Bio-inspired wireless sensor networks - a protocol for an enhanced hybrid energy optimization routing

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Article Info

ABSTRACT

Recently, there has been a focus on the significance of swarm intelligence-inspired routing algorithms for achieving optimum solutions in biologically inspired wireless sensor networks (WSNs). These protocols depict a network of wireless mobile nodes forming an infrastructure that is agile, dynamic, and independent of a central administrative facility. Among the challenges faced by bio-inspired WSNs, mobility awareness and excessive energy consumption (EC) stand out as significant hurdles, particularly in dynamic models with intermittent connections. This project seeks to tackle these obstacles by deploying the hybrid energy efficiency (HEED) approach to distributed clustering for network system cluster formation, along with fusion routing protocol of particle swarm optimization (PSO) and PIO to select cluster-heads and optimize solutions in bio-inspired WSNs. The success of the suggested approach is assessed using a variety of criteria, such as energy usage, rate of packet delivery, EC, and routing overhead and network lifetime. The methods like ad hoc on-demand distance vector's (AODV) and ant colony optimization (ACO) methods are employed in the testing and validation. In comparison to the reactive AODV routing protocol and ACO, the suggested routing protocol (HPSOPIO) reduces energy usage and increases network lifespan.

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1. INTRODUCTION

Wireless sensor-based networks (WSNs) are needed for variety of various applications, including the internet of things (IoT), embedded devices, and health monitoring. The suggested architecture allows for autonomous organization of these networks, extending their coverage by employing the hybrid energy efficiency (HEED) clustering technique and HPSOPIO routing protocols. It is a work that these sensor nodes to managing data transmission within their designated areas and provide essential context information about the WSN [1] environment. The bio-inspired WSN features a dynamic topology, intermittent connectivity, and resource-constrained devices. The main purpose is to address the varying power levels of every node when data is being sent from client nodes to the various types of multiple stations with in the WSN. This is accomplished by putting the HPSOPIO routing protocol and HEED clustering into practice. Data is sent between sink nodes and a base station (BS) via HEED-driven clustering, which groups nodes into clusters to raise the network's longevity. The recommended routing algorithm (HPSOPIO) then designates a cluster head (CH) for particular cluster and person in charge for data collection and delivering to the BS via an efficient, cost-effective multi-hop method.

Various existing methods and protocols [2], [3] have made efforts to improve the performance of the network by taking into account several assessment factors, including fitness functions, network longevity, energy efficiency, and mobility. As an alternative, the suggested routing protocol (HPSOPIO) evaluates a multifaceted fitness function at the system transport level, ultimately providing an optimal solution that considers both network mobility and network longevity. The nodes that will serve as CHs for extended periods of time are selected based on their degree of connectivity. Figure 1 explains the basic WSN network and Figure 2 explains he clustering in WSN, which has cluster members, CH and BS.

HPSOPIO incorporates self-learning mechanisms to enhance computational processes, leveraging principles of swarm intelligence. It operates by optimizing a fitness function through an optimization process involving a population of particles. Each particle undergoes optimization based on points processed through a particle swarm optimizer, tracking fitness function values and utilizing swarm dynamics to seek optimal solutions. This method facilitates particle movement towards optimal fitness function values by automatically re-centering particles with their respective velocities.

To extend the functional duration of WSNs and successfully meet their application objectives, a variety of demand routing-protocols and swarm intelligence approaches are utilized. Energy optimization during node-to-node communication is particularly crucial in extending WSN lifespan. Overseeing power usage at each sensor-node and considering their mobility are critical aspects for many WSN applications. By concentrating on energy usage during communication at each sensor node, this research seeks to reduce network energy consumption (EC) difficulties. This is accomplished by HEED-based clustering and the suggested routing protocol (HPSOPIO). With the help of the suggested routing architecture and HEED-based clustering, increased network efficiency is achieved. Multi-hop communication between BS and cluster-heads (CHs) is made possible while preserving a single-hop communication pattern inside each cluster.
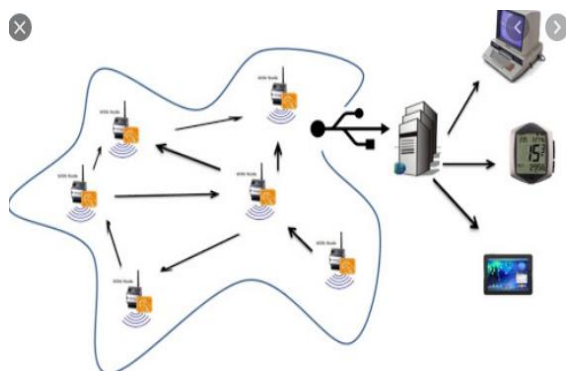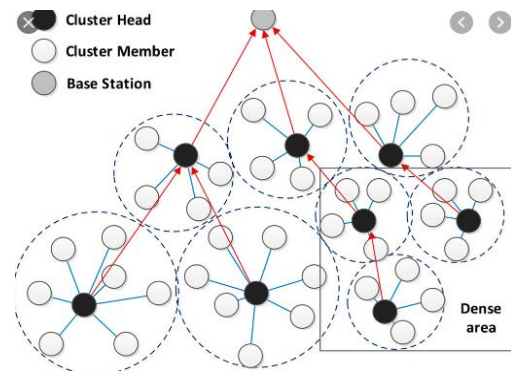

Figure 1. WSN network

Figure 2. Clusering in WSN

2. LITERATURE SURVEY

In various emerging applications of the IoT and WSN there is a need of using the efficient communication protocols [4] to minimize EC is a significant focus of research. In this study applies to a WSN clusters using genetic algorithm and its performance are compared with the fuzzy logic and other existing methods like LEACH method and K-means method. Tandon *et al.* [5] proposed the bio-inspired hybrid based cross layer routing for WSN in IoT to enable effective and energy-preserving routing. This method works based on utilizes a grid-based approach fuzzy logic for selection of CH and determination of path for routing. Limitations could include the complexity of implementing and maintaining the hybrid bio-inspired algorithm, potential scalability issues with a huge number of sensor nodes.

The cluster based routing protocols named as LEACH are proposed in [6] for the WSNs. The main aim of this method is to reducing the EC. But in this method LEACH protocol projects the increases in EC and it method will not consider the circulation for CHs. Scalability and robustness of IEEE-LEACH protocol in dynamic or harsh network conditions are not extensively covered. WSNs utilize low-power, multipurpose sensor nodes [7] to enable communication anywhere, anytime. In the recent years researchers are focused on the introducing the more energy efficient routing algorithms to prolong network lifespan. A limitation is that the comparison is based on simulations, and real-world applicability may differ. The conclusions are drawn from simulations and may not fully represent real-world conditions.

Premakumari *et al.* [8] proposed the two algorithms named as novel bio-inspired method and the modified bat optimization method a cluster-based routing protocol to optimize node coverage and improve localization accuracy in WSN. The paper does not extensively discuss real-world implementation challenges

and practical limitations of the proposed algorithm and protocols based on the clusters. Praharaj and Nayak [9] gives the overview of the challenges faced by the WSNs in introducing the energy efficient clustering and routing protocols across various arears. The various algorithms like genetic algorithm, and particle swarm optimization (PSO), offer benefits such as clustering nodes and increasing the overall network lifespan in WSNs. There is a lack of information about the potential trade-offs and drawbacks of implementing metaheuristic algorithms in WSNs.

Zulfiqar et al. [10] presented the novel bio inspired algorithm to the distribution of senor nodes in the mobile WSN. This proposed algorithm has optimized the energy based on the digestive system of the animals. and enhance network coverage with minimal equipment cost. However, it's important to note that this algorithm's limitations may include constraints related to real-world implementation, scalability issues, and the need for further validation in diverse network scenarios.

Patra et al. [11] demonstrated the energy efficiency of WSN is critical issue and hierarchical clustering with multipath routing is a crucial technique for improving packet overhead, network lifetime, QOS, and power consumption. The methodology's resilience to node failures and network disturbances should be thoroughly evaluated. Real-world deployment and testing of the HC-HGAPSO methodology need to be assessed for feasibility and adaptability in varied WSN environments.

Communication technology [12] has advanced, especially in WSN for controlled devices. WSN relies on sensor nodes that sense location and track changes for broad, accurate data collection. The paper does not discuss potential security implications or vulnerabilities that may arise from implementing the bio-inspired optimization-based routing protocol in WSN. To Evaluate the efficient routing protocol authors in [13] proposed the hybrid optimization method which leads to the reduce the consumption of energy in mobile WSN. The proposed method is based on combining grey wolf optimization and particle swarm optimization. However, the limitations of HOERP may include potential complexity in implementation, sensitivity to network changes, and the need for carefully tuned parameters to achieve optimal performance.

Saini and Kansal [14] stated that routing protocols algorithms to achieve the energy efficient in WSN which is leads to the enhance the network performance. The robustness of the algorithms in the face of hardware failures, environmental disturbances, or malicious attacks may be a concern. Integrating these algorithms into existing WSN infrastructure may pose challenges due to complexity and compatibility issues.

In WSN [15], efficient data collection is crucial for extending network lifespan due to energy constraints. The LEACH protocol is commonly used for energy-efficient data collection via clustering. However, existing clustering schemes suffer from uneven power consumption, motivating the use of meta-heuristic approaches. Additional information about the comparative EC and network lifespan improvements would provide a more broad understanding of the presented method.

Kaviarasan and Srinivasan [16], WSN energy efficiency is addressed through effective routing and hierarchy-based clustering techniques is used to efficient use of energy in network communication. The scalability of the proposed method and its performance in large-scale WSN deployments is not evaluated. The study does not analyze the potential computational overhead or communication overhead introduced by the deployment of the developed protocol in practical WSN deployments.

Saad et al. [17] deals the new algorithm based on the hybrid intelligent routing system. This method is applied to the WSN. The algorithm is the combination of the genetic algorithm and ant colony optimization (ACO) algorithms for data transmission, considering distance and energy parameters. The trade-offs between energy savings and data transmission efficiency, especially in high-traffic or congested networks, may present constraints.

Ghawy et al. [18] proposes advanced protocol based on the PSO method to address limitations in WSNs caused by the increasing number of IoT applications. MPSORP aims to optimize QoS parameters such as end-to-end latency, EC, and packet loss by using a multipath protocol. The paper does not provide specific limitations about the MPSORP or the study. If specific limitations were mentioned in the paper, they would be included in the summary. For a more comprehensive understanding of the limitations, a detailed review of the paper is recommended.

Vellaichamy et al. [19] introduces the method based on the optimal bio algorithm and a multi-criteria clustering system for WSNs to improve robustness and life of the network. The algorithm selects optimal CHs and utilizes both flame and slap swarm optimization for efficient data transmission to the sink. The demerits of the method are not applicable for the larger WSNs where there is a more number of sensor nodes will be present.

The proposed work [20] aims to improve the network lifetime of WSN using the enhanced monkey search algorithm (E-MSA) and class topper optimization (CTO) algorithm. It focuses on enhancing energy utilization by making better routing decisions using available distance and energy. The study does not extensively discuss potential security or reliability considerations associated with the proposed algorithms in WSNs.

A method aimed at improving the energy efficiency of applications operating on ad hoc mobile networks (MANETs) [21] has been developed. This involves modifying the bat optimized link-state routing protocol (BOLSR) within MANETs to enhance the proactive protocol referred to as optimized link state routing (OLSR). As described in [22], an ad hoc network is a temporary network connection devoid of routers or wireless base stations, typically established for transient network connections. Each node in such networks autonomously performs routing tasks without relying on any infrastructure, utilizing a flooding mechanism to transmit data rather than conventional routing techniques.

Hierarchical routing protocols are commonly utilized in networks of wireless sensors (WSNs) for efficient data communication, as they provide scalability and organization of sensor nodes. The low-energy adaptive clustering hierarchy (LEACH) algorithm, as outlined in reference [23], notably enhances the longevity of WSNs. To further improve the longevity within the WSN, a mobile sink node is utilized in place of a fixed sink node, and CHs are rotated During every round to optimize their remaining energy.

Ad hoc on-demand distance vector's (AODV) efficacy a reactive routing methodology, as mentioned in [24], has been enhanced by incorporating the Paillier homomorphic cryptographic mechanism to establish a security layer. The secure layer-AODV (SL-AODV) implementation adds confidentiality to secure routing packets (PR) and ensures the integrity of data transmission, thus improving the efficiency of the AODV protocol for on-demand routing. Vimalarani *et al.* [24] introduces a method employing particle swarm optimization (PSO) for cluster formation in MANETs, utilizing a stochastic parallel technique involving multiple agents. This modified network structure proves advantageous for cost-effective infrastructure networks, including military services, vehicle-to-vehicle communication, transport communication, and rescue operations. In bioinspired technology, [25] offers a combination of hybrid routing protocols grey wolf optimizer (GWO) with PSO to improve the global optimum solution. This approach is considered evolutionary because it integrates the functionalities of both variants instead of employing them independently and in parallel, resulting in a mixed approach where both variants contribute to generating final solutions for various problems.

The author introduced a hybrid approach [26], known as HPSO, to address this issue. This approach combines space transformation search (STS) with a novel modified velocity model. Experimental assessments conducted on eight benchmark functions demonstrate that HPSO exhibits favorable performance. In a prior investigation [27], hybrid algorithms were devised to minimize the likelihood of encountering local optima, particularly in the context of HPSOAC. Recently, a novel bio-inspired approach to enhance WSNs has emerged, known as HPCOGWO.

3. METHOD

This study presents a routing method that prioritizes energy efficiency and mobility specifically for WSNs. Cluster formation processes the HPSOPIO routing protocols usage, and the evaluation of various network analytic metrics are important components of the research. The Figure 3 gives the detailed methodology with advanced routing protocols.
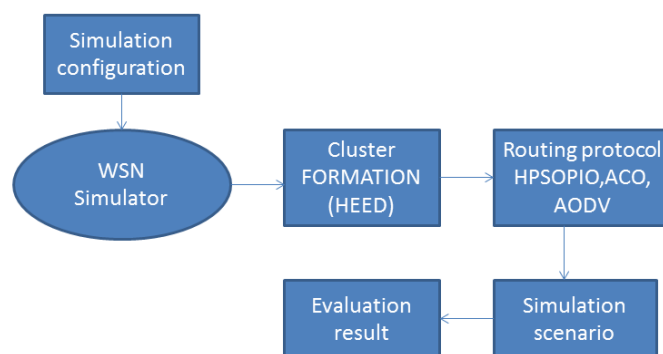

Figure 3. Proposed architecture

3.1. Cluster formation (HEED)

WSNs usually comprise a considerable number of sensors, usually between fifty and two hundred. These nodes are first placed in a 250 by 250 square meter area. Next, the two-dimensional deployment of these nodes a total of 200 is shown next to many BS. A 5-joule energy budget is allocated to each sensor

node. To efficiently organize the network, clusters are established using multiple BS or sinks employing the HEED clustering technique. Within the WSN, these BS broadcast information collection messages to all sensor-nodes. HEED selects a CHs while considering the left over energy of each node, aiming for a well-connected network structure, even when dealing with nodes of varying power levels. The proposed methodology is applicable for the two types one is single-hop and another one is multi-hop communication.

In the type of Multi-hod system of communication, HEED sets sensor node power levels and clusters to improve spatial reuse and reduce the quantity of sensor-nodes needed. This helps to guarantee that well-connected with network. Interestingly, high-power sensor-nodes are positioned with a least spacing of twice their distance as widely apart as the cluster's diameter. During communication procedures, this limitation aids in maintaining balanced inter-cluster data flow. When assessing communication costs, factors such as sensor range node degrees considered, ranging from the least to largest, and the consistency or variability of power levels, are considered, as demonstrated as (1).

$$AMRP = \frac{\sum_{i=1}^{M} MinPw_i}{M} \tag{1}$$

With help of the average minimum reachability power (AMRP) we can able to measure the cost of intra-cluster communication. The formula is shown in the (1).

The bio-inspired WSN network is established with the usage of using HEED clustering technique to ensure the following:
a) Nodes of the sensor communication exhibit dynamic behavior and offer services to a mobile agent.
b) The levels of the power of the sensor nodes is assigned in a way that ensures appropriate energy usage during multi-hop exchange of information amongst base stations.
c) Sensor nodes created using the technique (HEED) exhibit consistent processing characteristics while communicating data and remain unattended after deployment.
d) To guarantee a suitable temporal relationship, the condition TNO >> TCP is upheld during network processing. Here, TNO represents the time interval for protocol operations, and TCP signifies the clustering time interval.
e) Clustering serves the evaluating the selection of CHs for the suggested protocol for routing, intended to raise the bio-inspired WSN's energy efficiency and mobility.

3.2. Proposed algorithm-(HPSOPIO)

In this part, authors are proposing the interesting protocol based on the combination of hybrid PSO and pigeon inspired optimization called as the HPSOPIO technique for identifying the heads of cluster after the organization of sensor-nodes is suggested through the HEED clustering technique usages. The PS optimizer iteratively discovers optimal result for the system by randomly redistributing cluster-heads in each generation. As a particle traverses its network's stable path, the PSO invariably endeavors to adjust its velocity. Randomly generated values are given to compute the velocity aimed at the destination solution, aiming to reduce the consumption of energy per node. Increased velocity may be used to pinpoint the ideal solution of the particle swarm optimizer until the network's optimal solution is achieved. To achieve viable solutions for WSN network, the process may incorporate specific landmark operators of the pigeon block, utilizing each generation's fitness values. The swarm optimizer integrates each data point into the self-learning search model inspired by pigeon optimization.

3.2.1. Steps for proposed algorithm

Think of X as the collection of datapoints {x1, x2, x3, …, xn}, and V as the list of clusters {v1, v2, …, vc}.
i) Choose cluster centers 'c' at random.
ii) Compute the distance between cluster center and datapoint.
iii) Assign each datapoint to the cluster-centers that is closest to it out of all of them.
iv) Update the calculation for new cluster centers using:

$$v_i = \left(\frac{1}{c_i}\right) \sum_{j=1}^{c_i} x_i \tag{2}$$

$where\ c_i$ is the data point counts in cluster
v) Determine again how far off each data-point is from the recently discovered cluster centers.
vi) Proceed to step 7 if there has been no relocation of data points.
vii) Start by initializing the pigeon flock, assigning a positive random fitness value F1 to the first pigeon in a optimal group; E0.

viii) In this step algorithm determines the value of fitness by considering the near value between each member of the optimum group and each member of the pigeon set.

$$A_n = \{a^{(m)}, m = 1,2, \dots M\} \tag{3}$$

In the ideal group, M is the member numbers. Every optimum individual $a^{(m)}$ has k values for the function.
ix) The formula for the distance between the pigeon i and m in the optimal group is as follows:

$$b^{(m)}(i) = \sqrt{\sum_{j=1}^{k} \frac{a_j^{(m)} - f_j^{(m)}}{a_j^{(m)}}} \tag{4}$$

x) Each pigeon's rationalization can be further refined with use of individual fitness value and the separation from the ideal answer, with the ultimate goal of locating the optimum solution.

3.3. Simulation model parameters and its performance metric

To expand and improve WSN's bio-inspired technology, the proposed HPSOPIO protocol is simulated in NS2.34 version. The goal is to compute the way with the most energy and network mobility using HPSOPIO. Evaluate and compare the suggested HPSOPIO routing protocol's performance to that exhibited by the responsive AODV protocol and the current ACO protocol. In Table 1 the network simulation and its parameters were discussed.

Table 1. Parmeters used for the simulation

Simulation parameters	Values	Unit
Run in counts	6	-
Size of the queue	60	Packet
Model of mobility	Random	-
Size of packet	1024	Byte
Range of transmission	300	Meter
Protocol	HPSOPIO, ACO, AODV	-
Total area	1350	m^2
No of nodes	(50-300)	nodes
Time of simulation	(20–90)	Ms
Speed of every node	(1–12)	m/s
Type of traffic	UDP/CBR	-
Power transmitted	1.6	Joule
Power receipted	1.2	Joule
Idle power	0.06	Joule

WSN network performance is evaluated using the recommended routing protocol using a variety of criteria. The main obstacles to HEED-based clustering WSN routing are end-to-end (E2E) latency, network lifetime, packet delivery ratio (PDR), consumption of energy and throughput. Many approaches are available to address various routing issues, including as bandwidth, security, and quality-of-service and consumption of energy. The suggested method (HPSOPIO) was evaluated in relation to ACO and the reactive protocol (AODV) using the metrics covered in the ensuing subsections.

3.3.1. Performance metrics
E2E - delay, sometimes refers as the unidirectional delay, is the length of time a packet needs to travel via a network.

$$E2E\ delay = \frac{\sum_{i=1}^{n}(R_i - S_i)}{n} \tag{5}$$

Here, the variable n denotes the number of packets which is received by destination nodes and i represents the moment the packet is received inside the specified categorization range R_i and unique packet identification and the time it is delivered S_i.
EC It calculates the amount of energy used by each node relative to its initial energy level at the end of the experiment, as well as the amount of energy used by each node during the simulation.

$$EC = \sum_{i=1}^{n} in(i) - en(i) \tag{6}$$

PDR – it is the relation between the number of packets sent from the source and the range of packets received at the destination.

Network lifetime - this metric, is meant to replicate the period from the network's initial readying to the primary loss of coverage. As such, network lifespan will as an alternative be outlined because the 'time till the primary node dies.

Throughput – this parameter states the packet transmitting ratio per second at time of simulation

The routing packet ratio (ROR): it is the ratio of data packets sent to RP, where RP stands for the packets needed to find each node in network.

$$ROR = \left(\sum \frac{RP}{RP+DDP}\right) * 100 \tag{7}$$

4.   RESULTS AND DISCUSSION

This research section offers a succinct review of the findings from contrasting the existing ACO and AODV protocols with the suggested HPSOPIO methodology. The efficacy of the suggested protocol is assessed with the use of performance metrics like the PDR, EC, network lifespan, throughput, and ROR. The many node attributes included in the analytical study was node speed. To explore the mobility and energy efficiency problems in WSNs, the HEED technique used to establish the simulation environment, and HPSOPIO routing protocol used to choose the Heads of Cluster. A 250×250 square meter area was utilized to deploy 150 nodes for generating simulation results, with the sensing element nodes deployed to detect physical characteristics. The aforementioned performance metrics are used in this analysis to evaluate the WSN's potential to deliver effective network performance by extending network lifespan and reducing energy usage. The metrics are assessed at several iterations (50, 80, 110, 140, 170, and 200), with the corresponding outputs presented graphically. The parameters such as EC, network lifetime, PDR, E2E latency and throughput were observed for the HPSOPIO, ACO, and AODV protocols. It's noteworthy that the below diagrams illustrate how specific performance metric configurations impact HPSOPIO protocol scenarios, including energy reducing as usage and extending network lifespan. The performance measures such as PDR, end-to-end latency, EC, network lifespan, and throughput of the suggested HPSOPIO method, Table 2 compares the results with the competing current technology.

Table 2. Performance comparison for protocols varying with no of nodes

Parameters	Protocol model	50	80	110	140	170	200
E2E (S)	HPSOPIO	22.71	20.65	18.45	15.98	14.65	11.56
	ACO	27.65	25.65	24.74	21.96	20.12	19.56
	AODV	29.83	28.69	27.96	23.65	21.96	21.41
PDR (%)	HPSOPIO	78.5	84.5	87.32	91.23	93.65	95.65
	ACO	76.22	81.65	83.74	86.74	87.63	89.54
	AODV	75.45	79.68	81.85	83.52	85.35	88.74
EC (j)	HPSOPIO	13.52	15.69	19.63	23.41	24.56	26.36
	ACO	15.68	18.69	20.41	25.36	26.12	28.96
	AODV	17.25	19.36	23.65	26.85	28.96	31.25
Network lifetime	HPSOPIO	26,532.21	19,563.96	15,365.65	13,698.85	11,523.36	9,654.63
	ACO	21,521.18	15,968.85	11,965.96	8,756.12	6,123.63	4,658.14
	AODV	18,896.36	12,874.96	8,963.41	6,521.54	4,145.25	1,965.13
Throughput (b/S)	HPSOPIO	31,589.65	32,569.96	35,698.45	37,521.88	39,632.54	42,965.8
	ACO	27,963.63	28,965.14	30,145.36	32,521.36	34,587.25	37,125.63
	AODV	27,563.65	29,632.52	30,965.85	33,552.21	35,214.52	38,521.21

Figure 4 displays the impact of node count on energy-consumption across many runs for each of the three routing approaches. It has been noted that energy-consumption of nodes rises with their number. Additionally, HPSOPIO uses the least energy and AODV uses the most energy when nodes in the specified environment changes dynamically.

As seen in Figure 5, the network lifespan reduces as the number of nodes grows. Nonetheless, the recommended routing scheme does improve the longer network lifetime as the node count increases. Figure 6 illustrates the effect of node speed on the E2E latency of the HPSOPIO, ACO, and AODV protocols. The likelihood of a node connection failing increases sharply with sudden increases in node speed, increasing the E2E latency of routing protocols. Interestingly, it is demonstrated that HPSOPIO has the lowest E2E latency at high node speeds. Figure 7 demonstrates unequivocally that the PDR reached by adopting HPSOPIO is much higher than the other routing protocol systems, reaching up to 95.65% for the nodes in maxcount (200).

In contrast, the reactive AODV protocol and the ACO system have lower PDRs—88.74% and 89.54%, respectively.
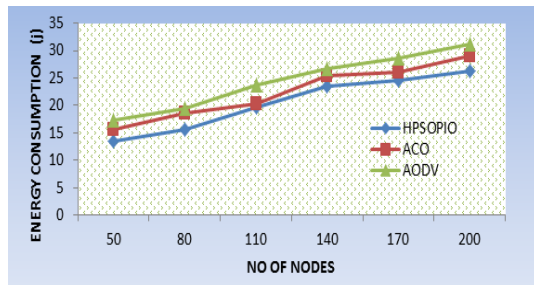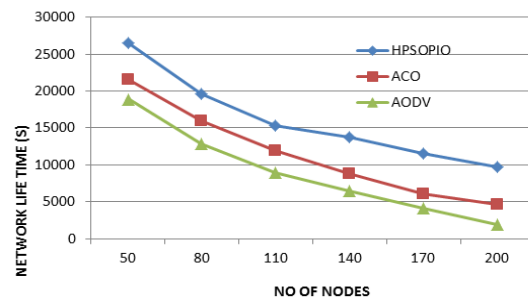

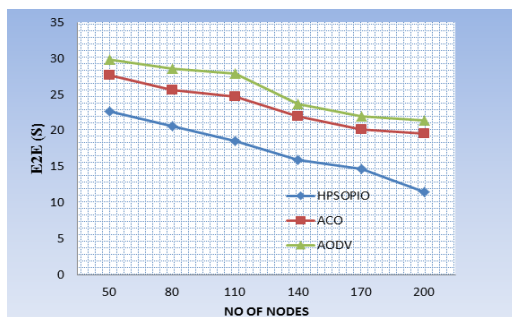Figure 4. Energy consumption

Figure 5. Network lifetime

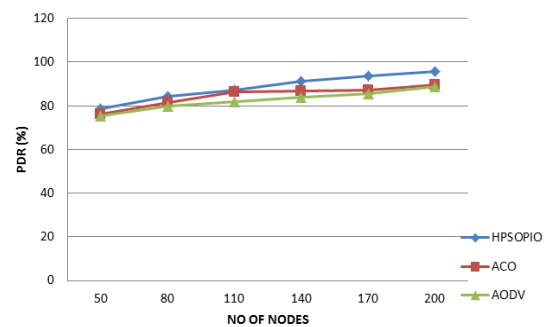
Figure 6. End to end delay

Figure 7. Packet delivery ratio

5.   CONCLUSION

With all of its fascinating features, the field of WSNs has garnered a lot of attention. The researchers have lately exploited the robust architecture of WSN technology to solve issues like mobility and energy usage inside the WSN environment. In this, the demonstration of the HPSOPIO protocol and replicated it in a WSN environment using the ns2 simulator. Numerous performance measures, including EC, PDR, ROR, E2E, network durability, and throughput, were evaluated the routing protocol's performance. The HPSOPIO protocol performed better than both the ACO protocol and the reactive version of the AODV protocol, according to the simulation findings. The recommended routing method demonstrates how it may improve nodes' energy-efficient pathways, resulting in a longer network lifespan.

REFERENCES

[1]   R. Ramamoorthy and M. Thangavelu, "An enhanced hybrid ant colony optimization routing protocol for vehicular ad-hoc networks," *Journal of Ambient Intelligence and Humanized Computing*, vol. 13, no. 8, pp. 3837–3868, Apr. 2022, doi: 10.1007/s12652-021-03176-y.
[2]   S. Saxena and D. Mehta, "An adaptive fuzzy-based clustering and bio-inspired energy efficient hierarchical routing protocol for wireless sensor networks," *Wireless Personal Communications*, vol. 120, no. 4, pp. 2887–2906, May 2021, doi: 10.1007/s11277-021-08590-1.
[3]   R. Yadav, I. Sreedevi, and D. Gupta, "Bio-inspired hybrid optimization algorithms for energy efficient wireless sensor networks: a comprehensive review," *Electronics (Switzerland)*, vol. 11, no. 10, p. 1545, May 2022, doi: 10.3390/electronics11101545.
[4]   P. Nayak and C. P. Reddy, "Bio-inspired routing protocol for wireless sensor network to minimise the energy consumption," *IET Wireless Sensor Systems*, vol. 10, no. 5, pp. 214–220, Oct. 2020, doi: 10.1049/iet-wss.2019.0198.
[5]   A. Tandon, P. Kumar, V. Rishiwal, M. Yadav, and P. Yadav, "A bio-inspired hybrid cross-layer routing protocol for energy preservation in WSN-assisted IoT," *KSII Transactions on Internet and Information Systems*, vol. 15, no. 4, pp. 1317–1341, Apr. 2021, doi: 10.3837/tiis.2021.04.008.
[6]   Y. Liu, Q. Wu, T. Zhao, Y. Tie, F. Bai, and M. Jin, "An improved energy-efficient routing protocol for wireless sensor networks," *Sensors (Switzerland)*, vol. 19, no. 20, p. 4579, Oct. 2019, doi: 10.3390/s19204579.
[7]   J. Singh *et al.*, "Energy-efficient clustering and routing algorithm using hybrid fuzzy with grey wolf optimization in wireless sensor networks," *Security and Communication Networks*, vol. 2022, pp. 1–12, May 2022, doi: 10.1155/2022/9846601.
[8]   S. B. N. Premakumari, P. Mohan, and K. Subramanian, "An enhanced localization approach for energy conservation in wireless sensor network with Q deep learning algorithm," *Symmetry*, vol. 14, no. 12, p. 2515, Nov. 2022, doi: 10.3390/sym14122515.

[9] S. K. Praharaj and C. K. Nayak, "Minimization of energy holes using bio-inspired energy optimization techniques in wireless sensor networks," *European Chemical Bulletin*, vol. 12, no. 10, 2023, doi: 10.48047/ecb/2023.12.si10.00368.

[10] R. Zulfiqar, T. Javid, Z. A. Ali, and V. Uddin, "Novel metaheuristic routing algorithm with optimized energy and enhanced coverage for WSNs," *Ad Hoc Networks*, vol. 144, p. 103133, May 2023, doi: 10.1016/j.adhoc.2023.103133.

[11] B. K. Patra, S. Mishra, and S. K. Patra, "Energy efficient clustering and optimal multipath routing using hybrid metaheuristic protocol in wireless sensor network," in *Lecture Notes in Networks and Systems*, vol. 376, Springer Nature Singapore, 2022, pp. 543–554.

[12] K. B. Baby and M. Lingaraj, "Bio-inspired routing protocol to enhance performance of wireless sensor network," *Journal of Physics: Conference Series*, vol. 1921, no. 1, p. 12078, May 2021, doi: 10.1088/1742-6596/1921/1/012078.

[13] V. Veerakumaran and A. Rajini, "Hybrid optimization-based efficient routing protocol for energy consumption minimization in mobile wireless sensor network," *International Journal of Computer Networks and Applications*, vol. 9, no. 5, pp. 591–600, Oct. 2022, doi: 10.22247/ijcna/2022/215919.

[14] A. Saini and A. Kansal, "Hybrid approach to reduce energy utilization in wireless sensor network using bio-inspired technique," *International Research Journal of Engineering and Technology (IRJET)*, vol. 6, no. 6, pp. 1411–1416, 2019.

[15] P. Nandhini and A. Suresh, "Energy efficient cluster based routing protocol using charged system harmony search algorithm in WSN," *Wireless Personal Communications*, vol. 121, no. 3, pp. 1457–1470, Jul. 2021, doi: 10.1007/s11277-021-08679-7.

[16] S. Kaviarasan and R. Srinivasan, "Developing a novel energy efficient routing protocol in WSN using adaptive remora optimization algorithm," *Expert Systems with Applications*, vol. 244, p. 122873, Jun. 2024, doi: 10.1016/j.eswa.2023.122873.

[17] A. Saad, I. Hegazy, and E. S. M. El-Horbaty, "Efficient bio-inspired routing algorithm for IoT," in *Proceedings - 2021 IEEE 10th International Conference on Intelligent Computing and Information Systems, ICICIS 2021*, Dec. 2021, pp. 303–310, doi: 10.1109/ICICIS52592.2021.9694257.

[18] M. Z. 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, May 2022, doi: 10.1155/2022/8455065.

[19] J. Vellaichamy *et al.*, "Wireless sensor networks based on multi-criteria clustering and optimal bio-inspired algorithm for energy-efficient routing," *Applied Sciences (Switzerland)*, vol. 13, no. 5, p. 2801, Feb. 2023, doi: 10.3390/app13052801.

[20] J. D. K. Hezekiah *et al.*, "Nature-inspired energy enhancement technique for wireless sensor networks," *Energies*, vol. 16, no. 20, p. 7021, Oct. 2023, doi: 10.3390/en16207021.

[21] M. Ahmad, A. A. Ikram, I. Wahid, M. Inam, N. Ayub, and S. Ali, "A bio-inspired clustering scheme in wireless sensor networks: BeeWSN," *Procedia Computer Science*, vol. 130, pp. 206–213, 2018.

[22] J. Wang, X. Yang, T. Ma, M. Wu, and J. U. Kim, "An energy-efficient competitive clustering algorithm for wireless sensor networks using mobile sink," *International Journal of Grid and Distributed Computing*, vol. 5, no. 4, pp. 79–92, 2012.

[23] N. Almansour and S. Alahmadi, "Secure ad hoc on-demand distance vector routing protocol in WSN," Apr. 2018, doi: 10.1109/CAIS.2018.8441991.

[24] C. Vimalarani, R. Subramanian, and S. N. Sivanandam, "An enhanced PSO-based clustering energy optimization algorithm for wireless sensor network," *Scientific World Journal*, vol. 2016, pp. 1–11, 2016, doi: 10.1155/2016/8658760.

[25] N. Holden and A. A. Freitas, "A hybrid PSO/ACO algorithm for discovering classification rules in data mining," *Journal of Artificial Evolution and Applications*, vol. 2008, pp. 1–11, May 2008, doi: 10.1155/2008/316145.

[26] M. A. Jubair *et al.*, "Bat optimized link state routing protocol for energy-aware mobile ad-hoc networks," *Symmetry*, vol. 11, no. 11, p. 1409, Nov. 2019, doi: 10.3390/sym11111409.

[27] A. Jain, D. S. Thakur, and V. Malviya, "A novel approach for gateway node election method for clustering in wireless mobile ad hoc networks," in *Advances in Intelligent Systems and Computing*, vol. 870, Springer Singapore, 2019, pp. 205–214.

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