SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V11I12P123

Volume 11 Issue 12, 255-262, December 2024

Original Article

Hybrid Optimization Algorithm for Reliable Routing in Wireless Sensor Network

Shankar Madkar[1], Aparna Patil[2], Mangal Patil[3], Anuradha Nigade[4], Sonali Pawar[5], Sanjay Pardeshi[6]

[1]*Department of Technology, Shivaji University, Kolhapur, Maharashtra, India.*
[2,3,4,5]*Department of Electronics & Communication Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering, Maharashtra, India*
[6]*Government Polytechnic Miraj, Maharashtra, India.*

[1]*Corresponding Author : srmadkar@bvucoep.edu.in*

Received: 13 October 2024 Revised: 14 November 2024 Accepted: 12 December 2024 Published: 31 December 2024

***Abstract** - In Wireless Sensor Networks (WSN), congestion is a major problem as data traffic increases to the channel's aggregate capacity. Routing is one of the best methods for reducing node energy usage and increasing throughput in WSNs. This research suggests an effective congestion avoidance strategy based on the Huffman coding technique and Forward Error Code (FEC) integrated with a metaheuristic optimization algorithm to enhance network performance. Using a hybridization of the traditional Zebra Optimization Algorithm (ZOA) and Harris Hawk Optimization (HHO) techniques, the proposed Zebra Hunt Optimization (ZHO) algorithm determines the optimal best paths for sharing the data packet. This process determines the best path for routing the data packet. Here, selection is based on fitness parameters such as flow-based features, buffer occupancy, bandwidth, and throughput. Then, the link quality estimation is evaluated for the identified optimal best path. Also, including a coding scheme in the data packet corrects the errors in transmitted data without retransmission and reduces redundancy.*

***Keywords** - Wireless Sensor Networks, Reliability, Zebra Hunt Optimization.*

1. Introduction

Congestion-free routing in Wireless Sensor Networks (WSNs) attempts to guarantee uninterrupted data flow by avoiding traffic jams. Congestion may result in delays, data loss, and a reduction in the overall effectiveness of the network due to WSNs' constrained resources [1]. Routing algorithms play a vital role in reducing congestion by making intelligent choices about the best possible route for data transfer. These algorithms consider variables, including real-time network conditions, node capacity, and available bandwidth.

Furthermore, load balancing to equally distribute data across many pathways and dynamic adaptation to adjust to fluctuating congestion levels may be part of congestion-free routing. Redundancy and retransmission are the two basic strategies WSNs use to ensure reliable data transfer. Applying error-correcting codes to data or making duplicates are examples of redundancy. For example, redundant data copies can be transmitted via several channels.

Assuring that another copy can be used to reconstruct the original data. In order to enable the receiver to identify and fix problems, error-correcting codes-such as Reed-Solomon codes-are appended to the sent data. When errors are found in the received data, retransmission becomes necessary. In order to guarantee that complete and error-free data eventually reaches its destination, the receiver asks the sender to resend missing or corrupted data packets.

Even in the face of network difficulties and congestion, these redundancy and retransmission strategies strengthen wireless sensor networks' data integrity and dependability. In recent years, much research has been devoted to hybrid protocols with low power requirements, network configuration, routing techniques, and analytical challenges in the context of WSN [9].

2. Literature Review

A survey was carried out on various metaheuristic optimization methods. Utilizing the Particle Swarm Optimization (PSO) algorithm, Ghawy et al. [1] developed a multipath protocol optimization strategy known as the Particle Swarm Optimization Routing Protocol (MPSORP). This protocol is used in Internet of Things applications based on Wireless Sensor Networks when facing unfair network flow and significant traffic loads. The evaluation of the MPSORP protocol was implemented using a range of configurations and features of the NS-2 simulator. Among the advantages of MPSORP are swift throughput, improved packet delivery ratio, decreased delay, and energy efficiency. However, a notable drawback of MPSORP is its higher energy consumption for data analysis.

Suresh Kumar et al. [2] proposed the Exponentially-Ant Lion Whale Optimization technique for routing focused on reliability and energy efficiency for delivering data packets. The E-ALWO method incorporates the Ant Lion Optimization, Whale Optimization Algorithm and Exponentially Weighted Moving Average. In this technique, the Cluster Head is responsible for the routing process, selecting CH using the ALWO algorithm while considering latency and energy constraints. The E-ALWO algorithm uses a fitness measure to identify the optimal path for data communication, considering factors such as delay, energy, distance, and trust within the fitness function. A limitation of the proposed method is its inability to identify the best course of action.

Bhola et al. [3] introduced a combination of the Low-Energy Adaptive Clustering Hierarchy (LEACH), energy-efficient routing protocols, and Genetic Algorithms (GA) to enhance energy efficiency during the operational lifetime of sensor nodes. In the hierarchical LEACH protocol, the cluster heads collect, compress, and transmit data from sensor nodes to the destination node. A genetic algorithm aids in determining the best actions using its fitness function. However, the performance of the proposed approach suffers regarding both lifetime and throughput.

Gorgich et al. [4] addressed the challenge of effective energy utilization in WSNs through a novel method based on the fish swarm optimization algorithm. Applying the fish swarm optimization technique in WSNs makes the routing protocol energy-aware and optimizes power consumption. This protocol was simulated using the OPNET 11.5 simulator. The fish swarm optimization technique's simulation results provide several advantages in terms of power consumption, throughput, end-to-end delay, signal-to-noise ratio, media access latency, and the likelihood of successful transmission. However, the quality of the supplied data was low due to an increased probability of noise.

Wang et al. [5] employed an enhanced Artificial Bee Colony (ABC) approach for selecting cluster heads during their clustering process. An improved ABC algorithm was developed based on the traditional ABC approach. The enhanced ABC algorithm considers factors such as the energy of cluster heads, cluster head density, cluster head positioning, and other relevant characteristics to tackle the clustering challenge in WSNs. The fuzzy-based clustering is optimized using the modified algorithm to identify the optimal clustering approach while the network is initializing and all nodes have identical energy levels. Introducing a polling control mechanism significantly enhances network performance and energy efficiency during steady transmission intervals. Nevertheless, issues with node-to-node communication persist.

Rawat et al. [6] developed PSO-EEC to improve the network lifetime and performance of the wireless network. This protocol uses the particle swarm optimization technique to select the cluster head within the network. The suitable cluster node is selected as the head using a particle swarm optimization-derived fitness function, which evaluates the node's degree, distance from the cluster head, and energy ratio. For multihop data transmission to the base station, this method identifies relay nodes using a fitness value that factors in the remaining energy of the cluster head and distance to the base station. The efficiency of the protocol is assessed by comparing its performance to numerous other methods through various criteria, including network lifetime, throughput and energy consumption. However, the PSO-EEC faces challenges with simulation parameters, resulting in suboptimal performance. Trojavaska proposed the Zebra Optimization Algorithm to find optimal solutions [7]. Alabool proposed the Harris Hawk Optimization technique [8].

For all applications within wireless sensor networks, effectively utilizing sensor energy has always been essential. Previously, several strategies have been proposed to tackle the challenge of node energy by developing suitable energy management techniques. Sensor node clustering is one of the most widely employed methods for addressing energy-related issues in networks. Various prior studies have established energy-efficient routing protocols in WSNs through optimization techniques. However, several challenges remain, such as heightened energy consumption, reduced performance, difficulties in identifying the optimal routing path, and poor data quality during communication issues and data transmission.

This research introduces a novel hybrid meta-heuristic optimization energy-efficient protocol to address these existing limitations. The hybrid optimization protocol aims to determine energy-efficient routes for data transmission, enhancing network longevity. Different optimization algorithms come with their unique strengths and weaknesses. Hybrid approaches integrate these algorithms to maximize their benefits.

In WSNs, hybrid optimization protocols strive for improved overall network performance, particularly regarding energy efficiency, by consolidating the strengths of various optimization techniques. WSNs typically balance multiple objectives, such as extending network lifetime, ensuring adequate data coverage, and reducing latency. While a single algorithm may perform exceptionally in one aspect, it may falter in others. Hybrid methods combine different algorithms to create a more effective balance.

Table 1. Analysis of existing and proposed energy-efficient protocol

Author Name	Algorithm Used	Objectives	Challenges	Performance
Ghawy et al. [1]	MPSORP	To develop a multipath protocol in WSN	consume more energy while processing	Energy usage, PDR, throughput, and end-to-end latency.
Suresh Kumar et al. [2]	E-ALWO	To develop energy efficient and reliable routing technique	It did not discover the best routing path	Reliability, delay, residual energy and throughput
Bhola et al. [3]	GA	To develop an energy-efficient protocol for enhancing energy efficiency with the lifespan of sensor nodes	Less throughput, lifetime performance	Throughput, latency, packet delivery ratio, and energy consumption
Gorgich et al. [4]	Fish swarm optimization algorithm	To develop energy efficient protocol that addresses the issue of optimal power consumption	The quality of transmitted data is poor	Power usage, throughput rate, medium access latency, delay, Reliability
Wang et al. [5]	ABC	To develop an energy-efficient protocol for selecting suitable cluster heads	Limitation in communication between sensors.	Network lifetime, energy, throughput
Rawat et al. [6]	PSO-EEC	To improve lifetime and performance	PSO-EEC suffer from simulation parameters that lead to poor results	Network lifetime, energy, throughput
Trojavska et al. [7]	Zebra Optimization Algorithm	To propose an improved version of the Zebra Optimization algorithm	Less convergence, speed, and produce low accurate results	-
Alabool et al. [8]	Harris Hawk optimization	To solve different types of optimization problems	struggle to escape local minima and find the absolute best solution	-

3. Proposed System

This paper proposes an effective congestion avoidance mechanism that utilizes a Forward Error Correction (FEC) combined with a metaheuristic optimization algorithm based on Huffman coding [10] to enhance network performance. Initially, the most optimal paths for data packet sharing are identified using the proposed Zebra Hunt Optimization algorithm, which hybridizes the traditional Zebra optimization and Harris Hawk optimization algorithms to find the best routing path. Fitness criteria such as buffer occupancy, bandwidth, throughput, and flow-based factors are considered to identify the best pathways. Next, the connection quality evaluation for the identified best paths is performed to select the optimal route that reduces data retransmission. Data redundancy is minimized when a Huffman FEC is applied to the data packet. This Forward Error Correction capability addresses a specific number of errors in the transmitted data without the need for retransmission. Consequently, the proposed routing technique provides redundancy and minimizes retransmission for reliable delivery.

3.1. Data Generation

Initially, the proposed method randomly generates some data packets. These data packets are shared in the wireless sensor network. Figure 1 shows the sample WSN with several nodes, sender and receiver.

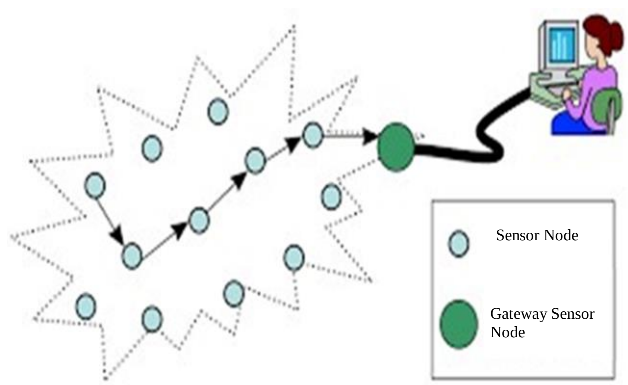

Fig. 1 Sample WSN

The proposed model uses 500 nodes for data transmission, and these nodes continuously gather information from surroundings, which is then sent to the sink node. Most of the time, tens to thousands of these sensor nodes are dispersed across an area of interest, where they cooperate to complete a shared task and self-organize into a network via wireless communication.

3.2. Optimal Path Identification Using ZHO

The suggested Zebra Hunt Optimization algorithm finds the best paths for sharing the data packet by hybridizing the traditional Zebra optimization [27] and Harris Hawk optimization algorithms [28] to find paths for data packet routing. Because the position and fitness function of the zebras should be altered at every iteration, the best solution is generated at each stage of the process. In general, zebras carry out two actions that might be characterized as instinctual behaviours.

1. Exploration phase
2. Exploitation phase

3.2.1. Exploration Phase

Foraging theories are employed in the first stage to bring the population's understanding of zebra activity up to date. Zebras mostly eat grasses and sedges, although they will also eat other plant parts such as roots, bark, fruits, buds, and leaves if these resources are rare. The individual considered the most skilled in the group is called the "zebra leader" in a Zebra optimizer. The zebras' whereabouts during the foraging season are updated using the following equations.

$$Z_{x,y}^{new,fs1} = Z_{x,y} + r.\left(l_y - I.Z_{x,y}\right) \tag{1}$$

$$Z_x = \begin{cases} Z_x^{new,fs1}, & Ft_x^{new,fs1} < Ft_x \\ Z_x & ,else \end{cases} \tag{2}$$

Where, $Z_x^{new,fs1}$ denotes the x[th] zebra update agreeing to the first stage, $Z_{x,y}^{new,fs1}$ stands for its y[th] dimension value, and its fitness function is denoted as $Z_x^{new,fs1}$. Zebra leader (finest candidate) is denoted as l, l_y denotes its y[th] dimension, r said as [0, 1] arbitrary value, I=round (1+r) here, the value of I should be one or two. Population mobility shifts significantly more if the value of I equals two.

3.2.2. Exploitation Phase

It is possible to think of lions as the main zebra predator. Zebras that approach bodies of water face the danger of becoming crocodile prey. Different predators require different strategies for zebras to defend themselves against. In this stage, Harris Hawk's optimization algorithm is used to escape zebra from lions. Mathematical equations for moderate and severe besiege are represented as below,

$$Z(p+1) = \Delta Z(p) - G\left|JZ_{zebra}(p) - Z(p)\right| \tag{3}$$

$$\Delta(p) = Z_{zebra}(p) - Z(p) \tag{4}$$

$$Z(p+1) = Z_{zebra}(p) - G\left|\Delta Z(p)\right| \tag{5}$$

Variance among the prey's position and recent location is the arbitrary number within (0, 1), and it stands for avoiding the unpredictable bounce tendency of the prey while conducting the evasion operation. At each iterative process J, the value can change to show the characteristics of prey activities. Light surrounds with a slow, quick leap that appears when $|G|\geq 0.5$, while rough encirclement is followed by a slow, swift leap when $|G|<0.5$. Here G stands for prey's energy and it is denoted as, $G=2G_0(1-(p/P))$.

$$B = Z_{zebra}(p) - G\left|JZ_{zebra}(p) - Z(p)\right| \tag{6}$$

$$B = Z_{zebra}(p) - G\left|JZ_{zebra}(p) - Z_m(p)\right| \tag{7}$$

$$C = B + S \times lf(D) \tag{8}$$

$$Z(p+1) = \begin{cases} B, if \ f(B) < Ft(Z(p)) \\ C, if \ f(C) < Ft(Z(p)) \end{cases} \tag{9}$$

$$lf(a) = 0.01 \times \frac{u \times \sigma}{|v|^{\frac{1}{\beta}}} \tag{10}$$

Where, D stands for the size of the problem, S means arbitrary parameter represented by the size of 1xD. The levy flight component is assumed from Equation (10), and it is denoted as lf. B and C is used in Equations (8) and (9) whereas u and V are randomly generated parameters in (0,1) and β stands for standard parameter with a value 1.5. Here, fitness factors like buffer occupancy, bandwidth, throughput, and flow-based features are considered to select the optimal best path. The hybrid optimization model is implemented using the following steps: link quality estimation [15] and Huffman coding and CRC.

Table 2. Algorithm for zebra hunt optimization

ZHO Algorithm
1. Initialize ZOA and HHO parameters.
2. Generate the initial population (Zebra positions).
3. Routing a. Exploration Phase (ZOA) • Update Zebra positions using ZOA equations. • Evaluate the fitness of each position. • Retain the best solutions. b. Exploitation Phase (HHO) • Initialize Hawks with the best Zebra solutions. • Update Hawks' positions using HHO equations. • Evaluate fitness and refine solutions. c. Select the best routing path.
4. Use the best path for data transmission and update node energy.
5. Repeat until the best solution is identified.
6. Link quality estimation is carried out.
7. Huffman code is used to compress the code to reduce redundancy.
8. FEC is used for error correction to avoid retransmission

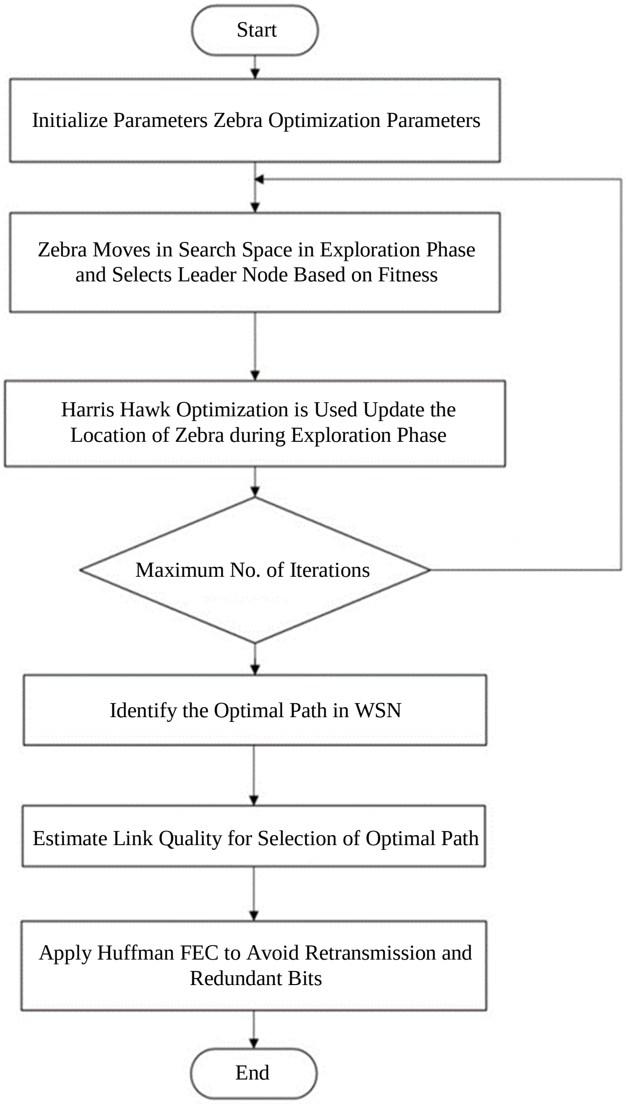

Fig. 2 Flowchart of ZHO

4. Results

This section compares the proposed method with certain existing methods to show how reliable data redundancy is. Throughput, Packet Delivery Ratio (PDR), energy usage, network longevity, end-to-end delay, and other performance metrics are analyzed to show how much better the proposed model is.

4.1. Performance Evaluation

The proposed ZHO algorithm is simulated using MATLAB to create an inventive and successful network model for routing. This section provides the evaluation results in terms of Energy Consumption and throughput.

The proposed method attains fewer outcomes in energy consumption analysis compared to other approaches. For t=540 and t-1080, the proposed technique results in 71.6448 J and 73.2768 J energy consumption, respectively. This method used less energy to transmit data packets, improving the network's lifetime. Performance evaluation of Average delay is shown in Figure 3.

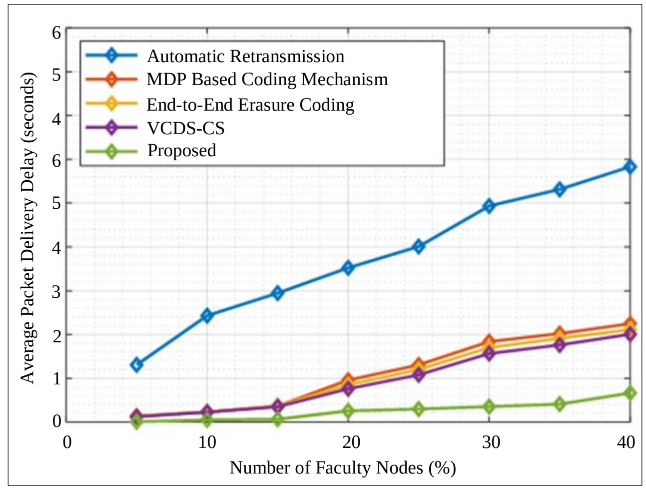

Fig. 3 Average packet delay Vs. faulty nodes

The proposed ZHO technique is compared with automatic retransmission, MDP based coding mechanism, end-to-end erasure coding and coded packets over lossy links (VCS-DS) [30]. The packet delay in the retransmission approach is greater than in the other approaches. An undelivered packet requires more retransmissions, which causes the delay to increase.

The average packet delivery delay rises as the number of faulty nodes in the network grows. Additionally, more data and acknowledgment packets are dropped, and each packet necessitates retransmission. Compared to other methods, the proposed method produces reduction delay performance. The entire amount of data sent during a single round of data collection results are shown in Figure 4.

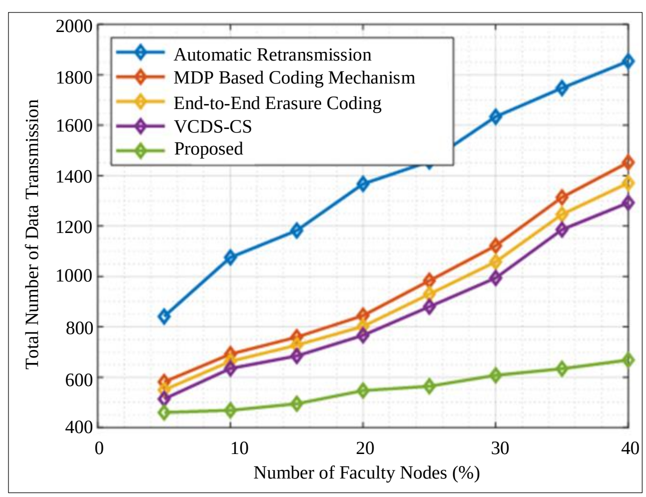

Fig. 4 Total number of transmitted data

As the number of faulty nodes increases, so does the volume of data transmissions required for retransmission. The proposed method effectively reduces the total number of data transmissions by analyzing the quality of link states, which enables the determination of the optimal level of packet redundancy. With more malfunctioning nodes, the amount of transmitted data also rises. This proposed mechanism identifies the best course of action to ensure reliable data delivery while minimizing data transmissions compared to alternative methods. The energy consumption of the defective nodes is illustrated in Figure 5.

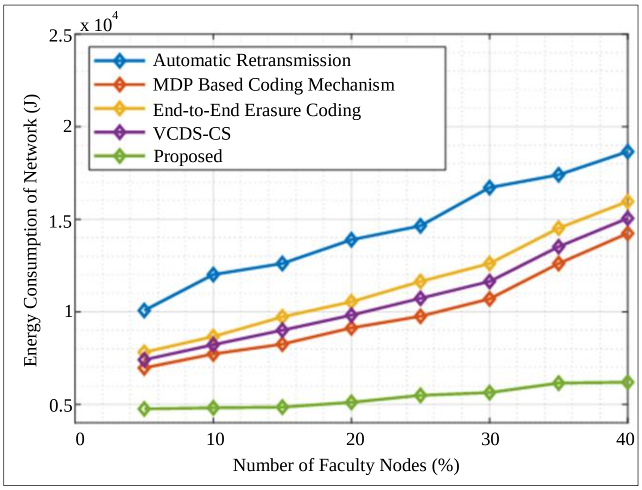

Fig. 5 Total energy consumption analysis

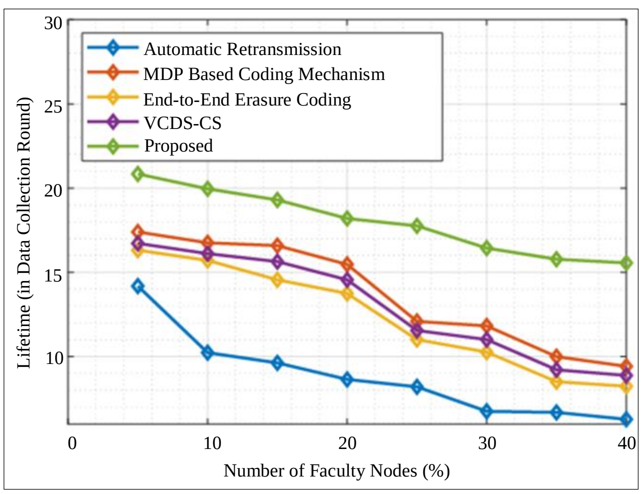

Fig. 6 Lifetime analysis

The faulty node analysis in terms of total energy consumption is analyzed. Energy consumption is observed for nodes 10, 20, 30 and 40. The proposed technique attained 4812.736 J, 5111.392 J, 5635.264 J, and 6198.304 J energy consumption results for the number of faulty nodes 10, 20, 30, and 40, respectively. The suggested mechanism uses less energy than alternative approaches because it minimizes the number of data transmissions through the link quality estimation mechanism. A lifetime analysis of the proposed method is shown in Figure 6.

The proposed method attained improved lifetime results using novel approaches compared to other methods. The lifetime collection is analyzed for the number of rounds and nodes. Suppose the number of nodes is increased as the lifetime is also increased. Compared to the previously mentioned approaches, this optimal policy minimizes the quantity of data transmissions. Therefore, the proposed mechanism reduces energy consumption. Number of alive nodes in terms of rounds is shown in Figure 7.

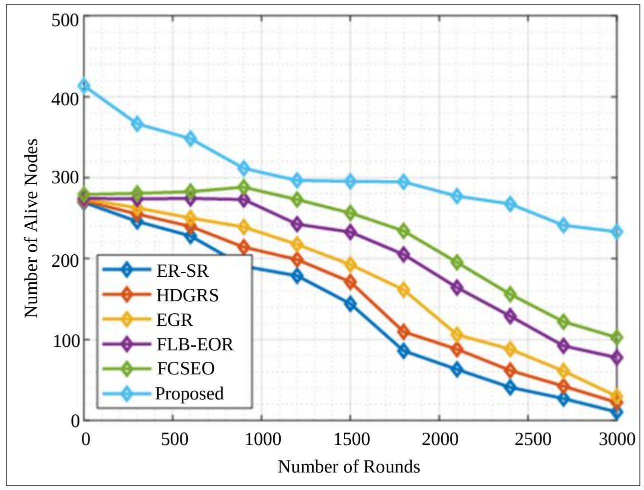

Fig. 7 Number of alive nodes in terms of rounds

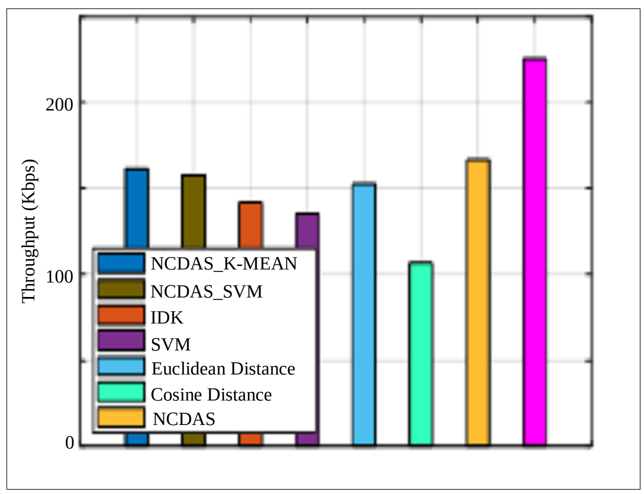

Fig. 8 Throughput analysis

Effective Region Source Routing (ER-SR) protocol, Firefly Load Balancing based Energy Optimized Routing (FLBEOR), Evolutionary-Game-based Routing (EGR), Hybrid Red Deer Salp Swarm (HRDSS), and Fuzzy Criminal Search Ebola Optimization (FCSEO) are some of the methods that are compared to the suggested method [31]. The suggested strategy achieved more alive nodes in each iteration than other methods. The suggested approach yields less results for other methods, but it has 212 nodes for 3000 rounds, 276 for 2000 rounds, and 350 for round 500. The throughput evaluation of proposed and existing models is shown in Figure 8.

It is observed that the proposed approach attained high throughput, which is 220.22 Kbps compared to other approaches. The Proposed method is compared with existing approaches like k-mean Neighbourhood-Enabled and Cluster-Based Data Aggregation Scheme (NCDAS_k-mean), NCDAS_SVM, IDK, SVM, Euclidean distance and cosine distance [32]. Existing approaches are attaining fewer throughputs compared to the proposed approach.

4.1.1. Limitations

- The algorithm increases computational complexity, which requires more computational resources, including time and memory.
- Misalignment in the operations can lead to ineffective optimization.

5. Conclusion

The proposed ZHO optimization-based routing protocol in WSN with a Forward error control technique for reliable data transmission yields better results in simulation. The throughput observed is 220Kbps. There is a significant rise in throughput ie. more than 15% compared to other techniques. After 3000 simulation rounds, the numbers of alive nodes are more than 200 out of 500. It shows that node lifetime has increased and consumes less energy. The coding schemes reduce retransmission and redundancy. The number of faulty nodes is smaller than that of existing methods.

5.1. Future Scope

With the increasing complexity of problems in real-world applications, metaheuristics algorithms provide robust methods to find near-optimal solutions within a reasonable timeframe. As computational power continues to improve, These algorithms can handle larger and more complex problem spaces. It can be integrated with machine learning techniques [32] to enhance performance. For instance, hybrid approaches combined with deep learning for feature selection or reinforcement learning for optimization control are gaining traction. Advances in parallel and distributed computing enable metaheuristic algorithms to effectively exploit multiple processors or distributed computing resources. This capability is crucial for scaling optimization tasks and tackling big data problems. These algorithms are inherently adaptive and can evolve to handle dynamic environments or changing problem conditions. This adaptability makes them suitable for real-time decision-making and optimization in dynamic systems. The future of metaheuristic optimization protocols also lies in interdisciplinary research collaborations.

References

[1] Mohammed Zaid Ghawy et al., “An Effective Wireless Sensor Network Routing Protocol Based on Particle Swarm Optimization Algorithm,” *Wireless Communications and Mobile Computing*, vol. 2022, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] K. SureshKumar, and P. Vimala, “Energy Efficient Routing Protocol Using Exponentially-Ant Lion Whale Optimization Algorithm in Wireless Sensor Networks,” *Computer Networks*, 197, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Jyoti Bhola, Surender Soni, and Gagandeep Kaur Cheema, “Genetic Algorithm Based Optimized Leach Protocol for Energy Efficient Wireless Sensor Networks,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, pp. 1281-1288, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Shiva Gorgich, and Shayesteh Tabatabaei, “Proposing an Energy-Aware Routing Protocol by Using Fish Swarm Optimization Algorithm in WSN (Wireless Sensor Networks),” *Wireless Personal Communications*, vol. 119, no. 3, pp. 1935-1955, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Zongshan Wang et al., “An Energy Efficient Routing Protocol Based on Improved Artificial Bee Colony Algorithm for Wireless Sensor Networks” *IEEE Access*, vol. 8, pp. 133577-133596, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Piyush Rawat, and Siddhartha Chauhan, “Particle Swarm Optimization-Based Energy Efficient Clustering Protocol in Wireless Sensor Network,” *Neural Computing and applications*, vol. 33, pp. 14147-14165, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Wenmin He et al., “Improve Zebra Optimization Algorithm with Adaptive Oscillation Weight and Golden Sine Operator,” *Research Square*, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[8] Hamzeh Mohammad Alabool et al., “Harris Hawks Optimization: A Comprehensive Review of Recent Variants and Applications,” *Neural Computing and Applications*, vol. 33, pp. 8939-8980, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] M. Baskar et al., “Energy Efficient Congestion Free And Adaptive Mechanism For Data Delivery in Underwater Wireless Sensor Networks Using 2H-ACK,” *Research Square*, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Le Yang et al., “Energy Efficient Cluster-Based Routing Protocol for WSN Using Multi-Strategy Fusion Snake Optimizer and Minimum Spanning Tree,” *Scientific Reports*, vol. 14, no. 1, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[11] Boniface Kayode Alese, Bamidele Moses Kuboye, and Omolara Iyabode Alabede, “Development of Recovery and Redundancy Model for Real Time Wireless Networks,” *Journal of Computer Science Research*, vol. 4, no. 3, pp. 12-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[12] Kamanashis Biswas, "A Multipath Routing Protocol for Secure Energy Efficient Communication in Wireless Sensor Networks," *Computer Networks*, vol. 232, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] Addisalem Genta, D.K. Lobiyal, Jemal H. Abawajy, "Energy Efficient Multipath Routing Algorithm for Wireless Multimedia Sensor Network," *Sensors*, vol. 19, no. 17, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[14] Zahid Ullah Khan et al., "A Comprehensive Survey of Energy-Efficient MAC and Routing Protocols for Underwater Wireless Sensor Networks," *Electronics*, vol. 11, no. 19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Linlan Liu et al., "A Link Quality Estimation Method Based on Improved Weighted Extreme Learning Machine," *IEEE Access*, vol. 9, pp. 11378-11392, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[16] Xinlu Li, Brian Keegan, and Fredrick Mtenzi, "Energy Efficient Hybrid Routing Protocol Based on the Artificial Fish Swarm Algorithm and Ant Colony Optimisation for WSNs," *Sensors*, vol. 18, no. 10, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] Neelakandan Subramani et al., "Controlling Energy Aware Clustering and Multihop Routing Protocol for IoT Assisted Wireless Sensor Networks," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 21, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[18] Marcin Lewandowski, and Bartłomiej Płaczek, "Data Transmission Reduction in Wireless Sensor Network for Spatial Event Detection," *Sensors*, vol. 21, no. 21, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[19] Latha R et al., "Routing Protocol Using Ant Colony Optimization- Traveling Salesman Problem," *Procedia Computer Science*, vol. 230, pp. 515-521, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Rehmat Ullah et al., "Improving Resource-Constrained IoT Device Lifetimes by Mitigating Redundant Transmissions Across Heterogeneous Wireless Multimedia of Things," *Digital Communications and Networks*, vol. 8, no. 5, pp. 778-790, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[21] Ali Seyfollahi, Meysam Moodi, and Ali Ghaffari, "MFO-RPL: A Secure RPL-Based Routing Protocol Utilizing Moth-Flame Optimizer for the IoT Applications," *Computer Standards & Interfaces*, vol. 82, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Jyoti Bhola et al., "Performance Evaluation of Multilayer Clustering Network Using Distributed Energy Efficient Clustering with Enhanced Threshold Protocol," *Wireless Personal Communications*, vol. 126, pp. 2175-2189. [CrossRef] [Google Scholar] [Publisher Link]

[23] Gulista Khan et al., "An Energy-Efficient Event Reliability Protocol for Wireless Communication Networks," *Mobile Information Systems*, vol. 2022, pp. 1-10. 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Mostafa Ali Babaei Shahraki et al., "RQAR: Location-Free Reliable and QoS-Aware Routing Protocol for Mobile Sink Underwater Wireless Sensor Networks," *International Journal of Communication Systems*, vol. 36, no. 6, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[25] Prakash K Sonwalkar, and Vijay Kalmani, "Energy Efficient Hop-by-Hop Retransmission and Congestion Mitigation of an Optimum Routing and Clustering Protocol for WSNs," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 3, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[26] Gudla Sateesh, & Kuda Rao Nageswara, "A Reliable Routing Mechanism with Energy-Efficient Node Selection for Data Transmission Using a Genetic Algorithm in Wireless Sensor Network," *Facta Universitatis, Series: Electronics and Energetics*, vol. 36, no. 2, pp. 209-226, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[27] Eva Trojovská, Mohammad Dehghani, and Pavel Trojovský, "Zebra Optimization Algorithm: A New Bio-Inspired Optimization Algorithm for Solving Optimization Algorithm," *IEEE Access*, vol. 10, pp. 49445-49473, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[28] Fulin Tian, Jiayang Wang, and Fei Chu, "Improved Multi-Strategy Harris Hawks Optimization and Its Application in Engineering Problems," *Mathematics*, vol. 11, no. 6, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[29] De-gan Zhang et al., "New Approach of Multi-Path Reliable Transmission for Marginal Wireless Sensor Network," *Wireless* Networks, vol. 26, no. 2, pp. 1503-1517, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[30] Sai Krishna Mothku, and Rashmi Ranjan Rout, "Markov Decision Process and Network Coding for Reliable Data Transmission in Wireless Sensor and Actor Networks," *Pervasive and Mobile Computing*, vol. 56, pp. 29-44, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[31] M. A. Matheen and S. Sundar, "A Novel Technique to Mitigate the Data Redundancy and to Improvise Network Lifetime Using Fuzzy Criminal Search Ebola Optimization for WMSN," *Sensors*, vol. 23, no. 4, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[32] Computational Intelligence and Neuroscience, "Retracted: A Neighborhood and Machine Learning-Enabled Information Fusion Approach for the WSNs and Internet of Medical Things," *Computational Intelligence and Neuroscience*, vol. 2023, no. 1, 2023. [CrossRef] [Google Scholar] [Publisher Link]