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EERP-WOA: Energy Efficient Routing Protocol using an enhanced Whale Optimization Algorithm for WSN

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Abstract. Wireless sensor networks (WSNs) are mostly made up of tiny, intelligent devices known as wireless sensors that can monitor, gather, and transmit data. Sensor nodes are generally equipped with very limited energy resources. One of the primary problems in the WSN is data routing and node energy consumption, so an efficient technique that accounts for network energy is required. This paper suggests a novel energy-efficient routing protocol called EERP-WOA using an enhanced Whale Optimization Algorithm (WOA) by integrating a novel fitness function in the clustering phase. Simulation results show that the proposed EERP-WOA protocol performs better than ESO-GJO and PSO-LSA protocols regarding energy conservation and extending network lifespan.

Keywords: *WSN; WOA_A-star; energy consumption; lifespan*

I. Introduction

Leveraging radio-frequency technology, such as wireless media, to send data over the air eliminates the need for wired connections [1]. Rather than employing connected connections, it is the conventional technique for bolstering the cellular network in the closing phases of communication between smartphone devices and wired networks [2]. The fusion of wireless communication technologies and miniature electronic systems has led to a technological revolution in measuring devices known as wireless sensor networks (WSN). These are collections of tiny electronic devices that can measure specific physical events in the surroundings in which they are used. They are extensively employed in diverse domains such as engineering, healthcare, and environmental monitoring to efficiently supervise remote areas at a minimal expense [2,3]. WSNs are decentralized networks of sensors that can detect and analyze the activities of the surrounding environment [4]. Since wireless communication is the main factor causing node energy consumption, communication methods that use less energy are critical to significantly decreasing node energy consumption and prolonging network lifespan. Due to its direct impact on energy dissipation in WSNs, routing is the most efficient way to address issues related to energy usage in these systems [5,6].

This paper proposes an energy-efficient routing protocol using an updated whale optimization algorithm (WOA) called EERP-WOA to considerably educe WSN energy consumption and extend the network's lifespan. The proposed EERP-WOA protocol integrates the enhanced WOA algorithm, which includes a novel fitness function during the clustering phase to select a suitable group of cluster heads (CH). The paper's primary contributions, as stated in the previously mentioned ideas, are:

In the clustering phase, to select a set of suitable CHs, we apply the enhanced WOA by integrating a novel fitness function that combines multiple parameters, such as the residual energy of the sensors and the CHs, the number of the sensor in the cluster, and the distance between the CHs and the sensors nodes.

In the data transmission phase, we employ TDMA (Time-Division Multiple Access) scheduling during data transfer operations.The simulation results indicate that compared to the ESO-GOJO and PSO-LSA protocols, the suggested EERO-WPA protocol performs better in network energy conservation and lifespan extension.The rest of the paper is organized as follows: the whale optimization algorithm is presented in Section 2. Some related works are discussed in Section 3. Our proposed EERP-WOA

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protocol is described in Section 4. In Section 5, we thoroughly evaluate the performance of our contribution based on the analysis and simulation results, providing a comprehensive understanding of its potential impact. Section 6 concludes our work and provides some future research suggestions.

II. Whale Optimization Algorithm

A meta-heuristic optimization method that draws inspiration from nature, the WOA, was first presented by Mirjalili et al. [7]. WOA is derived from the hunting behavior exhibited by humpback whales. WOA employs a random or optimum search agent to replicate hunting behavior to locate and capture prey. Additionally, it utilizes a mechanism that uses a spiral bubble net to attack, inspired by humpback whales, to grab prey effectively. Similar to other optimization techniques, the WOA consists of two distinct phases: exploitation and exploration. The phase of exploration involves doing a comprehensive search on a global scale to find the best possible solutions. In contrast, exploitation focuses on conducting a more limited search on a local scale. Exploitation involves investigating a limited (but potentially fruitful) area of the search space to improve a known good solution 'S.' This procedure consists of enhancing (refining) the search in the immediate area surrounding the solution 'S.' Put, a local search is being carried out. Exploration involves thoroughly investigating a larger area of the search space to uncover more promising solutions that still need to be perfected.

Furthermore, the WOA commences by generating a whale population initialized with randomly assigned positions. During the initial iteration, the search agents adjust their places relative to a search agent that is randomly selected. Starting from the second round, the search agents modify their position According to the best answer found up to that point. An agent is chosen randomly for search if the value of |A| > 1; this aids in the exploration process. Once the optimal solution is selected, the value of |A| is adjusted to be less than 1 (|A| < 1). This leads to exploitation as all the search agents will come together. Hunting can be elucidated through three distinct phases: searching, encircling, and attacking the target. Whales mimic the encircling behavior to update their positions during the optimization process, namely around the location of the current best search agent. The act of attacking prey represents the exploitation phase of this optimization technique. Exploitation involves searching inside a limited (but potentially fruitful) area of the search space to enhance the caliber of the solution 'S' within its immediate vicinity. This operation involves enhancing (refining) the search in the immediate area of the answer 'S.' The value of $\vec{A}$ falls within the range of [-1, 1].

Consequently, exploitation is triggered when the absolute value of $\vec{A}$ is less than $1(\vec{A} < 1)$, causing all search agents to converge to reach the optimal solution. The exploration phase relies on the manipulation of vector A to activate the search agents in their quest for improved solutions, much to a comprehensive search. The magnitude of |A| is set to a value greater than 1, which compels the search agent to move from the search space quickly. Unlike the exploitation phase, the search agents in this phase update their position by selecting a search agent at random instead of choosing the most optimal search agent.

III.Related works

To enhance energy efficiency and extend the network's lifespan, B. N. Priyanka et al. [8] tackled this challenge by implementing topology control, optimal CH selection, and scheduling techniques to minimize collisions. A circular WSN, consisting of various layers, was analyzed. The nodes were randomly distributed, with a higher density of nodes closer to the sink. The expansive circular region was partitioned into several segments. The WOA was utilized to implement dynamic cluster head selection in each sub-sector. The residual energy and network lifetime were used to evaluate the effectiveness of the suggested method. The performance of the proposed method was assessed by contrasting it with the application of the PSO (Particle Swarm Optimization) and LEACH (Low-Energy Adaptive Clustering Hierarchy) protocols. Comparing the suggested method to the LEACH and PSO processes, the findings showed that the residual energy ratio decreased by 39% and 50%, respectively, for a starting energy of 50 Joules.

J. Nasiri et al.[9] introduced a novel meta-heuristic clustering technique inspired by the collective feeding behavior of humpback whales. The WOA algorithm was devised to address the widely encountered clustering problem. The results were compared with the widely recognized k-means clustering method and other commonly used stochastic algorithms, including PSO, artificial bee colony, differential evolution, and genetic algorithm clustering. The computational analysis, based on the intra-cluster distance function and standard deviation, demonstrated the successful application of the WOA algorithm in solving clustering difficulties.

In their study, Ashwin R. Jadhav et al. [10] introduced a cluster head selection technique called WOA-Clustering (WOA-C), based on the WOA—the algorithm aimed to improve energy efficiency. The suggested technique facilitated the selection of energy-conscious CH by utilizing a fitness function that took into account the node's remaining energy and the neighboring nodes' total energy. The algorithm was assessed for network longevity, energy effectiveness, data transfer rate, and overall reliability. In addition, the performance of WOA-C was evaluated compared to other commonly used routing protocols like LEACH. The suggested algorithm demonstrated higher performance in residual energy, network longevity, and a more extended stability period, as evidenced by extensive simulations.

For CH selection, Bali, H. et al. [11] created a multi-objective function. The distance function was used to form the clusters. Following the creation of clusters, data for each CH was gathered and sent to the BS via a fuzzy inference system, which helped in the selection of the supercluster head. Finally, hop count routing was applied to the data-transfer process. An Oppositional-based Whale optimization algorithm (OWOA) was created for multi-constrained QoS routing. The performance of the suggested OWOA methodology was examined using a variety of criteria, and it was contrasted with more established methods including WOA, genetic algorithms, and particle swarm optimization. In contrast to the current approaches, the suggested OWOA method produced an effective result.

Proposed protocol

Our contribution seeks to reduce the size of the energy gap issue, increase energy efficiency, and lengthen the lifespan of WSN. Its foundation is an algorithm centrally managed and applied at the sink level. Two phases make up our approach: the clustering phase and the data transmission phase.

Clustering phase

At the beginning of each clustering phase, all nodes work in unison to transmit their information regarding their current energy state and location to the sink. The sink then calculates the average residual energy of the network. It selects only nodes with residual energy greater than or equal to the value of the average residual energy of the network to be eligible to be chosen as the CH.

The average remaining energy of the network is given by equation (1).

$$ARE = \frac{\sum_{i=1}^{N} E(n_i)}{N} \quad (1)$$

Where $E(n_i)$is the current remaining energy of live nodes i and N is the total live nodes.

The sink then runs our proposed algorithm based on the WOA algorithm to determine the best CHs for the current round. Each search agent (or whale) is randomly positioned in this algorithm, and then the node closest to its position is cloned. The fitness value is calculated for all search agents, and the best one is selected as the reference. The other search agents position themselves relative to the best agent, and the WOA parameters are updated accordingly. Using multi-hop data transfer and dynamic CH selection for each sub-sector, this method achieves uniform energy depletion by allowing for the dynamic selection of the most energy-efficient cluster heads for each round. To choose CHs in each round, the method suggests using n nodes to represent search agents. Whale positions in WOA are used to model search agent positions, which are represented by CH in 2D space. The optimum solution and ideal CHs are chosen based on the position of the best search agent. Initially placed at random, the search agent copies the nearest node. Each search agent's fitness value is determined, and the top candidate is chosen.

In the first, equation (2) is used to get the fitness value for each CH candidate as follows:

$$Fitness = \alpha * f_1 + (1 - \alpha) * f_2 \quad (2)$$

Where α is a constant used to evaluate the effect of sub-objectives f_1 and f_2.

The first sub-objective f_1 given by equation (3), represents the sum of the ratios of the remaining energy of all sensors in the particular cluster to the remaining power of CH(i).

$$f_1 = \frac{\sum_{j=1, j \neq i}^{n_c} E(j)}{ECH(i)} \quad (3)$$

Where;

n_c represents the nodes number of the particular cluster,

E(j) represents the remaining energy of the sensor j, ECH(j) represents the remaining energy of the sensor CH(i).

The second sub-objective f_2 (equation 4) is the total sum of the inter-cluster distances.

$$f_2 = \sum_{j=1, j\neq i}^{n_c} d(p,i) \quad (4)$$

Where;

d(p, i) represents the Euclidean distance between the sensor p and the sensor CH(i) To calculate $d(p,i)$, we use the Euclidean distance shown in the following Equation (5).

$$d(p,i) = \sqrt{(x_p - x_i)^2 + (y_p - y_i)^2} \quad (5)$$

Where x_p and y_p are the coordinates of member node , and x_i and y_i are the coordinates of CH(i).

In the second, equation (6) is used to determine the coefficient vectors as follows:

$$\vec{V} = \left|\vec{C} * \overrightarrow{X^*}(t) - \vec{X}(t)\right| \quad (6)$$

Let t be the current iteration. $\overrightarrow{X^*}$- represents the position vector of the best solution achieved thus far, $\vec{X}$ is the position vector, and $\vec{C}$ is a vector of coefficients generated using equation (7).

$$\vec{C} = 2 * \vec{r} \quad (7)$$

Where $\vec{r}$ is a random vector in [0,1].

Then, we apply equation (8) to get the new position.

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} * \vec{D} \quad (8)$$

Where $\vec{X}_{rand}$ is a randomly selected whale from the current population. $\vec{A}$ and $\vec{D}$ are calculated using the both equation (9) and equation (10).

$$\vec{A} = 2 * \vec{a} * \vec{r} - \vec{a} \quad (9)$$

Where $\vec{a}$ is linearly decreasing from 2 to 0 over iterations and $\vec{r}$ is always a random vector in [0,1].

$$\vec{D} = \left|\vec{C} * \vec{X}_{rand} - \vec{X}\right| \quad (10)$$

Finally, we select the sensor closest to the new position among them, designated as CH.

The pseudocode for the CH Selection phase is displayed in Algorithm 1 below.

Algorithm 1: *Pseudocode of the CH Selection phase*

Input: n: number of CH candidate, member nodes of each CH candidate.

Put the best position $\vec{X}$ for each CH is its initial position;

for i=1 to n **do**

  while (t < max_iter_num) ***do***

  Calculate the fitness value using equation (2);

  determine the coefficient vectors using equation (6);

  Calculate the new position X according to equation (8);

  Update CH position;

  Update best position $\overrightarrow{X^*}$ if $\vec{X}$ is better than $\overrightarrow{X^*}$;

  end while;

CH ←Node closest to position X*;

end for;

output: The optimal cluster heads for the current iteration.

The following Fig. 1 illustrates the architecture of our proposed protocol.

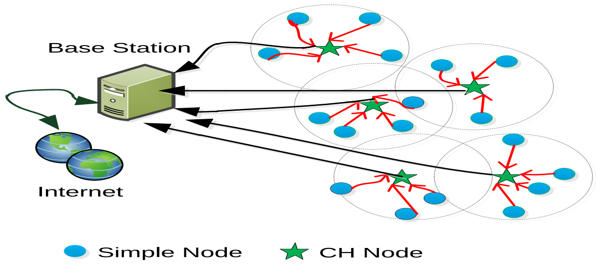

Fig.1. Architecture of our proposed protocol

Data transmission phase

Using TDMA scheduling, the CH assigns time slots for each CH node to communicate during intra-cluster data transmission based on the average node number in each group. Next, to transfer the data to the BS, each CH combines the data it has received with its collected data. The data will then be delivered directly to the BS.

The flowchart shown in Fig. 2 illustrates the different steps of our contribution.

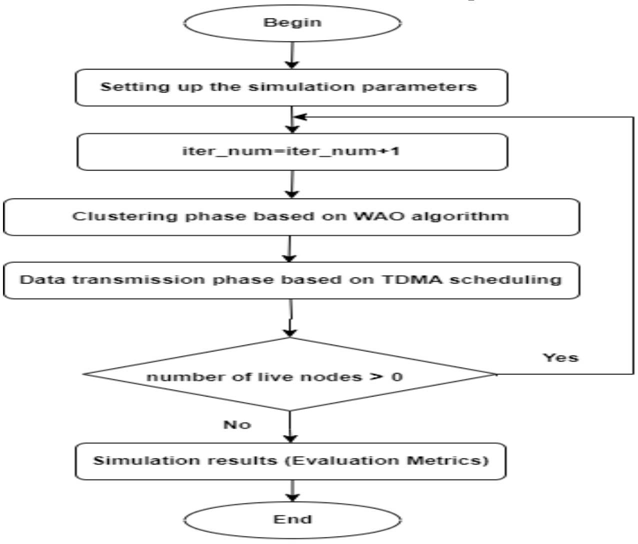

Fig.2. Our protocol flowchart

IV. Simulation results and discussion

In order to show the efficacy of the EERP-WOA protocol in terms of energy consumption, number of alive nodes, total residual energy, and network lifetime. Simulation results are compared with those of the ESO-GJO [12] and PSO-LSA [13] protocols. In the simulation zone, we build multiple network configurations using a thousand randomly placed sensor nodes. For every result below, you can see the average of the twenty individual simulation results. Because of the random deployment, each simulation has the same parameters but a different configuration for the sensor nodes.

Energy Model

We employ the identical energy model presented in [14] to account for the energy consumption in transmission and reception operations. The following Fig. 3 shows the energy model used.

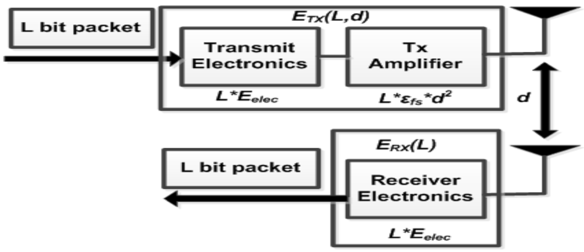

Fig.3. Energy model used

Simulation parameters

The simulation parameters are listed in Table 1.

Table 1: Simulation parameters for the network

Parameter	Value
Network Zone	1000 x 1000 m^2
Node numbers	1000
BS Coordinate	(0,0)
All nodes' initial energy	0.5 J/node
Energy dispersed per bit	50 nJ/bit
Size of data packet	6400 bits
Transmitter amplify (if $d < d_0$)	10 pJ/bit/m^2
Transmitter amplify (if $d \geq d_0$)	0.0013 pJ/bit/m^4

Data packet aggregation's energy	5 nJ/bit/signal
Value of α used in *Fitness* function	0.5

Results & Discussion

In this subsection, we present the simulation results obtained and discussion. Fig. 4, Fig. 5, Fig. 6, and Fig. 7 compare these protocols in terms of the different evaluation metrics cited above.

a) Energy consumption

This evaluation metric quantifies the ovral energy dissipated by all alive nodes in each round.

Fig. 4 compares our proposed EERP-WOA protocol and ESO-GJO and PSO-LSA protocols regarding the total energy consumption.

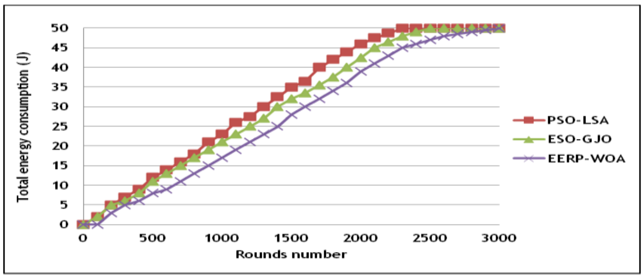

Fig.4. Total energy consumption vs. rounds number

According to the simulation results, Fig. 4 demonstrates that the suggested EERP-WOA protocol performs better than the ESO-GJO and PSO-LSA protocols. The EERP-WOA protocols effectively minimize network energy consumption and extend the network's lifespan by considering the energy impact of the objective functions.

b) Live nodes number

An additional measure of a network's lifespan is the quantity of active nodes inside it. The identical protocols are compared in Fig. 5 with respect to the number of live nodes in each rounds.

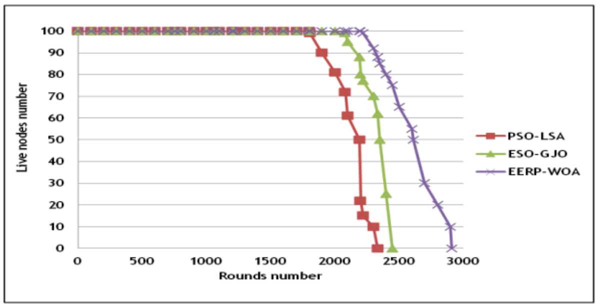

Fig.5. Live nodes number vs. number of round

Fig. 5 illustrates how the number of active nodes drops for each of the three protocols as a result of the nodes running out of energy and becoming useless, unable to send or receive data packets, after each round. In contrast to ESO-GJO and PSO-LSA, our suggested EERP-WOA protocol has a higher number of live nodes over rounds. ESO-GJO and PSO-LSA nodes both fail after 2448 iterations. Nonetheless, there are still 75 live nodes in the proposed EERP-WOA. This shows that the energy management effectiveness of EERP-WOA may be attributed to balanced energy distribution among nodes and good CH rotation.

c) Residual energy

This assessment statistic represents the amount of energy that remains within the network after each cycle. The cumulative remaining energy of these four treatments is quantified in Fig. 6.

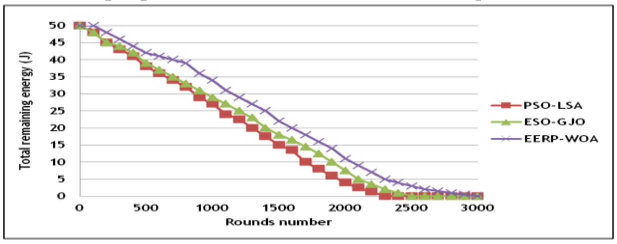

Fig.6. Network's total remaining energy vs. rounds number

Fig. 6 illustrates a consistent pattern: the remaining energy decreases as the number of repeats increases for all three methods. The main reason for this is the energy consumed by the sensor nodes during both transmission and reception tasks. Nevertheless, our proposed EERP-WOA protocol distinguishes itself by consistently maintaining a more uniform energy consumption pattern. The distinctive characteristic of EERP-WOA leads to a notably greater amount of leftover energy in each round, specifically around 31 Joules after 1100 rounds. ESO-GJO and PSO-LSA, on the other hand, have lower energy retention levels, approximately 27 Joules and 24 Joules respectively. Every single node in the ESO-GJO and PSO-LSA networks cease to function after the 2448th round. Nevertheless, the proposed EERP-WOA still retains around 3.5 J of remaining energy. The increased lifetime of EERP-WOA suggests that it is well-suited for applications that require continuous operation without recharging. This makes it a better choice for networks where sustained performance over time is more important than initial high performance.

d) Network lifespan

The number of rounds from the beginning of the protocol execution to the First Node Dead (FND), Half Node Dead (HND), and Last Node Dead (LND) is known as the network lifespan. Fig. 7 examines the network lifespan of our proposed EERP-WOA protocol compared with ESO-GJO and PSO-LSA protocols.

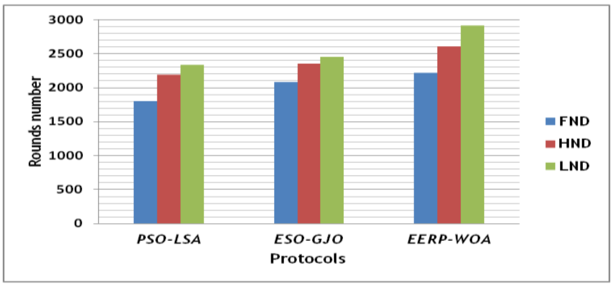

Fig.7. FND, HND and LND comparison vs. round number

Fig. 7 demonstrates that our proposed protocol, EERP-WOA, performs better than ESO-GJO and PSO-LSA based on the FND, HND, and LND metrics. Specifically, EERP-WOA loses its first node at iteration 2220, fifty percent of the nodes by iteration 2610, and its final node by iteration 2910. This surpasses the values of the other two procedures, FND, HND, and LND. Our technique outperforms ESO-GJO and PSO-LSA in terms of these three indicators in that specific order.

As depicted in the figures above, The performance of EERP-WOA is superior due to the implementation of our proposed technique, which effectively reduces energy dissipation during reception and transmission by selecting CHs. This decreases the total energy dissipation of the network and enhances its lifespan. The EERP-WOA protocol is notable for its capacity to consistently and efficiently manage energy usage. An improved energy management system is crucial for extending the lifespan of the EERP-WOA network and enhancing its stability. Furthermore, the network lifespan is assessed and appraised using the FND, HND, and LND measures, and EERP-WOA once again demonstrates its superior reliability as a protocol. It significantly prolongs the lifespan beyond the capabilities of ESO-GJO and PSO-LSA, even up to the final stage of a dead node.

Additionally, it substantially prolongs the lifespan of the initial node. It ensures that more than 50% of the network's nodes remain operational for an extended period compared to the other two protocols. The extended lifespan of this network is especially advantageous for networks deployed in dangerous environments, where the uninterrupted operation of nodes is crucial for ongoing data gathering and monitoring. Finally, EERP-WOA exhibits enhanced performance with a substantial increase in the number of active nodes in each iteration compared to ESO-GJO and PSO-LS. The quantity of active nodes exemplifies WOA_A-star's practical management of node energy.

The proposed EERP-WOA protocol is an ideal choice for high-stakes applications that require minimal maintenance and high reliability due to its numerous advantages in energy management, reduced node mortality, and extended network longevity.

V. Conclusion

This paper presents a new routing protocol for energy-efficient management in WSNs. Our main goal is to minimize energy consumption and extend the network's lifetime by using the enhanced WOA and TDMA scheduling technique. Focusing on selecting the optimal CHs at the clustering phase, we have proposed an enhanced WOA by integrating the distance between the sensor nodes and the sensor nodes' remaining energy in the proposed fitness function—furthermore, the adopting TDMA scheduling technique avoid the collision during data transmission whtin clusters and between the selected CH nodes to the sink node.

Compared with the ESO-GJO and PSO-LSA protocols, The simulation results indicate that the EERP-WOA's performance is the best regarding energy consumption, number of alive nodes, network remaining energy, and network lifetime. This result is attributable to the efficiency of our protocol, which employ an enhanced WOA using the novel fitness function and adopt the existing TDMA scheduling technique.

Our forthcoming project will involve a comparative analysis of the proposed EERP-WOA protocol with other established methodologies. In order to enhance the effectiveness of our suggested technique, we intend to integrate more parameters into the fitness function. Furthermore, we intend to include it into alternative simulation environments such as NS2, NS3, and OMNeT++.

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