

# Optimizing Energy Consumption Using Fruit Fly and Ant Colony Optimization Algorithms in Wireless Sensor Networks

Rajeev Kumar<sup>1</sup>, Reeta Bhardwaj<sup>2</sup>, Pawan Kumar<sup>3</sup>

<sup>1,2</sup>Assistant Professor, DAV Institute of Engineering & Technology, Jalandhar, Punjab, India.

<sup>3</sup>Research Scholar, I.K.Gujral Punjab Technical university, Jalandhar, Punjab, India.

## Abstract

Wireless sensor networks (WSNs) are crucial in sensing environmental conditions in far-flung areas. However, their energy consumption remains a critical issue, affecting the network's lifetime and coverage area. Clustering has emerged as an efficient strategy to prolong sensor network lifespan, and the Fruit Fly Algorithm (FFA) and Ant Colony Optimization (ACO) are promising techniques for cluster formation and efficient path establishment, respectively. This work proposes a pioneering approach by combining FFA for cluster formation and ACO for path establishment. This novel algorithm is implemented in MATLAB and evaluated in both homogeneous and heterogeneous environments. This work makes a comparison between the Biogeography-Based Optimization Algorithm (BOA) and the Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm. Our results indicate that the new algorithm significantly surpasses both BOA and LEACH in the light of network lifetime and coverage area, particularly in heterogeneous environments.

## Keywords

Fruit Fly, Ant Colony, BOA, LEACH, Path Optimization, Clustering

## 1. Introduction

Advancements in modern technology have led to the development of small electrical sensor devices requiring minimal power. These sensors are deployed in remote locations as part of wireless sensor networks (WSNs) to measure various physical variables [1]. WSNs find applications across industries, including environmental monitoring, disaster management (such as detecting air pollution, landslides, and forest fires), distributed situational awareness, geographic targeted investigations, smart monitoring, defence reconnaissance, as well as wellness monitoring tasks like blood glucose monitoring, cancer detection, and managing mass casualty disasters. In contrast to conventional networking solutions, WSN technology offers several benefits, like effortless installation, lower implementation costs [2], enhanced accuracy, and scalability, across various applications. Typically comprising hundreds of sensor nodes (SNs), WSNs facilitate seamless interaction among nodes to transmit high-quality data to a central base station (BS) without reliance on existing infrastructure [3]. This self-organizing feature allows WSNs to be deployed as required. As depicted in Figure 1, SNs are distributed randomly across remote locations or sensor fields, establishing connections with each other to measure physical variables.

Additionally, replacing fully deployed sensor nodes (SNs) is highly challenging in various settings [4], especially in hostile environments like mines and battlefields. The accuracy and reliability of the transmitted data improve with the increased number of SNs monitoring a particular region or event. Figure 1 shows how, in accordance with the chosen routing protocol or algorithm, each SN transmits sensed data to the base station (BS). In addition to allowing SNs to optimize routes in order to reduce costs, this protocol specifies how SNs communicate data in order to transmit sensed information to the BS [5]. The routing algorithm chooses the path. It is frequently constructed as a clustering or load-balanced tree routing method. A routing protocol that is economical is created to achieve the best balance between properties like scalability, timeliness, and resilience. The routing protocol's primary goal is to use as little energy as possible to greatly increase the life expectancy of the network [6]. Balancing these Quality of Service (QoS) standards makes routing in WSNs challenging. Given that sensor nodes

10.48047/jocaaa.2024.32.01.68

(SNs) are primarily battery-operated devices, energy efficiency is of utmost importance. Therefore, effective management of sensor nodes' (SNs) energy consumption is crucial to increase the longevity of the network and maintain its usefulness for an acceptable duration [7], specifically when the nodes rely entirely on energy usage.

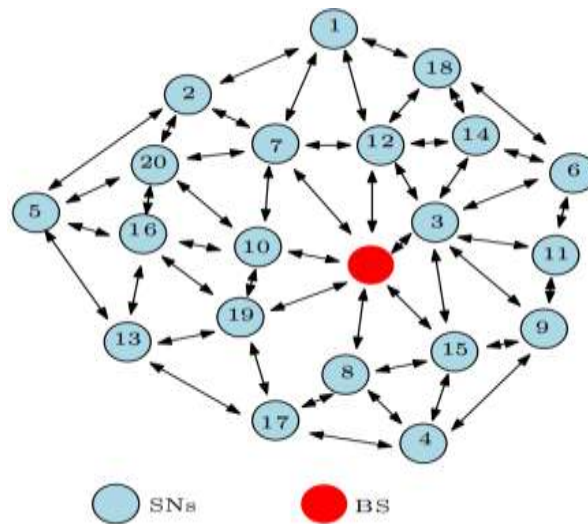


Figure 1. Simplified diagram of a wireless sensor network (WSN).

### 1.1 Energy-efficient routing

Routing indeed imposes additional strain on energy supplies, particularly in multi-hop solutions where nodes nearby sink bear more packet-routing responsibilities, leading to quicker battery depletion. Various routing paradigms incorporate general energy-saving mechanisms, which we'll discuss next.

i. Cluster architectures: A cluster head (CH) is a designated node that oversees each cluster in a cluster design, which divides the network into clusters [8]. In addition to interacting with the base station or other cluster heads, the cluster head is in charge of assigning tasks to the cluster members. Cluster techniques aim to improve energy efficiency in a number of ways: by reducing the range of communication within the cluster, which lowers the amount of power used for transmission; by reducing the number of transfers made by the cluster head through data fusion; by reducing the amount of energy-intensive tasks assigned to the cluster head, such as coordination and aggregation; by permitting some cluster nodes to shut down while the cluster head takes care of forwarding tasks; and finally, by distributing the usage of energy among nodes through cluster head rotation [9]. By establishing a hierarchy within the network, cluster topologies not only improve energy efficiency but also enhance network scalability.

ii. Energy as a routing metric: Energy concerns are incorporated into the setup path stage of sensor networks in order to extend their lifespan [10]. This makes it possible for routing algorithms to choose the subsequent hop based on the nodes' remaining energy as well as the fastest pathways. Two new energy-conscious cost functions have been introduced by researchers. When choosing a route, the Exponential and Sine Cost Function based Route (ESCFR) function favors sensors with higher residual energy, ensuring energy balance [11]. This makes it an especially notable function. ESCFR is a useful tool for energy-aware routing since even a small change in nodal energy can have a big impact on the cost function value. The Double Cost Function based Route (DCFR) protocol takes into account both the nodes' rate of energy consumption and remaining energy. This is important because hotspot nodes often run out of energy quickly. Even in networks with obstacles, DCFR enhances the routing protocol's energy-balancing performance by taking into account both elements [12].

iii. Multipath routing: Despite being less complicated than multipath routing protocols, single-path routing can quickly deplete energy along the selected path. By alternating forwarding nodes, multipath routing, on the other

10.48047/jocaaa.2024.32.01.68

hand, enables a fairer allocation of energy among nodes [13]. To find various node-disjoint paths, for instance, the Energy Efficient Multipath Routing Protocol (EEMRP) uses a cost function depending on energy levels and hop distances. The traffic rate is then split up across these chosen paths. Between a source and a sink, the EECA (Energy-Efficient and Collision Aware) protocol creates two node-disjoint, collision-free pathways. Providing many paths, multipath routing techniques improve network stability more quickly than single-path schemes, which require rearranging a new route in the event of a node failure [14].

iv. Relay node placement: Energy holes or network fragmentation can result from the early loss of nodes in a particular location. Sometimes, though, this circumstance can be avoided by distributing nodes equally or by include relay nodes with improved capabilities. This prevents sensor hotspots, guarantees coverage and k-connectivity, and enhances the energy balance amongst nodes. Finding the bare minimum of relay nodes or where to put them best to increase network longevity has been the subject of several studies [15]. For instance, in order to minimize the average hop distance between each of the nodes and its closest sink, researchers strategically arrange static sinks.

v. Sink mobility: When a static base station is used in a WSN architecture, sensors close to it typically run out of battery power faster than other sensor nodes. The reason for this imbalance is that all traffic is routed toward the sink, which puts more strain on the nodes that are closest to it. By using a mobile base station that roams the network to gather node data, it is possible to distribute the load across nodes and increase the lifetime of the network [16]. Due to single-hop communication, sink mobility not only improves connectivity and reliability in sparse systems but also lowers disputation, incidents, and message loss. Controlling the base station's movement enables research into reducing excessive latency, buffer overload, and loss of energy.

## 2. Literature Review

In paper [17], author suggested a TEMSEP to enhance the energy consumption in huge-scale Wireless Sensor Networks. Rather than transmitting data continuously, the network nodes were focused on transmitting their data only according to requirement. For this, these nodes responded reactively against the changes in applicable metrics. A novel thresholding framework was put forward to generate a perfect system for this kind of reactive behavior to detect trials, depending upon values of heterogeneous thresholds. The SW model was built for regulating the data reporting frequency which led to mitigate load of network, optimize power utilization of energy-enabled nodes, and prolong the duration of network. In simulation outcomes, the suggested protocol was more effective for alleviating the traffic-load around 53% and saving overall dissipated energy around 73%. Furthermore, this protocol augmented a stability period up to 69% and prolonged the duration of network up to 56% in contrast to other methods.

The author presented an EE-TLT [18] for SN energy deployment and stabilization. This protocol aimed to split the regional network into clusters, having several nodes balanced in every cluster. Every cluster was responsible for dividing the nodes again into polygons. The TLT method was implemented to transmit the data only using short links. The energy residual and distance were taken in account amid candidate nodes and the BS for verifying CH or relay CH mote in every polygon or sector. Moreover, this protocol was exploited to select an optimal stage length to transmit data in every round due to which the data packets transmitted to sink, were maximized. According to experiments, the introduced protocol was robust for balancing the energy consumption amongst sensors as well as enhancing the ratio of data packets sent to sink and EE up to 25% against first existing algorithm, 15% against next, and 10% than last method.

The MOALO-FCM technique was introduced by the authors of the study [19] to achieve trade-offs between different optimization goals. Thereafter, an adaptive membership function (AMFR) technique was put forward for avoiding the issue related to unbalanced energy consumed by relay nodes (RN). Two-dimensional (2D) and 3D scenes were considered with correlative algorithms in experimentation for computing the presented algorithm with respect to POS sets, lifespan of network, power utilization of SNs and relay nodes (RNs), amount of living motes, and run time of methods. The experimental outcomes validated the supremacy of presented

approach over existing methods. Moreover, this algorithm was capable of mitigating energy usage, extending the duration of network, and offering several methods.

In order to reduce energy consumption and extend the lifespan of WSN, the authors [20] developed a novel routing protocol. A novel method was presented for selecting cluster head (CH) relied on energy at every sensor node (SN). This method was deployed for alleviating the energy utilization of SNs and prolonging the life span of WSN. The complex task was to select Cluster Heads set and its amount. This method was implemented for exploring precise paths. FFO algorithm was employed based on variation in network topology, power etc. The devised method was simulated in contrast to traditional methods. The simulations depicted that the devised method was performed well and yielded lower EC and superior PDR amid SNs and base station (BS). Furthermore, this method expanded the duration of WSN.

In order to ensure accurate optimum energy conservation, the authors [21] developed a CBPR approach dubbed DE-SEP. The energy and distance metrics were considered to select CH for providing priority for relatively greater power nodes and to choose the closer nodes from sink as Cluster Head. Besides, this method was utilized to enforce a restriction on amount of Cluster Heads. It resulted in deploying a precise number of CHs for avoiding redundant cluster generation and diminishing the energy consumption. The experiments revealed that the established protocol had offered longer duration of network, higher stability period, greater throughput, and enhanced normalized residual energy (RE). This protocol was led to maximize the normalized RE up to 5%, 41%, and 41% than other algorithms.

A novel Davies-Bouldin K Nearest Neighbour (DBKNN) and Radial-ANFIS architecture was proposed by the authors [22] to reduce energy usage in WSNs. This initial task was to split the deployed nodes and extract the node features. The Laplacian Cubic Cheetah Optimizer (LCCO) was exploited for selecting cluster heads (CHs) based on features and initial method was applied for clustering the nodes. At second, the AI-GTBO method was employed to choose relay nodes (RNs) based on weight value, which were later utilized for generating routes amid node and Base Station (BS) and evaluating the shortest route. Nodes were utilized for sensing the data after developing the network and computing the association amid every data. The redundant node was detected when the second algorithm was fed with analytic output. In the end, the remaining node data was employed to transmit data to BS. The NRI-PCA was utilized to mitigate the first dimension. The experimental results confirmed that the suggested framework was more effective to mitigate energy usage and enhancing duration and throughput. The accuracy of this framework was found 0.9649 and the power usage was 3748J for fifty nodes.

In paper [23], author projected an IBORSDFNL method to enhance energy efficiency [23]. Various paths were generated to aggregate the data effectively in WSN. Two processes were executed for discovering the route path and selecting it. This method was utilized for generating various route paths from distributed sensor nodes (SNs). An improved buffalo optimization (IBO) algorithm was utilized to select the finest route so that the data was aggregated at lower EED and higher PDR. Various metrics, such as EED, power usage and PDR were employed for simulating the projected method. Based on simulation, the projected method was performed well in contrast to other methods for mitigating energy utilization, EED and maximizing PDR.

An enhanced Engroove Leach (EL) protocol was created by the authors of the research [24] to extend network functioning at reduced energy consumption. The clustering and routing protocols were implemented for prolonging the duration of network. The MIHFO model was adopted to cluster the data. The power, distance to BS, were exploited for selecting the cluster head (CH). A Heuristic Wing Ant-fly Optimization (HWAFO) algorithm was deployed for selecting the optimum route from CH to BS. An analysis was conducted on the number of active nodes, power usage, and the amount of packets sent to sink. On MATLAB, the developed protocol had provided higher throughput, greater packet delivery rate (PDR), least drop ratio, and lower energy consumption (EC).

A new MOC technique for merging SNs of wireless sensor networks was created by the author of the research [25]. Furthermore, an Election based Aquila Optimizer (EAO) algorithm was presented in which Aquila Optimizer

10.48047/jocaaa.2024.32.01.68

(AO) was integrated with Election-Based Optimisation Algorithm (EBOA) for choosing CH so that the finest Cluster Head was selected. Moreover, this algorithm was deployed with CNN called O-CNN for maximizing the precision and accuracy. The experimental results demonstrated the superiority of designed method over existing techniques and attained an accuracy of 99.23%, throughput of 76.92%, packet delivery ratio (PDR) of 99%, life span of network of 98.24% and energy consumption of 50%. Additionally, this method was resistible for tackling the complexity occurred in precision agriculture.

To reduce energy usage, the author of the study [26] wanted to use an EAR approach that relies on GoLCA. This technique had alleviated the homogeneous energy utilization when the life span of network was expanded with respect to RE, amount of lively neighbourhoods, and a sleeping schedule. A set of rules was employed to analyse dissimilar behaviours of WSN in a discrete dynamic (DD) model. This technique was emphasized on integrating this model with a difference of ASA. In findings, the recommended technique was applicable in balancing power rate, and prolonged duration of network than existing approaches. Additionally, this method led to mitigate energy consumption with PP methods for mitigating power usage.

### 3. Research Methodology

This research work is based on network deployment, cluster formation and data routing from cluster head to base station. The cluster formation is done using fruit fly algorithm and path will be established using ant colony optimization. The details are given:

**1. Network Deployment:** - One of the fundamental prerequisites for the application of a clustered wireless sensor network is the random distribution of nodes. Randomly distributed sensor nodes give rise to cluster heads, which further exacerbates a number of problems. It is necessary to prevent the cluster head from being disposable due to its excessive use of energy. Additionally, the cluster head prevents communication over long distances, and nodes below them are added here as well. The nodes—known as cluster heads—are not chosen in accordance with the planned requirements and are therefore not flawless. It was nearly hard for nodes to be available in remote areas of the network due to their conditions, which further contributed to the improper nodes. These nodes serve as cluster heads when the intra-cluster energy is raised. When compared to the sender and recipient nodes, the authentic node uses less energy. As long as the system receives the wide spectrum in a coordinated fashion, the nodes' battery usage is significantly reduced. For each cluster head, the parent node is chosen in order to isolate actions and boost productivity. Each sensor node's competence is given two value functions, which aids in the node's selection as the cluster head. The average power of neighbouring nodes is determined by their distance from the base station, and the degree of nodes generates functions. In order for the cluster head to form, higher degree nodes must be generated. If the cluster head has higher degree can cover large number of nodes which avoids the expensive communications.

**2. Cluster Formation:** - After the network is established, it will be split up into clusters. The clusters will be formed based on the distance. The formed clusters will be optimized using fruit fly algorithm, as shown in Figure 2. Fruit flies rely on their keen sense of smell and vision to locate food, which is superior compared to other fly species. Leveraging swarm intelligence optimization, FOA is adept at adjusting parameters swiftly and effectively due to its optimization speed and parameter flexibility. Guided by the fitness function, which acts as an odor concentration decision function, FOA aims to iteratively adjust the fruit fly population within the solution space. This process typically involves four steps.

1. Initialization: Initialization entails determining the starting parameters for the fruit fly population, such as population size, maximum iterations, initial positions, and step length. This enables fruit flies to navigate towards their target using random flight directions and ranges.

$$X(i) = X_0 + Step \quad (1)$$

$$Y(i) = Y_0 + Step \quad (2)$$

The initial position of the fruit fly is denoted by  $X_0$  and  $Y_0$ .

2. Judgment: Compute the scent concentration (scent) of the fruit fly position using the fitness function.

$$Smell(i) = Function(S(i)) \quad (3)$$

$$S(i) = \frac{1}{Sqrt(X(i)^2 + Y(i)^2)} \quad (4)$$

3. Movement: Movement involves selecting the fruit fly individual with the highest concentration within the population, designating its location as the ideal position. Subsequently, instruct the remaining fruit flies to move in that direction based on their initial step length.

$$X(i+1) = (X_i + Step) * S(i) \quad (5)$$

$$Y(i+1) = (Y_i + Step) * S(i) \quad (6)$$

4. Iteration: Repeat steps (2) and (3) until the scent concentration either meets the predefined threshold or reaches the maximum number of iterations. The fitness function selects the root mean square error (RMSE), described as follows:

$$min\delta_R = \sqrt{\sum_{i=1}^n (y_i - \hat{y}_i)^2 / n} \quad (7)$$

This indicates the projected position value as  $\hat{y}_i$ , the discrete position data utilized for processing denoted by  $y_i$ , the count of data represented by  $n$ , and the root mean square as  $\delta_R$ ,

**3. Path Establishment:** - The data transmission path is defined from the cluster head to the base station. The ant colony optimization algorithm will be used to optimize the path, as shown in Figure 3. ACO is a nature inspired approach that simulates how real ants behave when they are trying to find the shortest route to food sources. Ants are prone to choosing pathways indicated by the strongest pheromone concentrations. The ACO algorithmic approach uses mechanisms of cooperation and optimization to simulate the ants' natural behavior. By mimicking the strategies employed by real ants, the ACO algorithm quickly determines the best path from the source of food to their nest without the need for any visual cues. The ACO algorithm generates solutions through a number of rounds. Several ants create a comprehensive solution in each iteration by utilizing the heuristic data and the collective experiences of previous ant groups. The pheromone trail that forms on the component parts of a solution is indicative of these cumulative experiences. Using the transition rule, each ant visits each other cluster head after starting at a different cluster head at random. Updating the pheromone data frequently is the learning process.

#### 1. The transition rule

In the path, the  $k^{th}$  ant begins from city  $r$ , the selection of next city  $s$  is done amongst the remote cities memorized in  $J_r^k$

$$s = \underset{u \in J_r^k}{argmax} [\tau_i(r, u)^\alpha \cdot \eta(r, u)^\beta] \text{ if } q \leq q_0 \text{ (Exploitation)} \quad (8)$$

For visiting the new city  $s$  with the probability  $p_k(r, s)$ ,

$$p_k(r, s) = \begin{cases} \frac{\tau(r, s)^\alpha \cdot \eta(r, s)^\beta}{\sum_{u \in J_r^k} \tau(r, u)^\alpha \cdot \eta(r, u)^\beta} & \text{if } s \in J_r^k \\ 0 & \text{otherwise if } q > q_0 \end{cases} \quad (9)$$

#### 2. The pheromone update rule

The solution was enhanced by updating the pheromone trails. The local and global updating is comprised in the trail update process. The local trail update formula is expressed as:

$$\tau(r, u) = (1 - \rho)\tau(r, s) + \sum_{k=1}^m \Delta\tau_k(r, s) \quad (10)$$

Where, the rate to evaporate the pheromone trail is depicted with  $\rho(0 < \rho < 1)$ .  $\Delta\tau_k(r, s)$  denotes the amount of pheromone trail whose insertion is done to edge  $(r, s)$  using  $k$  ant amid in the tour. This is defined as

$$\Delta\tau_k(r, s) = \begin{cases} \frac{Q}{L_k} & (r, s) \in \pi_k \\ 0 & otherwise \end{cases} \quad (11)$$

In which  $Q$  represents the constant parameter, the distance of the sequence  $\pi_k$  that the ant toured is illustrated with  $L_k$

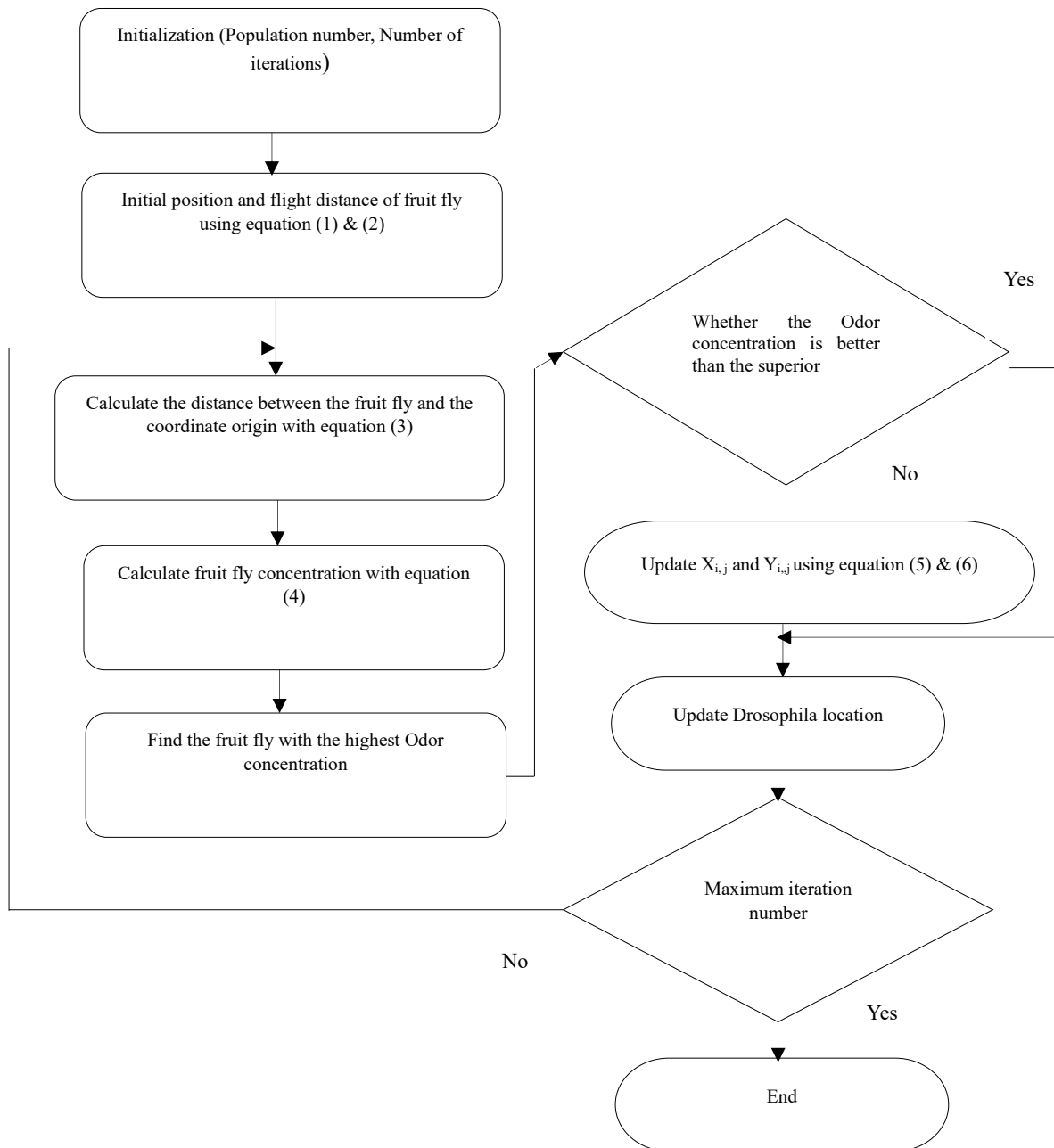


Figure 2: Fruit fly for Cluster Formation

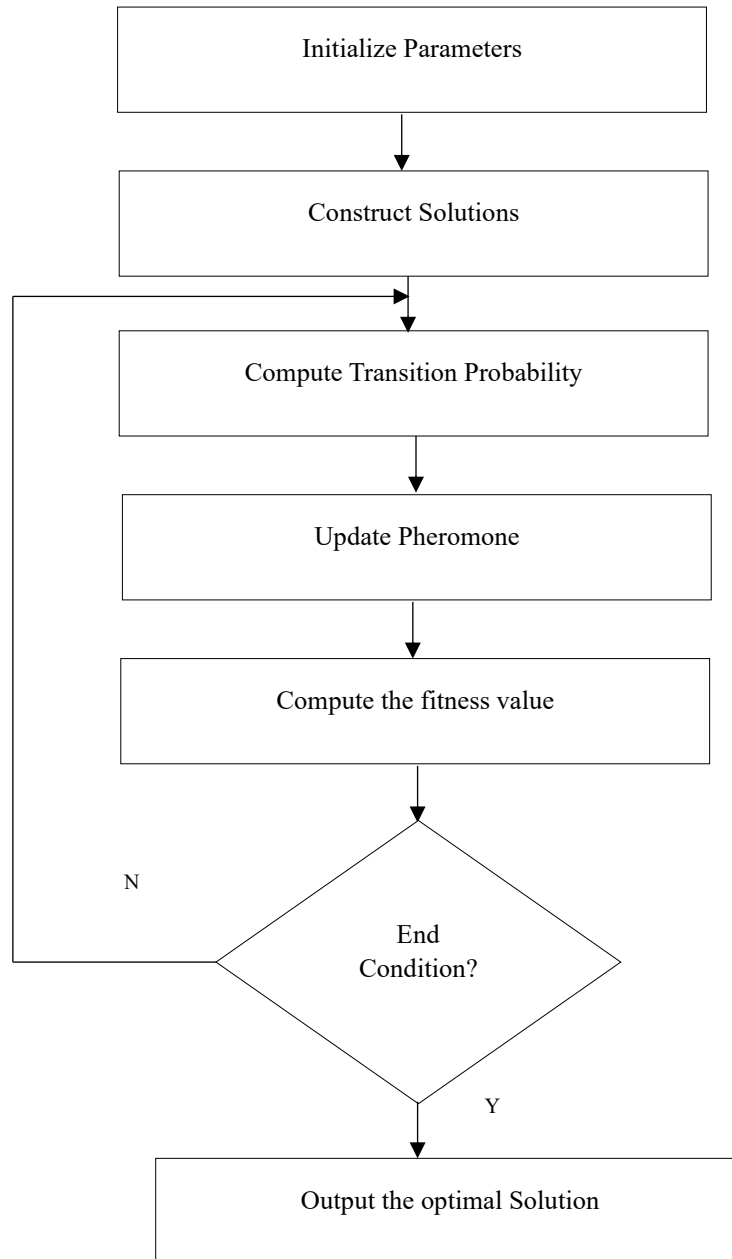


Figure 3: Ant Colony optimization for Path Optimization

#### 4. Result and Discussion

This work emphasizes on mitigating power utilization of WSNs. To improve lifetime of wireless sensor networks two optimization algorithms are applied which are fruit fly and ant colony optimization. The next task is to partition the entire network into clusters and choose CH in every cluster depending upon distance and power. The sensor nodes which have least distance to sink and the selection of maximum energy within the cluster as CH. The fruit fly algorithm is applied in the cluster formation and optimizing the formed cluster. The CH aggregate data from SNs within cluster and transmit data to sink. The optimal path will be established from cluster head to base station for the data transmission. The ant colony optimization algorithm is applied for optimizing route from CH to sink. The suggested model is tested on the both type of network which are homogeneous and heterogeneous in nature. The simulation metrics are explained in table 1. Table 2 described the sensing coverage ratio parameters. And table 3 showed the number of rounds nodes get dead.

Table 1: Simulation Parameters

Parameter	Description	Value
A	Area of network	(0, 0) - (200, 250)
L-BS	BS location	(150, 250)
N	Number of nodes in network	100
$E_{initial}$	Initial energy of all nodes	0.5 J
$E_{fs}$	Free space channel model	50 nJ/bit
Emp	Multi-path fading channel model	0.0013 pJ/bit/m <sup>4</sup>
$d_0$	Distance threshold	87 m
EDA	Data aggregation energy	5 nJ/bit/signal
DP size	Data packet size in bit	4000
CP size	Control packet size in bit	200

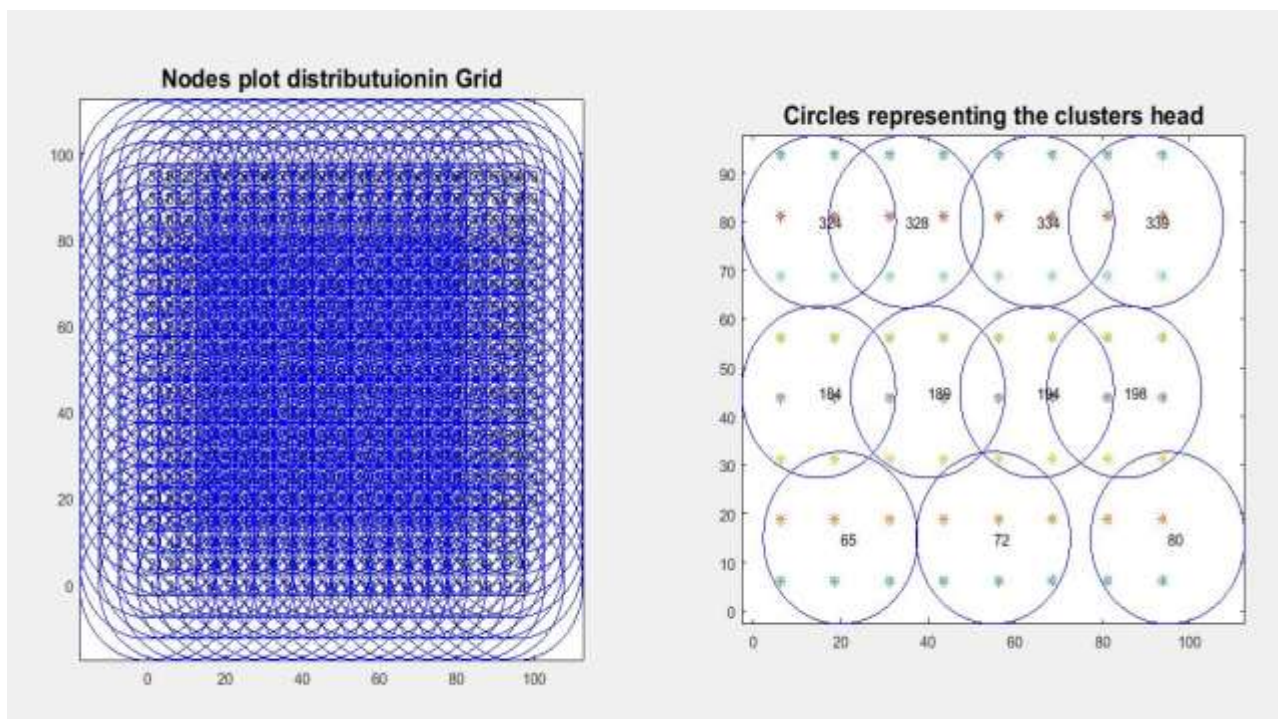


Figure 4: Node distribution and cluster formation

Figure 4 represents the deployment of entire network using restricted amount of nodes. The nodes are utilized randomly and the partition of entire network into clusters. The cluster heads are also shown in each cluster which are represented for the data aggregation.

Table 2: Sensing Coverage Ratio

Algorithm	Value
LEACH	0.2
BOA	0.4
Homogeneous Network	0.7
Heterogeneous Network	0.9

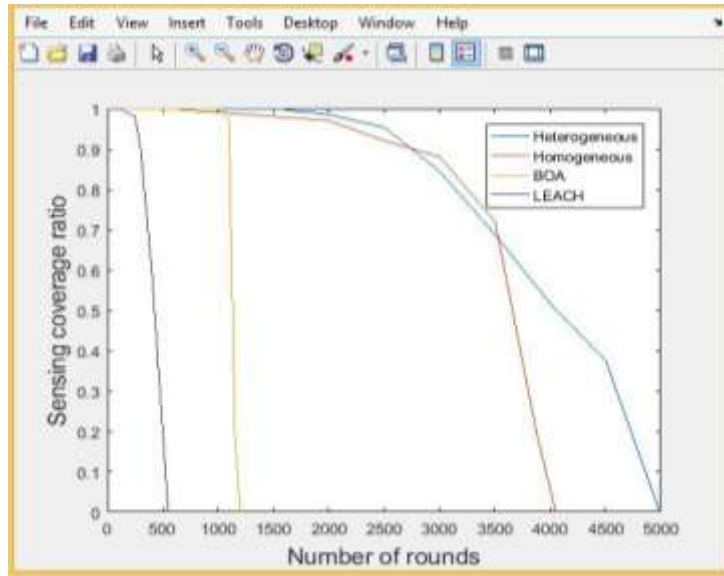


Figure 5: Sensing coverage ratio

Figure 5 illustrates the comparison of sensing coverage ratio of different method for the performance analysis. The LEACH protocol is compared with butterfly optimization and also with proposed algorithm in heterogeneous and homogeneous scenarios. The analysis exhibits the performance of suggested method in heterogeneous scenario as compare to homogeneous scenario, BOA and LEACH protocols.

Table 3: Number of Rounds Nodes Get Dead

Algorithm	Value
LEACH	500
BOA	1200
Homogeneous Network	3500
Heterogeneous Network	5000

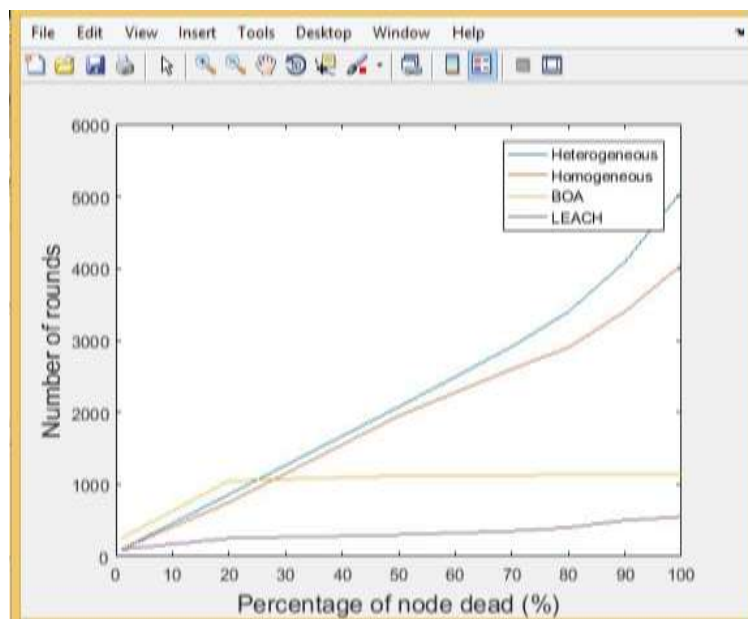


Figure 6: Percentage of dead nodes

10.48047/jocaaa.2024.32.01.68

Figure 6 indicates the comparison of suggested method with BOA, LEACH algorithms under homogeneous and heterogeneous scenarios concerning percentage of dead nodes. It is analysed that proposed algorithm under the heterogeneous scenarios has maximum performance as compared to other models.

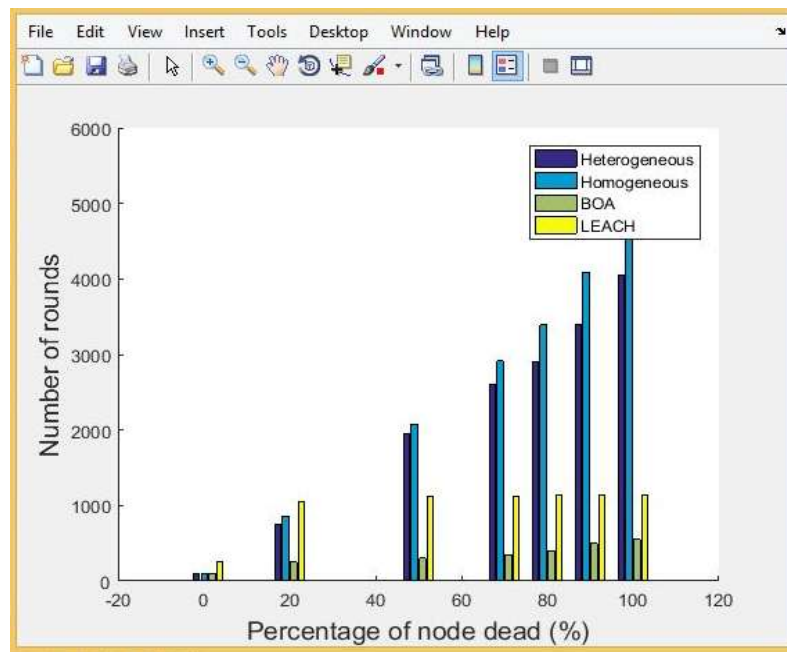


Figure 7: Network Lifetime Analysis

In figure 7, the suggested method in homogeneous and heterogeneous scenario is compared with BOA and LEACH protocol concerning duration of network. In analysis, the proposed method in heterogenous scenario has maximum lifetime as compared to other algorithms.

## Conclusion

In this study, we introduced an innovative method in which the Fruit Fly Algorithm (FFA) is employed for cluster formation and Ant Colony Optimization (ACO) for path establishment in wireless sensor networks (WSNs). MATLAB is executed to simulate introduced method and evaluated in both homogeneous and heterogeneous environments. We compared its performance against two popular algorithms, the Biogeography-Based Optimization Algorithm (BOA) and LEACH. Our results demonstrate that the introduced approach is more effective in contrast to both BOA and Low Energy Adaptive Clustering Hierarchy with respect to network lifetime and coverage area, especially in heterogeneous environments. This underscores the efficacy of our approach in effectively managing energy consumption and enhancing the performance and reliability of WSNs, particularly in scenarios that demand stringent environmental monitoring.

## References

- [1] A. G. Patil, C. R. Singla and O. Rajankar, "Design of Fuzzy Logic Clustering Algorithm for Energy Efficiency and Security in Wsn's," 2022 2nd Asian Conference on Innovation in Technology (ASIANCON), Ravet, India, 2022, pp. 1-6, doi: 10.1109/ASIANCON55314.2022.9909343.
- [2] G. Ramya, R. Nagarajan and S. Kannadhasan, "Energy Efficient Wireless Sensor Networks Using LEACH Network," 2021 International Conference on Advances in Technology, Management & Education (ICATME), Bhopal, India, 2021, pp. 83-87, doi: 10.1109/ICATME50232.2021.9732759

10.48047/jocaaa.2024.32.01.68

- [3] M. Sansoy, A. S. Buttar and R. Goyal, "Empowering Wireless Sensor Networks with RF Energy Harvesting," 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2020, pp. 273-277, doi: 10.1109/SPIN48934.2020.9071376.
- [4] M. K. Singh, D. Saxena, A. Rai and D. Kushwaha, "Energy Management Techniques of Wireless Sensor Networks for Internet of Things Applications," 2023 International Conference on IoT, Communication and Automation Technology (ICICAT), Gorakhpur, India, 2023, pp. 1-6, doi: 10.1109/ICICAT57735.2023.10263766.
- [5] A. F. Khalifeh, H. Abid and K. A. Darabkh, "Double Mobility WSN: Exploiting the Mobility of Sink and Cluster Head Nodes for Better WSN Energy Preservation and Lifetime," 2020 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), Vancouver, BC, Canada, 2020, pp. 1-4, doi: 10.1109/IEMTRONICS51293.2020.9216449.
- [6] A. S. H. Abdul-Qawy, A. B. Nasser, A. H. Guroob, A. -M. H. Y. Saad, N. A. M. Alduais and N. Khatri, "TEMSEP: Threshold-Oriented and Energy-Harvesting Enabled Multilevel SEP Protocol for Improving Energy-Efficiency of Heterogeneous WSNs," in IEEE Access, vol. 9, pp. 154975-155002, 2021, doi: 10.1109/ACCESS.2021.3128507.
- [7] S. Maurya and V. K. Jain, "Enhanced EECPP: Enhanced Energy Efficient Coverage Preserving Protocol for Heterogeneous Wireless Sensor Networks," 2018 Conference on Information and Communication Technology (CICT), Jabalpur, India, 2018, pp. 1-5, doi: 10.1109/INFOCOMTECH.2018.8722411.
- [8] V. S. Babu, P. Kumar, K. Balasubadra and T. Dineshkumar, "Link Correlation Procedure for Improving Energy Efficiency in Homogeneous WSN," 2022 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), Chennai, India, 2022, pp. 1-4, doi: 10.1109/ICPECTS56089.2022.10047771.
- [9] A. A. -H. Hassan, W. M. Shah, A. -H. H. Habeb, M. F. I. Othman and M. N. Al-Mhiqani, "An Improved Energy-Efficient Clustering Protocol to Prolong the Lifetime of the WSN-Based IoT," in IEEE Access, vol. 8, pp. 200500-200517, 2020, doi: 10.1109/ACCESS.2020.3035624.
- [10] A. G.R. and Gowrishankar, "An Energy aware Routing Mechanism in WSNs using PSO and GSO Algorithm," 2018 5th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2018, pp. 7-12, doi: 10.1109/SPIN.2018.8474140.
- [11] A. Panchal and R. K. Singh, "REHR: Residual Energy based Hybrid Routing Protocol for Wireless Sensor Networks," 2019 IEEE Conference on Information and Communication Technology, Allahabad, India, 2019, pp. 1-5, doi: 10.1109/CICT48419.2019.9066144.
- [12] K. S. Sankaran, N. Vasudevan and V. Nagarajan, "Data-Centric Routing in WSN for Energy Conservation using Directed Diffusion," 2020 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2020, pp. 1414-1417, doi: 10.1109/ICCSP48568.2020.9182169.
- [13] H. Amirinia and R. Liscano, "Optimized Application Driven Scheduling for Clustered WSN," 2020 International Symposium on Networks, Computers and Communications (ISNCC), Montreal, QC, Canada, 2020, pp. 1-6, doi: 10.1109/ISNCC49221.2020.9297230.
- [14] I. Azzouz, B. Boussaid, A. Zouinkhi and M. N. Abdelkrim, "Energy-Aware Cluster Head selection protocol with Balanced Fuzzy C-mean Clustering in WSN," 2022 19th International Multi-Conference on Systems, Signals & Devices (SSD), Sétif, Algeria, 2022, pp. 1534-1539, doi: 10.1109/SSD54932.2022.9955909.

10.48047/jocaaa.2024.32.01.68

- [15] S. Chamanian, S. Baghaee, H. Uluşan, Ö. Zorlu, E. Uysal-Biyikoglu and H. Kùlah, "Implementation of Energy-Neutral Operation on Vibration Energy Harvesting WSN," in *IEEE Sensors Journal*, vol. 19, no. 8, pp. 3092-3099, 15 April 2019, doi: 10.1109/JSEN.2019.2890902
- [16] H. S. Dhillon, K. Kumar and P. Chawla, "A Detailed Investigation of Wireless Sensor Network Energy Harvesting Schemes to Maximize Lifetime of Sensor Nodes," 2023 3rd International Conference on Intelligent Communication and Computational Techniques (ICCT), Jaipur, India, 2023, pp. 1-7, doi: 10.1109/ICCT56969.2023.10075842.
- [17] A. S. H. Abdul-Qawy, A. B. Nasser, A. H. Guroob, A. -M. H. Y. Saad, N. A. M. Alduais and N. Khatri, "TEMSEP: Threshold-Oriented and Energy-Harvesting Enabled Multilevel SEP Protocol for Improving Energy-Efficiency of Heterogeneous WSNs," in *IEEE Access*, vol. 9, pp. 154975-155002, 2021, doi: 10.1109/ACCESS.2021.3128507.
- [18] N. D. Tan and V. -H. Nguyen, "EE-TLT: Energy-efficient routing protocol using two-level tree-based clustering in wireless sensor network," in *Journal of Communications and Networks*, vol. 25, no. 6, pp. 734-749, Dec. 2023, doi: 10.23919/JCN.2023.000038.
- [19] H. Zhang, M. Zhang and J. Yang, "An energy consumption optimization strategy for Wireless sensor networks via multi-objective algorithm", *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 10, pp. 6371-6379, 8 January 2024, doi: 10.1016/j.jksuci.2024.101919.
- [20] B. Saoud, I. Shayea and A. A. El-Saleh, "New scheme of WSN routing to ensure data communication between sensor nodes based on energy warning", *Alexandria Engineering Journal*, vol. 80, pp. 397-407, 1 September 2023, doi: 10.1016/j.aej.2023.08.058.
- [21] A. Hossan and P. K. Choudhury, "DE-SEP: Distance and Energy Aware Stable Election Routing Protocol for Heterogeneous Wireless Sensor Network," in *IEEE Access*, vol. 10, pp. 55726-55738, 2022, doi: 10.1109/ACCESS.2022.3177190.
- [22] M. J. Rhesa and S. Revathi, "DBKNN and Radial-ANFIS Model for Energy Efficient Wireless Sensor Network," in *IEEE Access*, vol. 12, pp. 15917-15929, 2024, doi: 10.1109/ACCESS.2024.3358196.
- [23] S. S. Rani and K. S. Sankar, "Improved buffalo optimized deep feed forward neural learning based multipath routing for energy efficient data aggregation in WSN", *Measurement: Sensors*, vol. 27, pp. 963-970, 9 March 2023, doi: 10.1016/j.measen.2022.100662.
- [24] N. Meenakshi et al., "Efficient Communication in Wireless Sensor Networks Using Optimized Energy Efficient Engroove Leach Clustering Protocol," in *Tsinghua Science and Technology*, vol. 29, no. 4, pp. 985-1001, August 2024, doi: 10.26599/TST.2023.9010056.
- [25] V. Pandiyaraju, S. Ganapathy and A. Kannan, "An optimal energy utilization model for precision agriculture in WSNs using multi-objective clustering and deep learning", *Journal of King Saud University - Computer and Information Sciences*, vol. 35, no. 10, pp. 47-53, 18 October 2023, doi: 10.1016/j.jksuci.2023.101803.
- [26] J. Reyes, F. García, M. E. Lárraga, J. Gómez and L. Orozco-Barbosa, "Game of Sensors: An Energy-Efficient Method to Enhance Network Lifetime in Wireless Sensor Networks Using the Game of Life Cellular Automaton," in *IEEE Access*, vol. 10, pp. 129687-129701, 2022, doi: 10.1109/ACCESS.2022.3228585.