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White Shark Optimization-Based Routing Protocol for Reducing End-To-End Delay in MANET

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ABSTRACT: A Mobile Ad-hoc Network (MANET) is a wireless network composed of mobile nodes with dynamically changing communication paths. The nodes in a MANET freely join or leave the network at any time, resulting in a highly flexible and self-configuring topology. However, excessive end-to-end latency, poor dynamic topology adaptation, and uneven energy consumption are common problems with traditional routing protocols. To tackle these issues, this paper proposes a White Shark Optimization-based Routing Protocol (WSO-RP) for reducing end-to-end delay in MANETs. WSO-RP concentrate on minimising end to end delay whereas sustaining high packet delivery ratio and balanced energy usage. WSO stimulated by the intelligent hunting and navigation behaviour of white sharks, the WSO algorithm effectively balances exploration and exploitation to discover optimal routing paths. The proposed protocol considers key routing metrics such as link stability, node residual energy, hop count, and delay to guide route selection. WSO-RP significantly outperforms conventional and other bio-inspired routing protocols in terms of lower end-to-end delay, and higher packet delivery ratio, for real-time and delay-sensitive MANET applications.

Keywords: Mobile Ad-hoc Network, White Shark Optimization, End-to-End Delay, Throughput, Energy consumption

1. Introduction

A MANET is a wireless network topology containing movable communication channels and mobile network nodes in infrastructure wireless communication networks [1]. Each node in a MANET is equipped with a radio transmitter and a receiver, enabling wireless bidirectional communication with the system. A wireless network is broadly categorized into two types: infrastructure-based networks and infrastructure-less networks [2]. Consequently, MANETs' node mobility allows them to construct networks with a dynamic topology. MANETs are classified into two main types homogeneous as well as heterogeneous [3]. Due to several limitations in the network as well as node environment, the routing protocol is essential in MANETs as shown in figure 1 [4-5].

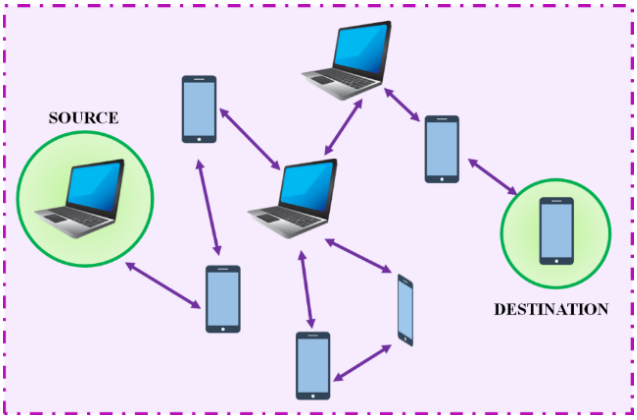

Figure 1: *Basic MANET structure*

Whereas, the research on MANETs have some limitations on the flexible dynamic architecture, Quality of Service (QoS), and restricted resources [6]. In civilian MANETs and other self-organized or self-configured MANETs, each node functions independently and do not have any common objectives with other nodes [7]. Moreover, an infrastructure-less or decentralized ad hoc wireless network, is independent of every network infrastructure, then a mobile node functions equally a router when interacting with other nodes [8]. MANETs fall into three categories: hybrid, reactive, and proactive [9]. Moreover, when a node requests information, the reactive or on-demand approach provides it [10].

Some of the following existing optimization techniques are utilized for reducing end-to-end delay in MANET is shown in table 1.

Table 1: *Existing methods*

Ref.NO.	Author & Year	Methods and its function	Advantages	Disadvantages
[11]	Kumar *et.al* & [2024]	Particle Swarm Optimization (PSO) as well as sleep scheduling (SS) algorithms to enhance the MANETs end-to-end delay.	PSO normally converges to an ideal or almost ideal solution very quickly. And also capable of handling dynamic changes in MANET topology due to its distributed nature.	PSO and SS takes lacks a strong mechanism to explore the entire solution space thoroughly.
[12]	Abdali *et al* & [2020]	To improve the MANETs delay and network lifetime Optimized Particle Swarm Optimization Algorithm (OPSOA) is utilized	OPSOA easily adapts to dynamic changes in MANET topology and efficient in resource-constrained environments .	OPSOA get stuck in local optima, especially in highly dynamic networks.
[13]	Srilakshmi *et al* & [2022]	Bacteria for Aging Optimization Algorithm (BFOA) is to improve and increase the delay factors in MANETs	Selects routes with nodes having higher residual energy, reducing the risk of node failures. BFOA optimize for multiple parameters such as delay, energy, and link quality simultaneously.	Takes more time to reach the optimal solution and more complex to implement and tune due to several biological parameters.
[14]	Sarhan *et al* & [2021]	In Elephant Herding Optimization (EHO) the	Distributes data transmission across	If exploitation is prioritized too

		adaptive relay nodes are selected in the network based on a high energy factor and the neighbour node ratio at each node, to prevent node failures due to energy depletion in MANETs	multiple nodes, reducing congestion and packet drops. Performs well in large-scale MANETs due to its distributed and parallel nature.	much, exploratory capabilities will suffer.
[15]	Shafi etal & [2023]	In MANETs the selected nodes and the optimal path toward the destination is determined using the Ant Colony Optimization (ACO)	Maintains multiple paths between source and destination, offering robustness and redundancy. Performs well in medium to large-scale MANETs due to parallel path discovery.	Large numbers of control packets (ants) are required to explore the network initially, increasing routing overhead.

2. Related work

Ahmed et al [16] (2024) have proposed an Enhanced Osprey Optimization Algorithm (EOOA) to chooses the optimal feature founded on factors like node stability as well as link stability. EOOA algorithm maintains a good trade-off between discovering new routes and reinforcing known optimal paths, reducing route failures in MANET. Nevertheless, EOOA contain complex fitness evaluations and parameter tuning, leading to increased processing time, especially in large-scale or resource-constrained MANETs.

Reka et al [17] (2023) have presented a Chicken Swarm Optimization (CSO) algorithm for handling global optimization issues in MANETs. Enhanced Chicken Swarm Optimization (ECSO), chicks are grouped into smaller sub-flocks to replicate the natural foraging behaviour observed in chicken swarms. CSO algorithm find stable and reliable routes by dynamically adjusting the roles and movements of nodes based on fitness values. However, frequent fitness evaluations and solution updates consume additional memory and energy, which could impact low-power nodes.

Khudair et al [18] (2023) have invented a Quantum-inspired Ant Colony Optimization (QACO) for creating original routes in MANETs. Quantum principles allow QACO to explore multiple routing paths simultaneously, reducing the stuck in local optima. QACO is scalable and perform well even in large and dense networks, maintaining efficient route discovery and maintenance Nonetheless, complex probability models increases the computational burden on MANET nodes.

Janani et al [19] (2024) have proposed an Aggregation-based Archive Population Optimization (AAPO) to improve the effectiveness of the MANETs. AAPO is designed to handle multiple conflicting objectives it well-suited for routing decisions in complex MANET, benefit in accelerate convergence and improve route stability. Nevertheless, performance depends on several parameters such as archive size, aggregation weights, and update thresholds, it is non-optimal in MANET.

Ravindran et al [20] (2024) have presented a Serial Exponential Coati Optimization Algorithm (SECOA) is for MANET routing. SECOA mimics the agile and serial movement behaviour of coatis and integrates exponential update rules to enhance search precision and convergence speed, it is important for adaptive routing in

MANETs. However, maintaining data for each coati agent (such as position, fitness, and path metrics) increase memory usage, particularly in dense or large-scale MANET.

2.1 Contributions of the work

- The purpose of the proposed WSO-RP protocol is to improve MANET routing efficiency. In order to enhance total network performance, it primarily concentrates on reducing end-to-end latency.
- Inspiration from white shark behaviour, modelling intelligent hunting and path-tracking strategies to balance exploration and exploitation during route detection.
- Improved Quality of Service (QoS) through reduction in End-to-End Delay and enhancement in packet delivery ratio.

The other section is structured as follows: In Section II, the proposed works are displayed. Section III explains the result and discussion. There is a conclusion in Section IV.

3. Proposed work

Figure 2 displays the block diagram of the suggested WSO-RP. WSO-RP is designed to reduce end-to-end delay in MANETs whereas preserving a high packet delivery ratio and balanced energy consumption.

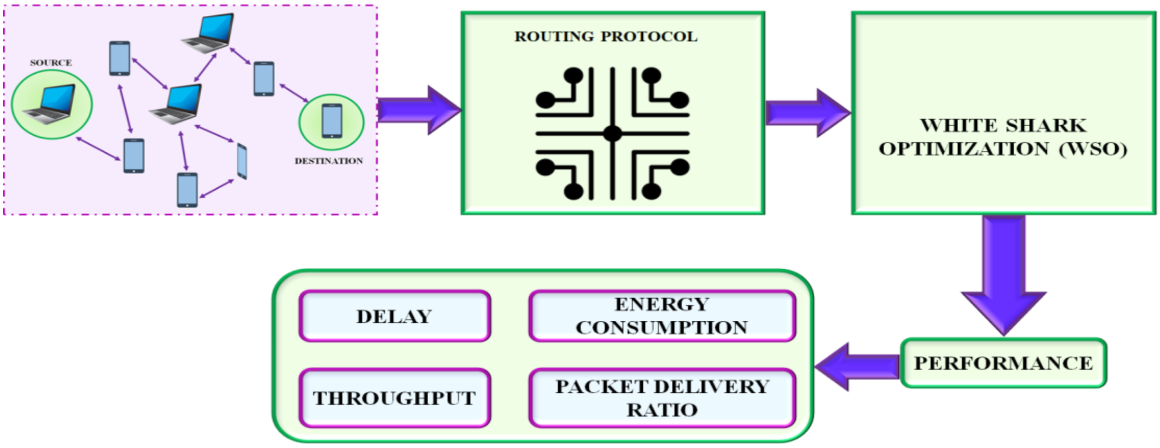

Figure 2: *Block diagram of proposed work*

The WSO algorithm is modelled after the clever hunting and navigational strategies of white sharks effectively strikes a balance between detecting new routes and choose the best ones. In WSO-RP, each mobile node contributes in route detection and maintenance by considering multiple routing metrics such as link stability, residual energy, hop count, and transmission delay, allowing the protocol to select the most reliable and efficient routes. The WSO algorithm iteratively modernizes the route collection process founded on the fitness of each path, reflecting real-time network changes. WSO-RP achieving lower end-to-end delay, higher packet delivery ratio, better energy utilization, and reduced control overhead, create it a robust and efficient routing solution for MANET. Furthermore, even in highly mobile situations, WSO-RP maintains consistent performance by dynamically adapting to changes in network topology. The multi-metric methodology of the protocol improves network lifetime and route reliability. Both small and large MANETs may operate effectively thanks to their scalability. Military networks and emergency communications are two examples of real-time, delay-sensitive applications that benefit greatly from WSO-RP. All things considered, the suggested protocol provides a workable and efficient answer to typical MANET routing problems.

3.1 White Shark Optimization Algorithm in MANETs

The WSO is a swarm intelligence optimization algorithm to reduce the end-to-end delay in MANETs. WSO pulls its core inspiration from the searching and destructive behaviour of great white sharks in the deep sea. These sharks are known for their exceptional hunting skills, which stem from their physical strength, sharp visual acuity, and keen olfactory senses. The optimization mechanism of WSO mimics three primary phases of shark hunting is showed in figure 3.

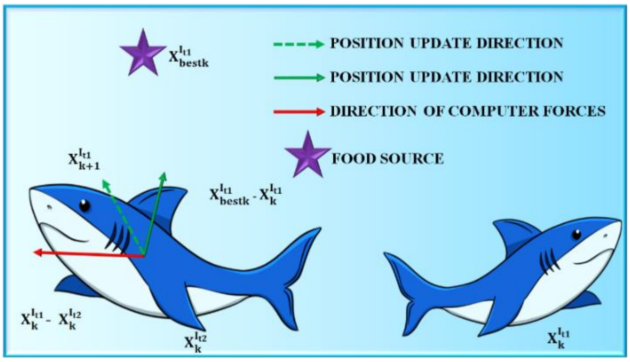

Figure 3: *Position Update Mechanism in White Shark Optimization (WSO)*

Initially, great white sharks detect vibrations and a signal in the water created by the movement of prey is shown in figure 4. Using their acute auditory and olfactory abilities, they effectively locate and navigate toward the prey. In the second phase, sharks engage in a random exploration of the ocean, constantly updating their positions to approach the most promising prey targets. Finally, they synchronize their movement based on the collective behaviour of the shark group, allowing them to their route.

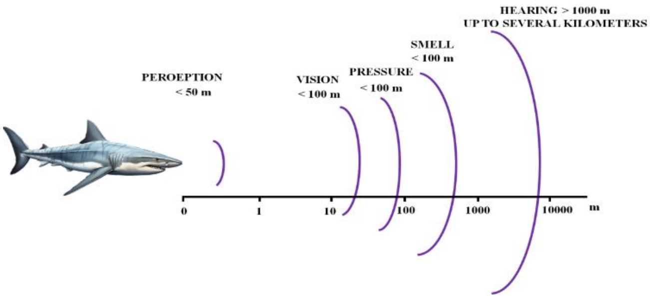

Figure 4: *Sensory perception spectrum of white sharks in natural hunting*

Mathematically, the position of a shark search space is symbolized as a vector $x_i = (x_1, x_2, \ldots, x_n)$ wherever n indicates the dimensionality of the optimization problem. The movement of sharks toward prey is characterized by a wave-like, oscillatory motion that guides their exploration and exploitation process.

$$v_{k+1}^{i} = \mu[v_k^i + p_1(x_{gbest_k} - x_k^i) \times c_1 + p_2(x_{best}^{v_k^i} - x_k^i) \times c_2] \qquad (1)$$

Here, i denotes the index of a specific white shark, and k refers to the current iteration number. The variable x_{gbest_k} represents the globally best position identified by the entire shark population during the k^{th} iteration, whereas $x_{best}^{v_k^i}$ corresponds to the best position found individually by the i^{th} shark in the same iteration. A key parameter, μ, functions as a contraction factor that controls the movement speed of the shark, helping to balance exploration and exploitation. Additionally, the coefficientsp_1 *and* p_2 are dynamic parameters that evolve over the course of iterations, adapting the behaviour of the algorithm as the search progresses. The termsc_1 *and*c_2 are random numbers ranging between 0 and 1, introducing stochasticity into the search process. Naturally, when a shark senses the scent or wave patterns left by a moving prey, it begins to move toward the prey's estimated location. However, due to the continuous movement of the prey, the original position no longer is accurate. Despite this, the residual scent at the previous location provides a trail for the shark to follow.

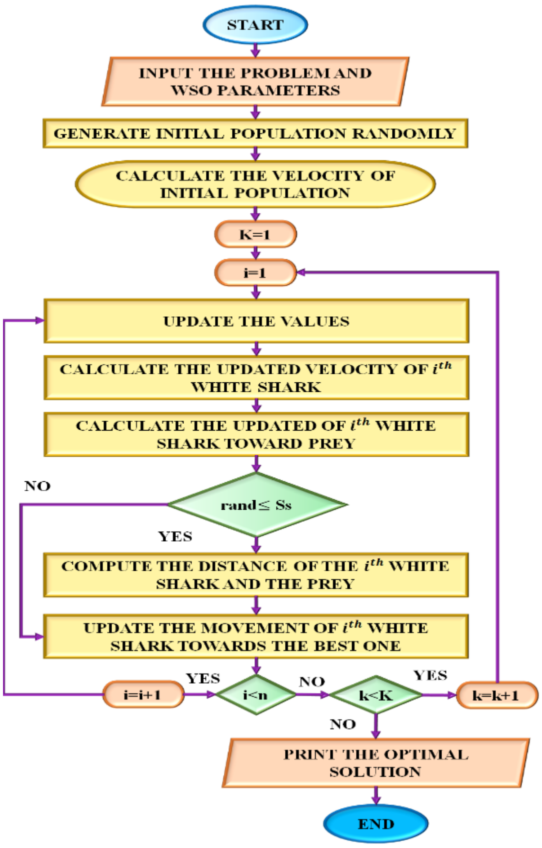

Figure 5: *Stepwise Flow Representation of WSO*

This behavioural insight is reflected in the position update mechanism of the WSO, wherein each white shark adjusts its path based on both the best-known individual position and the global best solution discovered so far. The corresponding position update equations are designed to emulate this sensory tracking and adaptive movement, allowing the algorithm to efficiently converge toward the optimal solution even in dynamic and complex search spaces. The corresponding position update equations are designed to follow this fleshly tracking and adaptive movement, allowing the algorithm to efficiently converge toward the optimal solution even in dynamic and complex search spaces.

$$x_{k+1}^{i} = \begin{cases} x_k^i \neg w_o + u\,.\,a + 1.b; & rand < mv \\ x_k^i + v_k^i\ if; & rand \geq mv \end{cases} \qquad (2)$$

$$a = sgn(x_k^i - u) > 0 \qquad (3)$$

$$b = sgn(x_k^i - l) < 0 \qquad (4)$$

$$x_0 = (a, b) \qquad (5)$$

The position of the k^{th} individual at the i^{th} iteration is denoted by x_k^i . To ensure that each shark remains within the valid search space, boundary constraints are applied using u and l, which denote the upper as well as lower limits of the search range, correspondingly. If a shark's updated position x_k^i exceeds these predefined boundaries, those out-of-bound elements are tracked by a vector w_o . The symbol ¬ is used to identify positions that remain within bounds, essentially complementing the positions indicated by w_o .Another important factor in WSO is the wave frequency, represented by f, which shows a role in modeling the oscillatory nature of shark movement as they respond to prey signals.

Along with their undulating motion, white sharks also have a certain likelihood of moving toward the direction of the prey's most well-known location. The calculations for this motion are as :

$$x_{k+1}^{i} = x_{gbest_k} + r_1 \bar{D}_w sgn(r_2 - 0.5) \quad r_3 < S_s \qquad (6)$$

$$\bar{D}_w = \left|rand \times (x_{gbest_k} - x_k^i)\right| \qquad (7)$$

$$s_s = \left|1 - e^{(-a_2 \times k/K}\right| \qquad (8)$$

$$x_{k+1}^{i} = \frac{x_k^i + x_{k+1}^i}{2 \times rand} \qquad (9)$$

This adaptive approach helps the algorithm avoid becoming trapped in local optima, thereby enhancing both global search and local refinement capabilities. A key feature of WSO is the introduction of an adaptive weight factor, which gradually decreases as iterations progress, allowing the algorithm to transition smoothly from exploration to exploitation.

Table 2: *A pseudo code of WSO*

Algorithm: A pseudo code of WSO

1. Define and initialize the parameters of the problem and WSO.
2. Generate the initial population and their initial velocities
3. Assess the fitness of the population
4. **While** $(k < K)$ **do**
5. Update the velocity of the population using eq.2
6. Update the populations position towards optimal pray using eq.6
7. Update the populations position towards best search agent using eq.7
8. Update the populations position with fish school behaviour using eq.9
9. Amend the position of search agents that bypass the boundaries
10. Assess the new position fitness
11. $K = k + 1$
12. **end while**
13. Return the best search agent obtained so far
14. Return the best search agent obtained so far as the global optimum.

Additionally, WSO reduces the complexity of parameter tuning by eliminating the need for manually setting intricate control parameters. To more boost search efficiency, individual sharks share positional information, promoting collective intelligence. A random disturbance mechanism is also incorporated to increase population diversity and minimize the likelihood of premature convergence, ensuring robust performance across diverse optimization problems.

4. Result and Discussion

The simulation configuration is designed for routing protocol using algorithm in MANETs. This section presents the effectiveness of the future procedure employing WSO-RP, along with a discussion and comparative analysis.

4.1 Performance Metrics

The comparison's parameters include the approaches throughput, PDR, energy consumption, network lifetime and delay.

a) Packet Delivery Ratio (PDR): The value is delivered into the total number of data packets communicated by all nodes, divided by the total number of data packets. This measure is found using the following formula:

$$PDR = \frac{\sum No.of\ packets\ received}{\sum No.of\ packets\ sent} \times 100 \quad (10)$$

b) End-to-End delay: The average time is the basis for the data packet. Based on the first data packet supplied to the destination, the time of the packet's transmission from the source is inferred and is calculated as follows:

$$E2E = \frac{\sum arrive\ time - send\ time}{\sum No.of\ packets} \quad (11)$$

c) Energy consumption: Each node's energy level at the end of the simulation is determined by this metric. To determine the amount of energy consumed:

$$Energy\ consumption = \frac{\sum Energy\ consumed\ in\ each\ node}{Initial\ energy} \times 100 \quad (12)$$

d) Throughput: A throughput measurement is expressed in bits per second. The bits transferred to the BS are known as the throughput.

$$T_p = \frac{Received\ packet\ size}{stop\ time - start\ time} \quad (13)$$

4.2 Experimental set

Table 3: *Parameters for MANET Performance Evaluation*

Parameters	Values
Simulation Area	$1500m\ X\ 1500m$
Number of nodes	$50, 100, 150, 200$
MAC layer protocol	$IEEE\ 802.11$
Simulation time	50,100, 150, 200 seconds
Mobility model	Random way point
Transmission range (m)	250
Extreme node speediness	$5\ m/s$
Data packet dimension	$512, 1024\ bytes$

Primary node energy (j)	50

4.3 Comparative analysis

4.3.1 Packet Delivery Ratio

Figure 6 compares the suggested WSO method with other established methods, including Ant Colony Optimization (ACO) [15] and Elephant Herding Optimization (EHO) [14], using the Packet Delivery Ratio (PDR). The findings show that WSO routinely attains a greater PDR value. The primary cause of this improvement is WSO's effective route selection, which takes latency, residual energy, and link stability into account. As a result, WSO guarantees more dependable data transfer than other bio-inspired strategies.

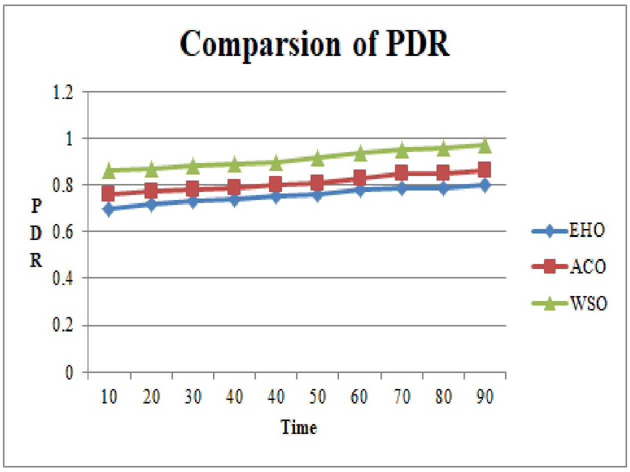

Figure 6: *Comparison of PDR*

4.4 Delay

Figure 7 End-to-end latency comparisons for EHO, ACO, and WSO algorithms with different packet counts are displayed in the figure. As the number of packets rises, particularly above 2000 packets, it is found that EHO shows a greater latency. ACO shows a consistent increase with packet load while maintaining a moderate latency. When compared to the other algorithms, WSO is the most effective at reducing transmission latency, as evidenced by its overall lowest delay.

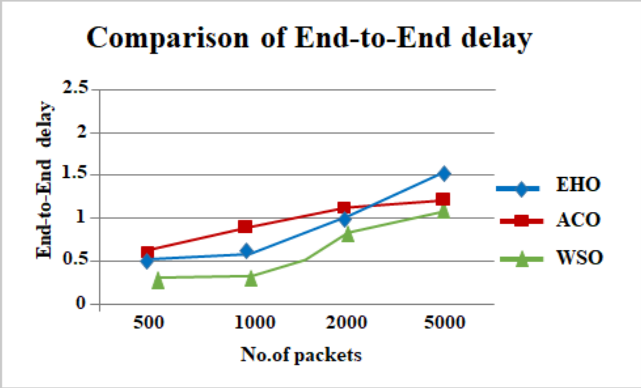

Figure 7: *Comparison of End-to-End delay*

4.5 Energy Consumption

The energy usage of the proposed WSO is analysed in the figure 8 using existing methodologies. When compared to other current routing techniques the proposed WSO algorithm provides superior energy consumption performance. The existing methods are EHO and ACO respectively.

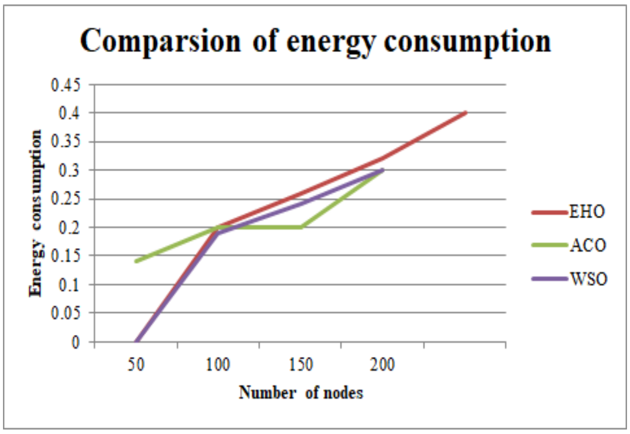

Figure 8: *Comparison of Energy Consumption*

4.6 Through Put

Figure 9 compares the proposed WSO throughput analysis with alternative methods. In terms of throughput, the proposed WSO strategy outperforms other strategies. The evaluation indicates that the WSO method provides data faster but the existing EHO and ACO provides the data slower.WSO results in a drop in throughput performance.

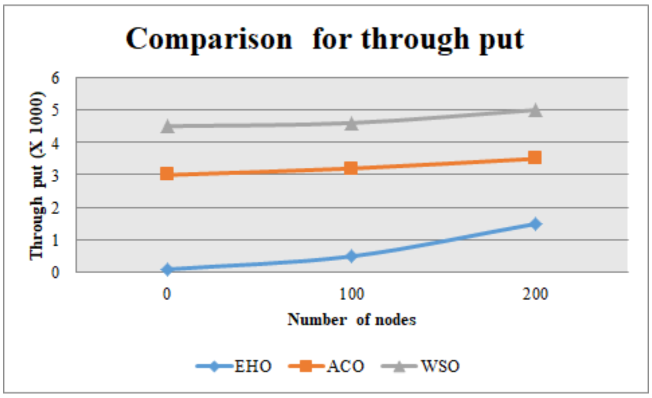

Figure 9: *Comparison of Through Put*

5. Conclusion

This study, a WSO based routing protocol is proposed to dynamic routing in MANETs. In conclusion, the proposed WSO-RP determines a highly effective approach for reducing end-to-end delay in MANETs. By leveraging the intelligent hunting strategies of white sharks, WSO-RP successfully balances exploration and exploitation to identify optimal routing paths. The protocol dynamically incorporates essential routing metrics such as link stability, residual energy, hop count, and delay, ensuring reliable and efficient data transmission. Simulation results that WSO-RP consistently achieves lower end-to-end delay, higher packet delivery ratio, as well as better energy consumption related to existing optimization techniques. These advantages create WSO-RP a suitable and durable solution for real-time and delay-sensitive applications in MANETs. This work can be expanded in the future by evaluating WSO-RP in larger MANETs with more mobile nodes. Adding security-conscious metrics could make it even more resilient to malevolent attempts. Furthermore, combining WSO with additional optimization strategies could improve routing effectiveness overall.

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