Energy Efficient Internet of Things Based Routing Algorithm

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***Abstract*— This paper provides a novel hybrid data routing algorithm that leverages metaheuristic techniques to enhance energy efficiency in Wireless Sensor Network (WSN) applications within the Internet of Things (IoT) framework. As high-speed networks continue to develop, the need for efficient IoT-enabled systems and services becomes increasingly crucial. This paper addresses these needs by providing an innovative solution that optimises data routing, thereby extending the operational life of WSNs and improving overall network performance. A dual comparative energy-efficient routing protocol for IoT applications, utilising the Lyrebird Optimization Algorithm (LOA) and Walrus Optimization Algorithm (WaOA) have been considered. We have proposed the comparative algorithm where Self adaptive LOA, and Self adaptive WaOA. Both have been separately applied to IoT-based routing, to overcome energy efficiency problems. Initially, these two proposed algorithms are individually analysed to choose a suitable algorithm for clustering and routing. The findings of this study demonstrate that the SaWOA algorithm is suitable for routing, while the SaLoA method is effective for clustering. By combining the strengths of these two algorithms, the performance of Cluster Head (CH) selection and routing in IoT networks has been improved. We have also compared and analysed the hybridization of the SaLoA and SaWOA algorithms, known as the SaLWOA algorithm, to achieve optimal performance. The findings show that SaLWOA provides up to a 25% improvement in network lifetime, 15-20% reduction in energy consumption, and 10-15% improvement in packet delivery ratio. Additionally, SaLWOA improves throughput by up to 63%, reduces latency by up to 45%, and maintains up to 32% more alive nodes compared to other well-known algorithms.**

Keywords— IoT, LOA, WaOA, cluster head, routing, SaLOA, SaWOA, SaLWOA.

I. INTRODUCTION

The rapid evolution of Internet of Things (IoT) systems demonstrates a notable technological advancement in which interconnected intelligent devices exchange network information to improve daily operations [1]. This form of communication is facilitated through a well-organized infrastructure comprising diverse technologies and protocols, enabling cyber-physical entities to efficiently share data [2]. Projections suggest a significant increase in IoT device connectivity, with estimations surpassing 50 billion interconnected devices by 2025 [3]. Nevertheless, this expansion brings forth challenges, particularly in relation to energy consumption, leading to the emergence of the Energy Efficient IoT perception. Designing and operating interconnected devices and systems with a focus on reducing energy consumption while maintaining functionality and performance standards lies at the heart of the Energy Efficient Internet of Things framework [4]. This transition is crucial for addressing sustainability concerns and prolonging the operational lifespan of IoT deployments [5]. Optimizing resource utilization, implementing intelligent energy management strategies, and embracing efficient communication protocols are vital actions in energy-efficient Internet of Things initiatives [6].

The establishment of sustainable IoT ecosystems that prioritize energy conservation without compromising functionality constitutes the central focus of investigation in the realm of energy-efficient IoT [7]. It explores innovative approaches to tackle common issues faced by IoT networks, such as low-power communication protocols, energy-efficient algorithms, and astute resource management techniques [8]. These challenges encompass issues like short device battery life, network congestion, and environmental sustainability concerns [9]. Enhancing data transmission, reducing network overhead, and improving overall system performance rely heavily on effective routing protocols and congestion control mechanisms [10]. The objective of the research is to cultivate an eco-friendlier Internet of Things infrastructure that aligns with global sustainability goals by advocating for energy-conscious design and operational principles. The outcomes of this investigation are poised to exert a significant impact on various industries, including smart cities, healthcare, and industrial automation. Energy-efficient Internet of Things solutions can enable innovative applications leveraging IoT technology while mitigating their adverse environmental impacts, as well as enhancing operational effectiveness and service delivery [11].

II. BACKGROUND

In 2020, Ansere et al., [12] examined the joint optimization of user selection, power allocation, and the number of activated base station (BS) antennas of many IoT devices while considering the transmit power and various Quality-of-Service (QoS) requirements in combinatorial mode. This paper presented a jointly energy-efficient iterative algorithm that guarantees convergence to near-optimal solutions by employing the Lagrangian dual decomposition method and a sequential convex approximation strategy. The nonconvex mixed-integer nonlinear programming optimization problem was NP-hard and had no workable solution. The primal optimization issue was decomposed into inner and outer loop subproblems and converted into a tractable convex optimization problem.

In 2022, Thilakarathne et al., [13] provided a summary of the Green Internet of Things (GIoT), after which the study presented the GIoT's issues and future directions. Regarded as a revolutionary technological paradigm, the Internet of Things (IoT) aims to facilitate connectivity among billions of globally networked objects. The Internet of Things is being used in many different fields, including smart cities and homes, smart traffic monitoring, smart healthcare, and many other businesses. Sensing the environment, gathering data from it, and sending it to distant data centres or the cloud are some of the primary features of the Internet of Things.

In 2021, Kaur et al., [14] proposed an energy-efficient and secure Internet of Things (IoT) model for e-health is. Securing the transfer and retrieval of biomedical pictures across the Internet of Things networks was the primary goal. This was accomplished by encrypting the biomedical pictures using the five-dimensional hyper-chaotic map (FDHC) and compressive sensing. FDHC, however, is plagued by the hyper-parameter tuning issue. The incoming biological images were then permuted and diffused using the acquired secret keys. To execute encryption on the input biological image, row-wise and column-wise permutation and diffusion procedures are applied. Because of its faster encryption and decryption of images, the suggested framework can be utilized to secure communication in green IoT networks.

In 2022, Almasoud et al., [15] proposed an energy-efficient framework, where multitier heterogeneous small cell networks offer wireless connection and seamless coverage for mobile users and Internet of Things nodes, this research. Our suggested system adaptively modifies the transmission power of small cells to minimize energy consumption, implementing an elastic cell-zooming algorithm depending on end-user traffic loads and quality of service. Additionally, a clustering-based IoT structure was used to achieve the high energy efficiency of IoT underlying small cell networks. A SWIPT-CH selection algorithm is proposed to maximize the average residual energy of IoT nodes and to lessen resource competition between IoT nodes and mobile users.

In 2021, Shafiq et al., [16] introduced the Robust Cluster Based Routing Protocol (RCBRP), which finds the routing paths with the lowest energy consumption. Six stages of the method are offered to investigate flow and communication. Suggested two algorithms: (i) an algorithm for energy-efficient routing and clustering, and (ii) an algorithm for calculating energy consumption and distance. By grouping the smart gadgets, the strategy balances the load and uses less energy. Validate the findings using comprehensive Matlab simulations. The findings demonstrate the superiority of the suggested scheme over alternatives concerning energy usage, the quantity of packets received at the base station, and the quantity of active and dead nodes.

In 2020, Serhani et al., [17] developed an adaptive routing protocol (AQRouting) based on Reinforcement Learning (RL) techniques. Each node can update its routing metric by its level of mobility, which is detected at different times. In the proposed protocol, two new features were introduced: (i) a new model that uses the Q-learning technique to detect the mobility level at each network node; and (ii) a new metric called Qmetric that accounts for both static and dynamic routing metrics and was updated to reflect changing network topologies. The mobility detection model enables the protocol to effectively manage network mobility by anticipatorily modifying its behavior.

In 2020, Chaudhari et al., [18] focused on developing a methodical and effective way to recognize the essential features of these kinds of applications, convert them into clear requirements, and then derive the related design considerations. Long battery life operation, expanded coverage, high capacity, and inexpensive device and deployment costs are the main characteristics of low-power wide area networks or LPWANs. M2M traffic management, large capacity, energy efficiency, low power operations, extended coverage, security, and interworking are only a few of the essential requirements that result from these qualities. The most popular LPWAN technology solutions on the market, both proprietary and based on standards, are included. These comprise, among others, long-term evolution (LTE)-M, Sigfox, LoRaWAN, and narrowband IoT (NB-IoT). Future cellular 5G technology's significance and how it works best with LPWAN technologies are also covered.

In 2020, Kumar et al., [19] suggested the IoT-NDC as a fundamental element of the and create a lightweight but robust keying protocol that can build confidence between an IoT device and the IoT-NDC. Furthermore, by proposing a peer-to-peer SecP for satisfying a variety of environments, try to locate and resolve this problem. On an open-sourced IoT platform, implemented secure communication (comm.). Determine that the approach that has been proposed was useful in achieving the stated goal and may be applied to the platform through evaluation and research using models and data from the SecPlogic.

In 2021, Malik et al., [20] provided an impression of the technologies that enable large IoT and 6G. The various energy-related issues that come up while utilizing fog computing in 6G-enabled large IoT are discussed. Classified several IoT energy-efficient fog computing technologies and outlined the latest research conducted in these domains. In conclusion, go over upcoming prospects and unresolved issues related to developing energy-efficient methods for fog computing on the upcoming 6G huge IoT network.

In 2020, Bharathi et al., [21] described the Energy Efficient Particle Swarm Optimization (PSO) based Clustering (EEPSOC) technique for selecting cluster heads (CHs) among various Internet of Things devices in an efficient manner. A CH will be chosen through the usage of EEPSOC once the Internet of Things (IoT) devices that are utilized to sense healthcare data are grouped into clusters. The CH is then in charge of using fog devices to transfer data from IoT devices to the cloud server. The healthcare data in the cloud server is then diagnosed using an ANN-based classification algorithm to determine the severity of the disorders. Using medical devices and the UCI dataset, systematic student perspective healthcare data is created for experimentation to predict the various student levels of disease severity.

In 2021, Sanislav et al., [22] proposed the Internet of Things (IoT) growth drives interest in low-power wireless sensors. These sensors were crucial in various sectors like transportation, healthcare, and defense. Long-term operation and sustainability are vital for IoT device design. Traditional battery-powered sensors can impact network lifespan and performance. Energy Harvesting (EH) technology can extend sensor lifespan and reduce battery use. EH also offered economic benefits and lower maintenance costs for networks. Recent advances and case studies demonstrate energy harvesting techniques for IoT. Future research must address challenges for widespread energy harvesting deployment in IoT environments.

In 2020, Zeadally et al., [23] demonstrated an increasing number of objects being connected to the Internet due to advancements in technology. These connected objects are forming the Internet of Things (IoT), which is a network of small, efficient nodes. Most IoT devices are battery-powered and require replacement every few years, leading to costly processes. Efficient energy management was crucial for communication in IoT objects to reduce costs. Energy-harvesting systems can provide a sustainable energy source for long-lasting IoT systems.

In 2022, Bharathi et al., [24] proposed a cluster-based wireless sensor network routing protocol with wireless energy harvesting to extend network energy. A three-tier clustering architecture with an integrated security mechanism is recommended for identifying and blacklisting risky sensor node behavior. The sink node selects cluster and grid heads based on cost function value in a cost-based clustering approach. IoT, with vast potential in various industries like intelligent transportation, has recently gained significance. PSO method was utilized to analyze nodes and clustering strategies in IoT. Growth in the popularity of IoT has led to the development of numerous new services, programs, devices, and protocols with integrated sensors.

In 2022, Ahmed et al., [25] proposed an Energy-Efficient Data Aggregation Mechanism (EEDAM) secured by blockchain for energy saving at the cluster level. Edge computing offers trusted services to IoT with minimal delay, integrating blockchain in a cloud server for security. Simulations were conducted to evaluate the proposed mechanism's performance and compare it with traditional energy-efficient algorithms. Results indicate the design effectively reduces data, ensures IoT security, and extends wireless sensor network (WSN) reach.

III. RESEARCH OBJECTIVES

Main objectives are to provide an energy-efficient IoT-based routing protocol using a metaheuristic algorithm, a comparative analysis-based algorithm selection for Cluster Head (CH) Selection and optimal routing and to analyse the performance of the proposed algorithm to enhance the network lifetime.

IV. RESEARCH QUESTIONS

Q1: How does the comparative analysis of the self-adaptive and hybrid algorithms help to achieve energy efficiency for IoT routing?
Q2: Does the SaLWaOA algorithm achieve better performance than the individual SaLOA and SaWaOA performance in IoT routing?
Q3: How does the SaLWaOA algorithm improves the network lifetime?
Q4: How is the comparison of SaLWaOA algorithm is better than traditional techniques while considering dynamic WSN of different sizes?

V. RESEARCH REQUIREMENTS ANALYSIS & SPECIFICATIONS

Hardware Requirements:

- Windows 10 64-bit operating system
- 12 GB RAM
- Intel(R) Core (TM) i3-9100F CPU @ 3.60GHz 3.60 GHz

Software Requirement:

- MATLAB 2022b

VI. RESEARCH PROJECT IMPLEMENTATION

The Research Project Implementation focuses on developing and testing the self-adaptive Lyrebird Optimization Algorithm (SaLOA) and the self-adaptive Walrus Optimization Algorithm (SaWaOA) for energy-efficient routing in IoT networks.

A. Self Adaptive Lyrebird & Walrus Optimization Algorithm (SaLWoA)

The Self-Adaptive Lyrebird & Walrus Optimization Algorithm (SaLWoA) is a hybrid algorithm that combines the strengths of the Self-Adaptive Lyrebird Optimization Algorithm (SaLOA) and the Self-Adaptive Walrus Optimization Algorithm (SaWaOA). This combination leverages the best aspects of both algorithms to enhance performance in energy-efficient routing for IoT networks.

Phase 1: Initialization

The algorithm begins by generating a population of potential solutions. These solutions are initialized randomly within the problem’s defined boundaries

Phase 2: Fitness Evaluation

After initialization, the fitness of each population member is evaluated using a predefined objective function. This fitness evaluation determines how well each solution addresses the problem at hand, with the results stored in a fitness vector, FFF. This vector guides the selection and optimization processes in subsequent phases.

Phase 3: Hybrid Selection

In the hybrid selection phase, SaLWoA combines the selection strategies from SaLOA and SaWaOA. The top-performing members of the population are selected based on their fitness, using a blend of SaLOA’s traditional selection mechanism and SaWaOA’s socially influenced selection. This ensures the algorithm retains the best solutions while considering group dynamics and interactions.

Phase 4: Crossover and Feeding Strategy (Exploration)

The crossover operation is driven by SaLOA’s adaptive crossover mechanism, generating new offspring by blending the features of selected parents. Simultaneously, SaWaOA’s feeding strategy, which simulates the walrus’s foraging behavior, is incorporated to enhance the exploration phase. This dual approach broadens the algorithm's search across the solution space while maintaining adaptive control.

Phase 5: Mutation and Migration (Exploitation and Social Interaction)

Mutation is a crucial aspect of the hybrid algorithm, with a self-adaptive mutation rate derived from SaLOA. Simultaneously, the algorithm incorporates SaWaOA's migration phase, where walruses simulate group movement to explore new solution space areas. This phase emphasizes social interactions and group dynamics, allowing the algorithm to exploit promising areas identified during exploration.

Phase 6: Escaping and Fighting Against Predators (Advanced Exploitation)

This phase is inspired by SaWaOA's exploitation mechanism, where walruses simulate escaping and fighting against predators. In the hybrid algorithm, this phase serves as an advanced exploitation strategy, refining the solutions and ensuring that the algorithm converges towards the optimal solution.

Phase 7: Iteration and Convergence

The hybrid algorithm iterates through the phases, alternating between the exploration-driven strategies of SaLOA and the socially driven strategies of SaWaOA. This iterative process continues until a stopping criterion is met, such as a predefined number of iterations or convergence based on fitness improvement. The best solution found during this process is selected as the final output of the algorithm.

VII. PERFORMANCE ANALYSIS

The suggested model's network lifetime analysis is compared to current optimization methodologies, taking into account varying node counts (50, 100, 150, 200, and 250).

The initial distribution of IoT nodes within a 500x500 area. Blue dots represent individual nodes, and the black square labeled "BS" represents the base station. This setup forms the foundation for the simulation, establishing the positions and energy levels of the nodes before the clustering and routing optimization.

Fig. 1 shows the nodes grouped into clusters using the k-means clustering algorithm. The magenta dots with yellow labels (e.g., CH1, CH2) represent Cluster Heads (CHs), selected based on their energy levels and positions. The colored dashed lines indicate the routing paths, showing how data is transmitted from the source node (node 85) to the base station through various Cluster Heads.

Figure 2 shows that SaLWOA has significantly prolonged network lifetime compared with the other algorithms. For 500 nodes, for instance, the network lifetime of SaLWOA is sustained at 89.77 rounds, whereas for SaLOA and SaWOA, it reaches 87.94 and 85.41 rounds, respectively. As for LOA and WaOA, their performance is significantly poor, incurring a network lifetime of 83.81 rounds and 77.45 rounds, respectively. Therefore, SaLWoA can enhance network lifetime from 2 to 16% due to the efficient energy management strategy, which prolongs the network's operational period.

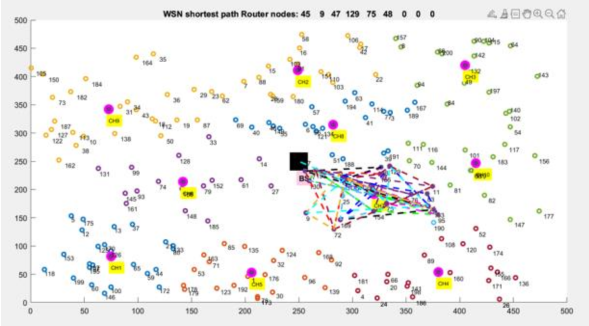

Fig. 1: Cluster Formation and Routing Paths

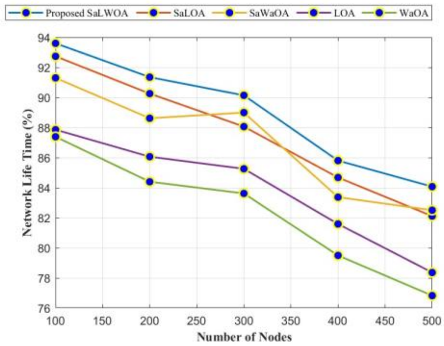

Fig. 2: Performance Analysis for Network Life Time

Fig. 3 shows that SaLWOA exhibits the minimum energy consumption compared to all other algorithms. For 500 nodes, the consumption by SaLWOA is 37.15 J, while SaLOA and SaWOA consume 39.17 J and 41.64 J, respectively. However, LOA and WaOA require considerably higher energy, at 42.84 J and 46.26 J, respectively. This results in a 10-25% reduction in energy consumption for SaLWOA compared to the other algorithms.

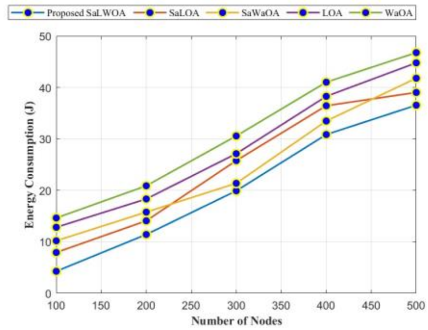

Fig. 3: Performance Analysis for Energy Consumption

PDR is one of the most important metrics for assessing the reliability of data transmission in any network. Figure 4 shows that SaLWOA outperforms the baseline algorithms by yielding a higher PDR, especially as the network size increases. For example, with 500 nodes, the PDR for the SaLWOA algorithm is 85.34%, while the PDRs for SaLOA and SaWOA are 84.93% and 83.18%, respectively. Conversely, LOA and WaOA exhibit much poorer PDRs, at 78.21% and 63.85%, respectively. In this regard, SaLWOA can enhance the PDR by up to 1-34% compared to other methods, thus highlighting its robustness in providing reliable data transmission as the network size increases.

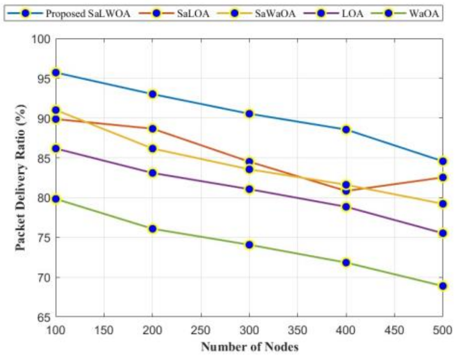

Fig. 4: Performance Analysis for Packet Delivery Ratio

Figure 5 shows that SaLWOA achieves the highest throughput for all node counts. In fact, in a network with 500 nodes, the proposed SaLWOA realizes a throughput of 11,003 bps, compared to 10,900 bps and 9,013 bps recorded by SaLOA and SaWOA, respectively. LOA and WaOA lag with throughput of about 8,251 bps and 3,967 bps, respectively. SaLWOA outperforms its competitors by approximately 10-63% in throughput, reflecting its ability to handle larger data volumes and perform consistently as the network size scales.

Figure 5 demonstrates that SaLWOA exhibits the lowest latency across all node sizes. At 500 nodes, SaLWOA achieves a latency of **12.44 ms**, compared to **14.56 ms** for SaLOA, **15.36 ms** for SaWOA, **18.47 ms** for LOA, and **22.45 ms** for WaOA. SaLWOA reduces latency by **10-45%** compared to the other algorithms, making it an ideal solution for IoT applications that require real-time data transmission.

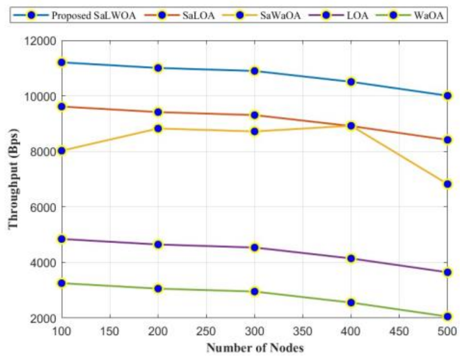

Fig. 5: Performance Analysis for Throughput

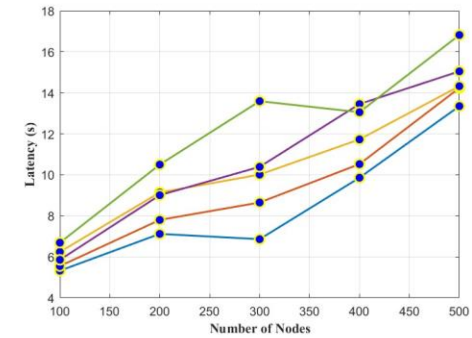

Fig. 6: Performance Analysis for Latency

Fig. 6 and Table 1 provides comparison of the number of alive nodes across varying node counts. SaLWoA consistently maintains a higher percentage of alive nodes compared to other algorithms, effectively balancing energy consumption and extending the network's operational life. SaLOA and SaWaOA also perform well but decline more sharply as the number of nodes increases. LOA and WaOA exhibit the lowest percentage of alive nodes, suggesting they are less efficient in preserving node energy over time.

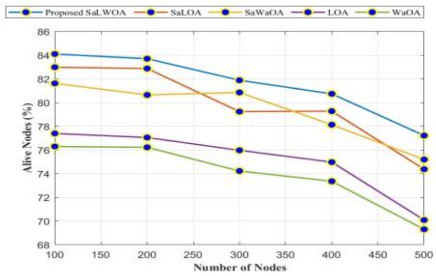

Fig. 6: Performance Analysis for Alive nodes

TABLE 1: COMPARATIVE ANALYSIS

Energy Consumption (J)					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	4.626	10.912	20.708	30.279	37.198
SaLOA	7.252	17.174	22.522	33.387	40.166
SaWaOA	9.84	16.347	24.768	36.795	39.252
LOA	13.113	19.916	28.15	38.921	44.133
WaOA	15.176	22.482	30.007	40.647	46.264
Packet Delivery Ratio (%)					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	95.784	92.554	90.378	87.677	85.34
SaLOA	91.758	86.312	86.933	81.949	82.308
SaWaOA	88.919	87.395	84.166	83.331	79.264
LOA	84.901	82.649	80.673	78.188	75.213
WaOA	79.212	75.916	73.648	71.635	69.385
Throughput (Bps)					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	11202	11005	10898	10501	10003
SaLOA	9612	9413.5	8921.4	8725.4	8413.2
SaWaOA	9223.9	8824.9	9306.8	8913	8824.3
LOA	7445.6	7347.6	7041	6846.2	6345.9
WaOA	5667.3	5870.4	5160.6	4967	3867.5
Network Life Time (%)					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	94.132	91.498	90.953	86.46	83.914
SaLOA	91.831	90.132	88.299	84.779	82.975
SaWaOA	92.319	88.712	89.645	82.885	81.155
LOA	89.194	86.375	85.31	80.565	78.914
WaOA	87.765	84.854	83.796	79.414	77.459
Alive Nodes (%)					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	84.608	83.55	81.123	80.628	76.583
SaLOA	82.753	83.027	79.772	77.739	75.179
SaWaOA	81.275	81.247	80.057	79.423	73.45
LOA	77.774	77.809	75.479	73.489	70.789
WaOA	76.786	76.008	74.47	73.908	69.419
Latency					
No.of Rounds	**100**	**200**	**300**	**400**	**500**
Proposed SaLWaOA	5.407	6.833	9.395	10.916	14.24
SaLOA	5.726	9.506	10.169	12.422	15.546
SaWaOA	5.921	8.758	10.875	11.517	15.743
LOA	6.206	11.338	13.106	13.739	17.293
WaOA	8.543	10.779	12.962	14.454	17.504

7. Conclusion, limitations, and future work

This paper presents a hybrid data routing algorithm that enhances energy efficiency in IoT-based WSNs using metaheuristics. Addressing the demand for high-speed networks, it introduces a dual-comparative protocol combining Self-adaptive LOA and Self-adaptive WaOA for energy-efficient routing. The hybrid SaLWOA algorithm optimizes residual energy, prolongs network lifetime, and stabilizes clustering. By improving the Cluster Head selection through reactive global search optimization, it ensures efficient data routing in heterogeneous WSNs. MATLAB evaluations confirm SaLWOA's superior performance in latency, throughput, network lifespan, energy consumption, trustworthiness, and delivery efficiency.

Limitations

- Depending on the IoT network's complexity and dynamism, the algorithm's efficacy may change,

resulting in inconsistent performance in different environments.
- IoT devices frequently handle sensitive data, which presents issues with data privacy, regulatory compliance (like GDPR), and morality.
- Data transmission and overall network performance in real-world Internet of Things deployments can be disrupted by interference from other wireless devices or environmental factors, making perfect operation unachievable.
- The scalability of the algorithm could provide a challenge as IoT networks grow in number and volume of data traffic, potentially impeding its capacity to effectively manage large-scale deployments.
- IoT networks are susceptible to a range of security risks, including cyberattacks, illegal access, and data breaches. Effectively addressing these security issues is essential, but it may also be very restrictive.

Future Scope

Large-scale IoT deployment method optimization, edge computing-based latency reduction, machine learning-based decision-making enhancement, and strengthened security features are possible areas of research. The expansion and evolution of IoT networks will be supported by these advancements, which will make them more secure, flexible, and efficient.

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