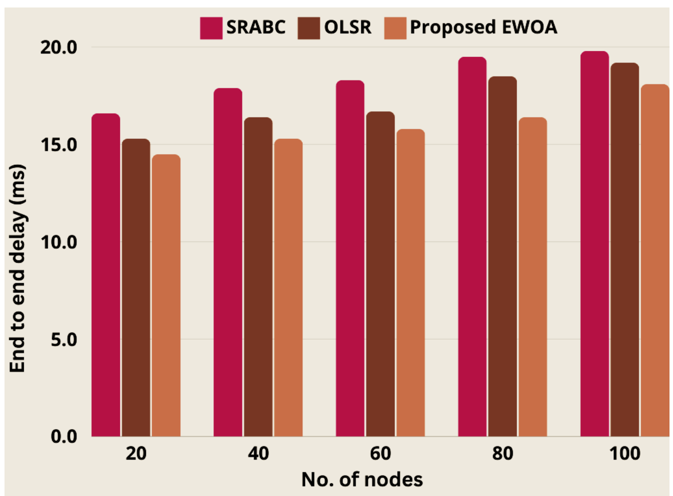

Fig 5. The end-to-end delay

The end-to-end delay is a critical metric that reflects the efficiency and responsiveness of a network. As shown in Figure 5, the proposed Enhanced Whale Optimization Algorithm (EWOA) consistently exhibits lower end-to-end delay compared to the existing SRABC and OLSR protocols across varying numbers of nodes. For instance, with 100 nodes, EWOA achieves an end-to-end delay of 18.1, whereas SRABC and OLSR record delays of 19.8 and 19.2, respectively. This indicates that EWOA effectively minimizes the time taken for data packets to traverse the network from the source to the destination, enhancing network efficiency and responsiveness. The superior performance of EWOA in reducing end-to-end delay can be attributed to its optimized routing strategies and efficient path selection mechanisms, which mitigate congestion and minimize packet transmission times.

Packet Delivery Ratio (PDR)

The term "Packet Delivery Ratio" (PDR) refers to the proportion of messages successfully transmitted from an origin to an end within a network. Figure 6 shows a comparison of the PDR achieved by the proposed algorithm and that of existing methods. The most trustworthy node-disjoint paths that satisfy the mathematical requirements of data transfer are those chosen by EWOA.

Packet Delivery Ratio (PDR) reflects the proportion of successfully transmitted messages within the network. As depicted in Figure 6, the proposed EWOA consistently achieves higher PDR values compared to SRABC and OLSR protocols across different time intervals. For example, at 1000 seconds, EWOA attains a PDR of 99.3%, surpassing the PDR values of 94.8%

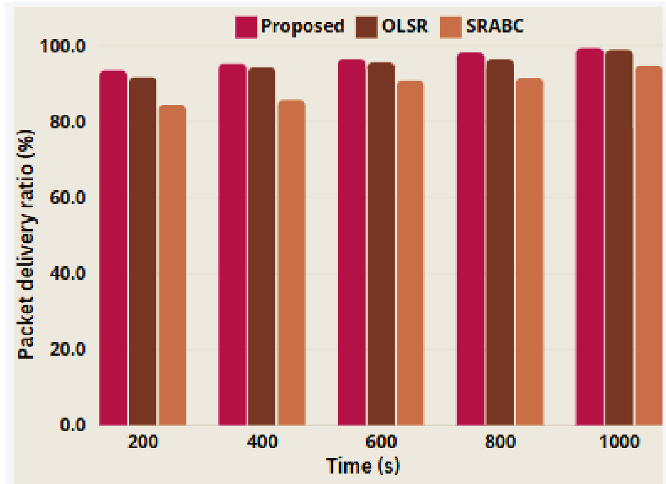

Fig 6. Packet delivery ratio

for SRABC and 98.9% for OLSR. This signifies that EWOA effectively ensures reliable and efficient packet delivery within the network. The improved PDR of EWOA can be attributed to its optimized routing mechanisms and robust path selection algorithms, which mitigate packet loss and enhance data transmission reliability.

Throughput

The unit of throughput is bits per second (bps). A certain number of data packets are sent to the receiver over a specific period of time. It is usually computed in bits of information per second.

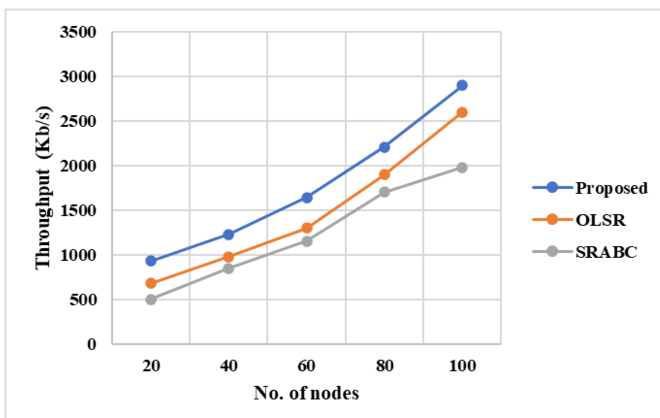

Fig 7. Throughput

Throughput measures the rate of data transfer within the network and is crucial for evaluating network performance. Figure 7 illustrates that the proposed EWOA consistently achieves higher throughput compared to SRABC and OLSR protocols across different time intervals. For instance, at 100 seconds, EWOA achieves a throughput of 2900 bps, outperforming SRABC and OLSR with throughput of 1980 bps and 2600 bps, respectively. This highlights the superior data transfer capabilities of EWOA, attributed to its optimized routing strategies and efficient utilization of network resources.

Routing overhead (ROH)

The ROH is measured as a percentage (%). The ROH represents the total number of packets sent by all nodes for controlling the total number of packets received from the destination node.

Routing Overhead (ROH) represents the percentage of packets sent by nodes for controlling packet routing within the network. As shown in the table, EWOA exhibits lower routing overhead compared to SRABC and OLSR protocols across varying numbers of nodes. For instance, with 100 nodes, EWOA records an ROH of 64.3%, while SRABC and OLSR exhibit ROH values of 74% and 69%, respectively. This indicates that EWOA minimizes unnecessary packet transmissions, reducing

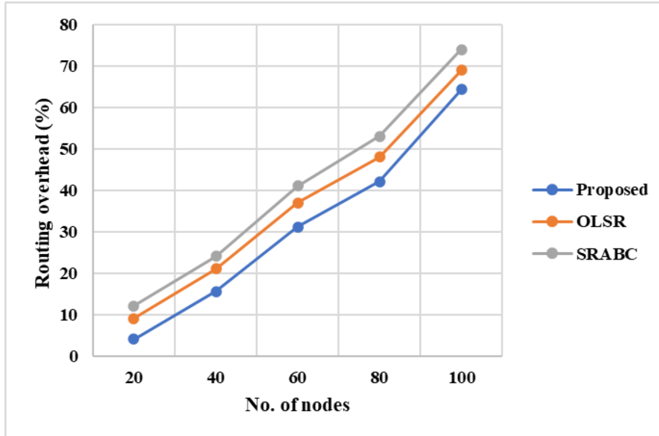

Fig 8. Routing overhead

network overhead and improving overall network efficiency. The lower routing overhead of EWOA can be attributed to its 305 optimized routing algorithms, which efficiently manage packet routing and minimize control packet transmissions which is depicted in Figure 8.

Unlike existing routing protocols that often prioritize individual objectives, the proposed protocol integrates and optimizes these objectives simultaneously. This holistic approach ensures a balanced and adaptable routing infrastructure, enhancing the overall efficiency and reliability of communication in dynamic MANET environments. The protocol leverages node-disjoint multipath routing to provide alternative paths, mitigating the impact of node failures and disruptions on communication. By emphasizing interference reduction and Packet Delivery Ratio (PDR) efficiency, the proposed work contributes to improved communication reliability. The innovative path selection mechanisms and the protocol's ability to dynamically adapt to changing network conditions constitute a groundbreaking contribution, addressing a significant research gap and advancing the state-of-the-art MANET routing protocols.

5 Conclusion

In conclusion, this study introduces an enhanced version of the Whale Optimization technique, denoted as EWOA, as a novel and superior approach to developing a robust MANET routing protocol. The primary objective of EWOA is to ensure the efficient transmission of data from source to destination, concurrently extending the network's lifetime. By incorporating energy-efficient decision-making processes, the proposed protocol minimizes the overall energy consumption of the sensing network. The integration of a node-disjoint path-finding approach mitigates routing failures arising from shared nodes across multiple pathways, enhancing the reliability of communication. The study showcases a multi-objective, function-based routing system that significantly improves overall performance. The comparative analysis with existing routing protocols such as SRABC and OLSR has revealed the superior performance of EWOA in terms of metrics like end-to-end delay, packet delivery ratio, throughput, and routing overhead. EWOA consistently outperforms its counterparts, showcasing its efficiency in minimizing delay, maximizing packet delivery, improving data transfer rates, and reducing network overhead. Furthermore, the scalability and robustness of EWOA have been demonstrated through experimentation with varying network sizes and conditions. The algorithm exhibits resilience to network dynamics, node mobility, and varying traffic loads, making it suitable for real-world MANET applications. Recommendations for future research include investigating the scalability of EWOA, conducting experiments in diverse network conditions, and exploring potential extensions or adaptations for specific application domains. These suggestions aim to advance the understanding and practical applicability of the proposed routing protocol in dynamic and evolving communication environments.

Future Remarks

The future of optimization techniques in MANETs lies in further enhancing adaptability, scalability, and robustness to dynamic network environments. Integration with emerging technologies such as Artificial Intelligence (AI), and Blockchain are potentially revolutionizing MANET optimization, paving the way for autonomous and secure communication. Moreover, interdisciplinary collaborations and real-world implementations are essential to validate the efficacy of these techniques and foster innovation in MANET research.

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