Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.754681

A METAHEURISTC SWARM BASED APPROACH FOR THE OPTIMIZATION OF ENERGY EFFICIENT NETWORK LIFETIME IN WIRELESS SENSOR NETWORKS

A.S. Sai Puneeth Theja[1], Dr. S. Swarnalatha[2], Dr. B. Shoban Babu[3]
[1]Research Scholar, Department of ECE, Sri Venkateswara University College of Engineering, Tirupati, A.P., India
[2]Professor, Department of ECE, Sri Venkateswara University College of Engineering, Tirupati, A.P., India
[3]Professor, Department of ECE, Sri Venkateswara College of Engineering, Tirupati, A.P., India

Abstract: This paper focuses on the implementation of Nature inspired metaheuristic algorithms in Wireless Sensor Networks (WSNs) such as Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA) can be implemented in WSNs. The performance is evaluated on Network Lifetime, Clustering of nodes, energy consumption levels. It is observed that the PSO and WOA are consistently shows better results than Low-Energy Adaptive Clustering Hierarchy (LEACH). However, The WOA have been competitive with the PSO algorithm with its results leaning towards on the better side. The study complements related research on the application of swarm intelligence in WSN by focusing on routing optimization, energy aware protocols and centralized clustering of nodes.
Keywords: Wireless Sensor Networks (WSNs) – Clustering – Routing optimization – Network lifetime – Metaheuristic algorithms – LEACH – PSO - WOA.

1. INTRODUCTION:

The Wireless Sensor Networks (WSNs) expanded its horizon in terms of its applicability of various applications such as Environmental monitoring, Military surveillance, Industrial automation etc. The individual system in this network, nodes play a role of transceiving information, sensing data from the surrounded environment, processing of the collected information and also have the decentralization to send or receive necessary information to the Base Station (BS). One of the major advantages of the WSNs are that its implementation especially where there is inaccessibility of human intervention[1].

In Wireless Sensor Networks, Clustering of nodes makes it easier to access all the nodes in the network. Clustering is grouping of nodes and electing a Cluster Head (CH) among those nodes. The BS only communicates with the CH, which has all the information of its Cluster Member nodes. This arrangement is robust to send and receive information. With this arrangement, the entire functionality of the network increases [2].

In addition to the clustering of nodes and data aggregation among nodes, the routing of data also plays a vital role in transmitting and receiving data among the nodes in a WSN or exchange of data among various WSNs or exchange of information with the BS. The main agenda of any routing algorithm is information transmission integrity and its transmission time.

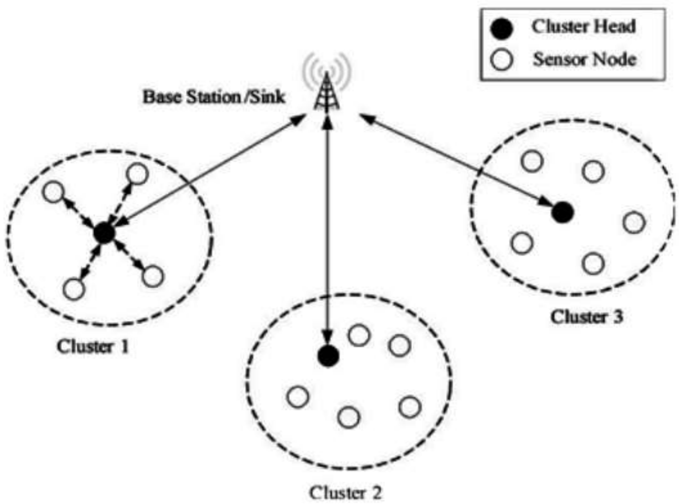


Figure 1.1: Clustered Wireless Sensor Network

The Metaheuristic algorithms are used to design such models for Wireless Sensor Networks. The optimization based on Metaheuristic algorithms are widely used for the engineering applications. The reason being that it has wide range of applications, easy implementation, can be implemented with minimum influence of local optima and gradient information. This Metaheuristic algorithms is especially used in Wireless Sensor network for various applications. A Metaheuristic algorithm based on Nature inspiration is used to optimize the parameters by mocking physical or biological phenomenon.[3]

The Nature inspired Metaheuristic algorithms can be broadly classified in to three categories [3]. They are (1) Evolution Metaheuristic algorithms, (2) Swarm based Metaheuristic algorithms and (3) Physics based Metaheuristic algorithms. The first category of Evolution based metaheuristic algorithm is based on the natural evolution of species. The second category is based on swarm based methods that imitates the social behavior of species. The third category is based on the physical phenomenon of the universe.

In the first category of metaheuristic algorithm classification, the search process starts with a random population. The carry forward point is that the best individual combined with the next generation individual. So that the optimization can happen by equally distributing the best qualities to all the nodes [4]. In the second category of optimization algorithms varies from algorithm to algorithm but a ballpark algorithm would be considering particles in a search space to find the best optimal solution. Also, by tracing the best solution or location of their paths. So that the particles consider its own best solution and the best solution the swarm as a whole obtained. The third category is basically imitating the physical world rules of the universe such as Ray Optimization algorithm, Gravitational Local search algorithm, Simulated Annealing algorithms [5,6] etc. The sub classification of Metaheuristic algorithms is shown in the below figure.

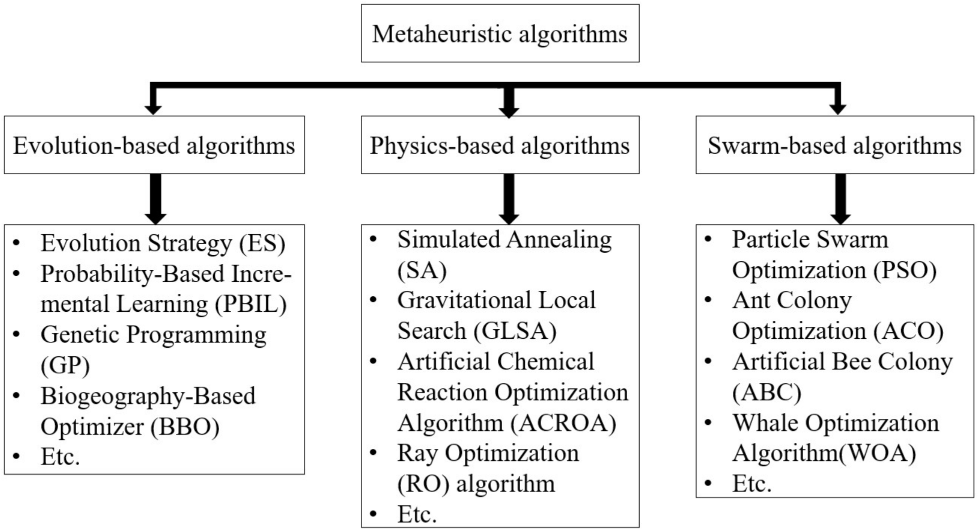


Figure 1.2: Classification of Metaheuristic algorithms

This paper focuses on the metaheuristic algorithms optimization especially based on swarm-intelligence algorithms such as Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA) along with the conventional algorithm such as Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm and identifying the optimized data in the swarm based algorithms.

2. LITERATURE REVIEW:

W. R. Heinzelman [7] et. al. suggests the extremely useful and innovative LEACH (Low-Energy Adaptive Clustering Hierarchy) method, which is a clustering-based protocol that uses the randomized iterations of local cluster-based stations, or cluster-heads, to divide the energy load among the network's sensors equally. LEACH reduces the amount of data that needs to be broadcast to the base station by integrating data fusion into the routing protocol and using localized coordination to provide scalability and robustness for dynamic networks. According to simulations, the LEACH can reduce energy dissipation by up to eight times when compared to traditional excursion routines. Furthermore, LEACH can equally disperse energy dissipation among the sensors, doubling the networks' useful system lifetime.

J.Xu et. Al [8] proposed a cluster routing algorithm to enhance the hierarchical routing protocol LEACH. In this algorithm, the original way of the selection of the cluster heads is random and the round time for the selection is fixed. In this algorithm, considering the remnant power of the sensor nodes in order to balance network loads and changes the round time depends on the optimal cluster size[9]. The simulation results show that our proposed protocol increases network lifetime at least by 40% when compared with the conventional algorithm.

J. Kennedy et. al. [10] came up with a new concept for the optimization of nonlinear functions using particle swarm methodology. Benchmark testing of the paradigm is described, and applications, including nonlinear function optimization and neural network training, are proposed. The relationships between particle swarm optimization and both artificial life and genetic algorithms are described. This algorithm is further extended for the implementation of Wireless sensor networks

T. M. Shami [11] analyses the Particle swarm optimization (PSO). This PSO is one of the most well-regarded swarm-based algorithms in the literature. Although the original PSO has shown good optimization performance, it still severely suffers from premature convergence. Because of this, numerous researchers have been altering it, producing a vast variety of PSO variations that perform marginally better or noticeably better. The basic PSO has mostly been altered through the use of four primary strategies: collaboration, multi-swarm approaches, hybridizing PSO with other well-known meta-heuristic algorithms like genetic algorithms (GA) [12] and differential evolution (DE) [13], and altering the PSO regulating parameters. This work aims to present a thorough analysis of PSO, covering its fundamental ideas, binary PSO, neighborhood topologies in PSO, historical and contemporary PSO variants, notable engineering uses of PSO, and its limitations. This study also highlights new research that solves feature selection challenges with PSO. Lastly, eight possible lines of inquiry that can assist researchers in improving the performance of PSO are provided.

Andronie et. al [14] discusses the management of data tools, sensing and computing technologies that can be used for the Internet of Things for the applicability in the Wireless sensor networks for data handling and aggregation. Ramalingam et. al [15] suggests a hybrid technique for Grey Wolf Optimization(GWO) algorithm

Seyedail Mirjalili et al.[15] proposes a new algorithm Whale Optimization Algorithm (WOA) which mimics the whales. In this paper, the discussion and comparison is done for various swarm based algorithms and the improvement shown in the WOA. which mimics the social behavior of humpback whales. The algorithm is inspired by the bubble-net hunting strategy. WOA is tested with 29 mathematical optimization problems and 6 structural design problems. Optimization results prove that the WOA algorithm is very competitive

The Swarm based metaheuristic algorithms shows adaptability and efficiency in the optimization of Wireless sensor networks. This can be done by the routing optimization, network lifetime and energy aware clustering methods. This infers individually to understand the various algorithms used in Wireless sensor network that manifests the design of the same for an optimized Network.

3. ANALYSIS OF THE METHODS

The conventional algorithms used in the Wireless sensor networks provides a limited optimization for the evaluation of various parameters such as clustering, network lifetime, energy efficiency, data aggregation etc. The proposed comparative analysis of conventional algorithm (LEACH) and swarm- based algorithms (PSO, WOA etc.) provides a better optimization in terms of clustering of the nodes, identifying the Cluster Heads (CH), Data aggregation, lifetime of the network, energy efficiency of the network etc.

3.1 Low Energy Adaptive Clustering Hierarchy (LEACH) :

The LEACH algorithm operates in two stages, Setup phase and steady state phase. In the setup phase, the nodes select a cluster head CH which has maximum energy and the other nodes in that cluster are member nodes. In the steady state phase, the member nodes send data to the cluster head and then the data aggregation occur within stipulated time for the further transmission to base station or to a sink.

The flow chart of the LEACH protocol is as shown below

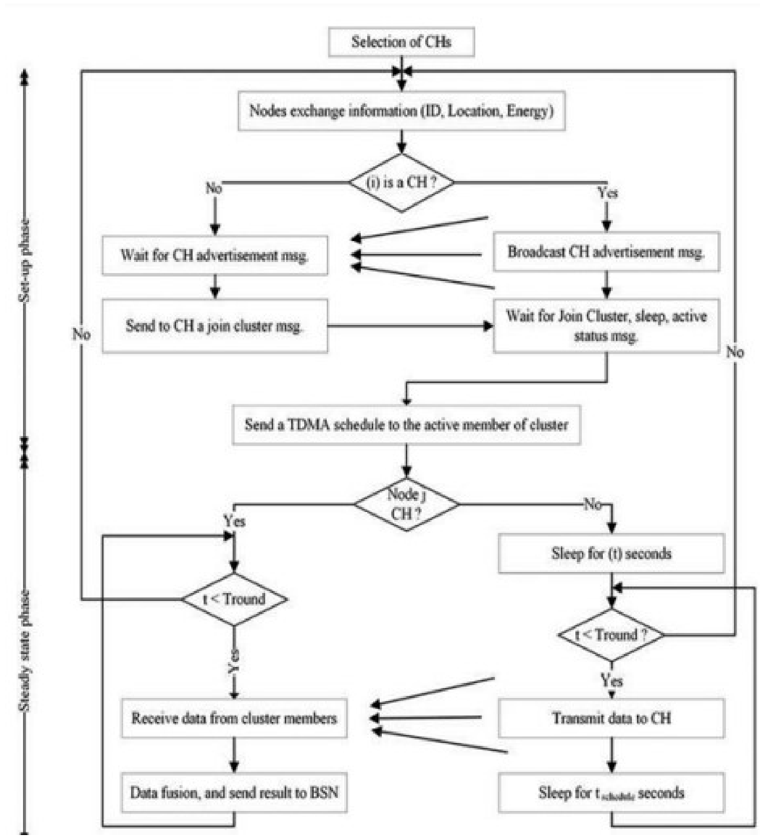


Figure 3.1: Flow chart of LEACH [16]

LEACH Algorithm procedure [17]:

i. Initialization of the network as per the Simulation configuration

ii. Calculate the node's energy for the ach round number

If the node's energy is zero, then each node is dead.

else if node's energy is neither zero nor maximum, then it is a member node in the cluster

else if node's energy is maximum, then it is Cluster Head

end if

iii. for each node 'i' do

if dead nodes equal to number of nodes

Store the value for each round number

end if

end for

iv. if node distance is greater than threshold,

include corresponding amplification factor

else include amplification factor when node distance is less than threshold

v. Count number of dead nodes

vi. Plot the round number and dead nodes

vii. Plot Network and other parameters

From the implementation of this LEACH algorithm, the Network lifetime, average energy of a node and the random node deployment of the nodes can be achieved. This result is then compared with the Swarm-based algorithms for the better optimization and selection of algorithm that best suited for certain applications.

The probability of the setup phase of each node to become a cluster head is given in the equation 1, 2. Also, the optimal path can be analyzed by using the equation 3

$$\sum_{i=1}^{N} p_i(t) = k \tag{1}$$

$$p_i(t) = \begin{cases} \dfrac{k}{N - k * (r\ modN/k)}, & C_i(t) = 1 \\ 0, & C_i(t) = 0 \end{cases} \tag{2}$$

$$h = K\left(\frac{Eavg}{hmin} * t\right) \tag{3}$$

where $C_i(t)$ is indicator function, r mod(N/k) is the most recent rounds, $p_i(t)$ is the probability of each node (N) to be a CH, h is the total hop count, K is constant, h_{min} is the minimum hop count in the current route, t is the current path traffic

3.2 Particle Swarm Optimization (PSO):

Particle Swarm Optimization mocks the social movement in the animal such as bird flock. In this algorithm particle moves dynamically with respect to the other particles. Here particle represents nodes, it can refer to a cluster head or a member node.

Particle Swarm Optimization algorithm is implemented to have an improvement in the consumption of energy by the nodes and improving the lifetime of the network and to have a better routing of data. This can be achieved by selecting a shortest path from the node to the BS with multi hopping.

The phases involved in PSO are Initial Phase and Update Phase. In the initial phase, It optimizes Objective function whose input is a swarm of particles, which is random. A path from sensor to the BS is established by giving priority to nodes. In the Update phase, depending upon the positions and velocities of each particles, the best solution for each iteration tracking is done and the global best among those particles forms a s a best solution. As a priority queue, new paths are generated in each iteration.

Further, the objective function is optimized by giving global best of the particles. Hence maximizing and minimizing the objective function and there by velocity and position updated by the following equation 4 and 5

$$V_i = w\ X\ V_i + C_1\ X\ r_1\ X(P_i - X_i) + C_2\ X\ r_2\ X\ G_i - X_i \tag{4}$$

$$P_s = P_i + V_i \tag{5}$$

In the above equations 4, 5; 'i' is the ID of particle population, V_i is the i^{th} particle velocity, P_i is the i^{th} particle best position, G_i is the global best for the i^{th} particle, X_i is the i^{th} particle position, C_1, C_2 are the coefficient of social and self components respectively, w is the coefficient of inertial weight, r_1 and r_2 are the random numbers between 0 and 1

The flow chart of Particle swarm optimization algorithm [18] is as follows:

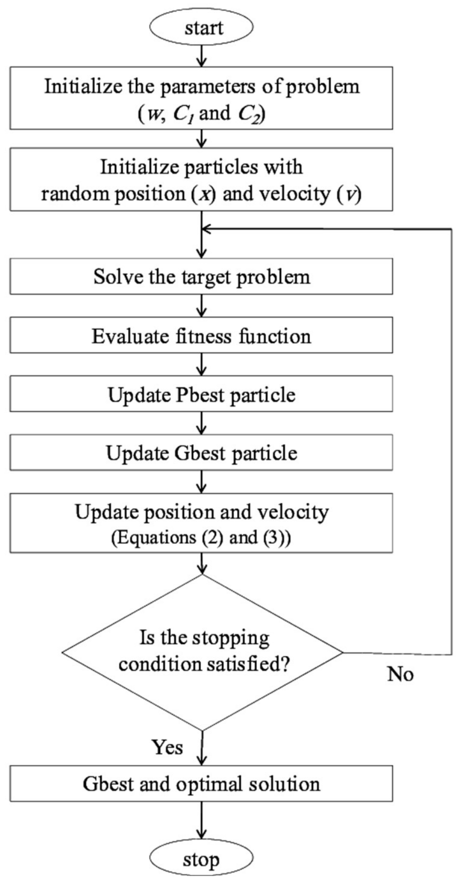


Figure 3.2: Flowchart of Particle Swarm Optimization

The algorithm is represented as the following

for iteration in the range (MaximumIterations):

Particle_Velocities_and_Position_Update()

Evaluate solutions()

Input_personal_best_network()

Update_global_best()

end loop

The corresponding costs of the objective function for each path is calculated by equation 6.

$$a = w_d \; X \; D + w_r + E.R + w_s \; X \; S.E \qquad (6)$$

Where w_s is weight of path distance, D is the total distance path, w_r is the weight of the energy ratio, E.R is the energy ratio of the path. w_s is energy weight, S.E is the sum of energies of the hops in the path.

3.3 Whale Optimization Algorithm (WOA):

Whale Optimization Algorithm (WOA) is one of the metaheuristic algorithms which is inspired by the hunting behavior of humpback whales. This algorithm uses a hunting behavior with optimal search agent to hunt its prey by a process called exploration and uses a spiral bubble-net attaching scheme for catching of prey by a process called as exploitation.

The two main phases of WOA is Exploration and Exploitation, which is broadly related to the other metaheuristic algorithms' Global search and Local search respectively In the First phase, Humpback whales exhibit two main hunting maneuvers: upward-spirals and a more complex three-stage process involving lobtail, capture loop, and coral loop.

In the second phase, Exploitation aims to refine the search around a known good solution, while exploration seeks to diversify the search to avoid local optima. WOA begins with a randomly generated population of solutions (whales), and in subsequent iterations, updates positions relative to the best solution found so far. During exploration, positions are updated relative to a randomly chosen search agent, promoting diversity in the search. As the algorithm progresses and a promising solution is identified, exploitation intensifies by updating positions with respect to the best solution obtained.

WOA's hunting behavior can be explained in three phases: searching, encircling, and attacking the prey, making it a powerful global optimizer for optimization problems.

3.3.1 Encircling the Prey:

Whales adjust their positions to mimic the encircling behavior as part of the optimization process, positioning themselves around the location of the current top-performing search agent. This encircling action is represented mathematically by the following equations 7,8.

$$\vec{D} = \left|\vec{C} \,.\vec{X}^*(t) - \bar{X}(t)\right| \tag{7}$$

$$\bar{X}(t+1) = \vec{X}^*(t) - \vec{A}.\vec{D} \tag{8}$$

Where t is the current iteration, $\vec{A}$ and $\vec{C}$ are vector coefficients and $\vec{X}$ is the position vector. $\vec{X}^*$ is the best solution for the position vector which is updated after every iteration.

3.3.2 Exploitation Phase (Attacking Prey):

The attacking behavior in the optimization process is modeled based on the bubble net attacking strategy observed in humpback whales. Two main approaches are used to replicate the bubble-net behavior: the shrinking encircling mechanism and the spiral updating position mechanism, each with a 50% probability of occurrence.

In the shrinking encircling mechanism, a parameter 'a' is gradually reduced from two to zero over the course of iterations, affecting the range of a random variable 'A' used in position updates. The spiral updating position mechanism mimics the helix structured maneuver of humpback whales during prey attacks, contributing to the exploitation phase of the optimization algorithm.

Exploitation involves refining the search in the vicinity of a promising solution 'S', with 'A' values between [-1, 1] inducing exploitation and facilitating convergence of search agents towards the best solution. The updating model is mathematically referred as below.

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A}.\vec{D}, & p < 0.5 \\ \vec{D}'.e^{bi}.\cos(2\pi l) + \vec{X}^*(t), & p \geq 0.5 \end{cases} \tag{9}$$

3.3.3 Exploration Phase (Searching Prey):

Exploration in the optimization process relies on adjusting the vector A to encourage search agents to explore the search space widely, resembling a global search strategy. During exploration, the value of |A| is set to greater than 1, prompting search agents to diverge far from their current positions to seek potentially better solutions.

In contrast to exploitation, where positions are updated relative to the best search agent, exploration involves updating positions based on randomly chosen search agents, as outlined in below equation 10 and 11 , facilitating a broader search across the solution space.

$$\vec{D} = \left|\vec{C} \,.\vec{X}_{rand} - \bar{X}\right| \tag{10}$$

$$\bar{X}(t+1) = \vec{X}_{rand} - \bar{A}.\bar{D} \tag{11}$$

WOA Algorithm procedure:

i. Initialization: Generate an initial population, Initialize parameters such as the maximum number of iterations, population size, and exploration-exploitation balance factors.

ii. Fitness Evaluation

iii. Exploration and Exploitation:

For each iteration:

Update the exploration-exploitation balance factor based on the iteration number or a predefined schedule.

Determine whether to explore or exploit based on the balance factor.

If exploring:

Update the positions of whales using the exploration mechanism, considering random search agents.

If exploiting:

Update the positions of whales using the exploitation mechanism, focusing on the best-performing search agents.

iv. Adjustment of Encircling and Attacking

v. Update Best Solution

vi. Return the best solution obtained, representing an optimized configuration for the WSN.

Amongst the algorithms in the previous sections Whale Optimization Algorithm (WOA) shows progressive improvement in terms of packet delivery, energy efficiency, network lifetime etc., the comparative results of these are mentioned in the next section.

4. RESULTS AND DISCUSSION:

4.1 Simulation Configuration:

The nodes in the Wireless Sensor network is positioned at random with the BS located at the center. In this paper, the initial consideration of simulation configuration is as shown

Table 4.1: Simulation Configuration

Parameter	**Value**
Coordinates	300x300
Number of nodes	50, 100, 500
Initial energy	0.1J
No. of rounds	500 - 2500
Energy depleted to transfer a bit	50*0.000000001 J
Energy depleted to receive a bit	50*0.000000001 J
Packet Length	200 Bits
Probability of cluster head	0.1

Aggregation Energy at Cluster Head	5*0.000000001 J

From the above Table 4.1 it is evident that there are three simulations done by varying the number of operating nodes 50, 100 and 500 for each of the three algorithms LEACH, PSO, WOA. Also, the probability of a node to become a CH, energy aggregation, Packet length etc. are considered for this simulation.

4.2 Simulation Performance Analysis:

For the analysis of these algorithms in wireless sensor networks, three parameters have been considered to understand the improvements. The three parameters are Network life i.e., number of nodes are operational at the end of all the round or iterations, Total average energy, number of packets delivered from nodes to Sink.

Table 4.2: Comparative analysis

Algorithm	**Initial No. of nodes deployed**	**Round/ Iteration Number**	**No. of Nodes Dead**	**Energy left in Network**	**No. of packets sent**
LEACH	50	100	50	0	879
PSO		100	31	0.1141	1029
WOA		100	28	0.1532	1780
LEACH	100	500	98	0.0114	1381
PSO		500	85	0.0121	2044
WOA		500	76	0.1428	3132
LEACH	500	1000	312	0.0813	4905
PSO		2089	500	0	3129
WOA		2258	500	0	6927

Table 4.2 depicts the comparative analysis of LEACH, PSO and WOA for the deployed 50, 100 and 500 nodes respectively and their parameter. It can be observed for the deployed 50 nodes, at the 100th round number, the nodes in the LEACH implemented network are all dead with no energy left and 879 packets sent. Comparing this with PSO and WOA, only 31 and 28 nodes are Dead after the 100th round, and a significant energy left in the network. Comparatively among PSO and WOA, WOA has an edge regarding the network lifetime and there by number of packets are also maximized.

Similarly, 100 nodes are deployed to the WSN using the same algorithms and the results are tabulated in Table 4.2. It can be observed that by using LEACH algorithm almost all the nodes are expired at the end of round 500 and so does the nodes use PSO algorithm. But, WOA algorithm shows improvement in the network lifetime.

To these algorithms, 500 nodes are deployed initially. Number of nodes vs. rounds for LEACH algorithm is plotted and it is shown in the figure 4.1. It is evident that 312 nodes are dead at the end of round 1000 and it is observed that all the 500 nodes are expired within the network at the round 1322.

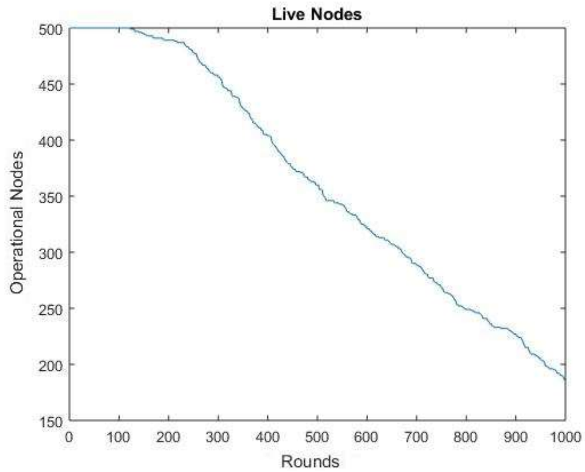


Figure 4.1 No. of Nodes vs. Rounds for LEACH algorithm

From the Figure 4.2, it is also observed that total 500 nodes are expired at the iteration 2089. So, the total packets sent is little over 2000 packets. It is an significant difference compared to the LEACH algorithm interms of number of packets sent. Although, the PSO algorithm can be improved to make the number of packets sent beyond the LEACH's. But, in the previous two cases i.e., number of nodes 50, 100; PSO performed quite significantly with comparison to LEACH.

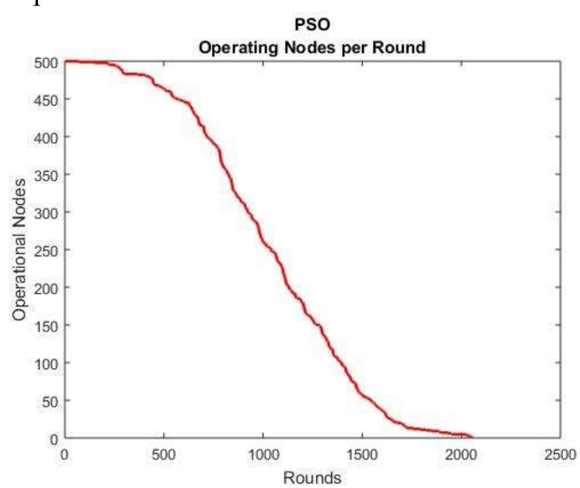


Figure 4.2 No. of Nodes vs. Rounds for PSO algorithm

Figure 4.3 represents number of nodes deployed to the network vs. number of iterations. Here, there are 500 nodes deployed to the network. It can be observed that all 500 nodes are dead at the round 2258. The WOA algorithm shows significant improvement over the other two algorithms interms of network lifetime improvement, packets sent to the BS and the energy efficiency. Whale Optimization Algorithm (WOA) performance can further be improved by the use of Genetic algorithm optimization. By this, there is a significant enhancement in the global optimization ability and convergence accuracy of the algorithm.

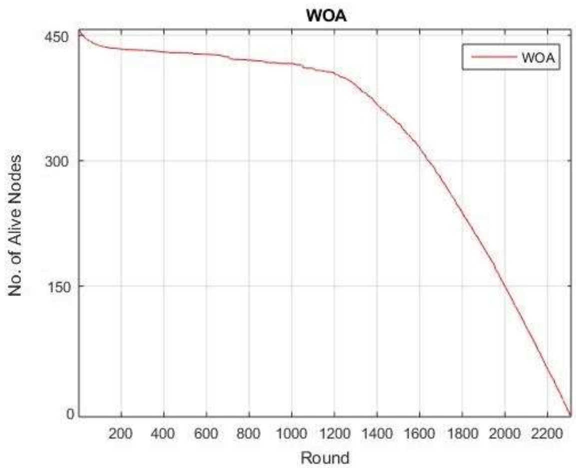
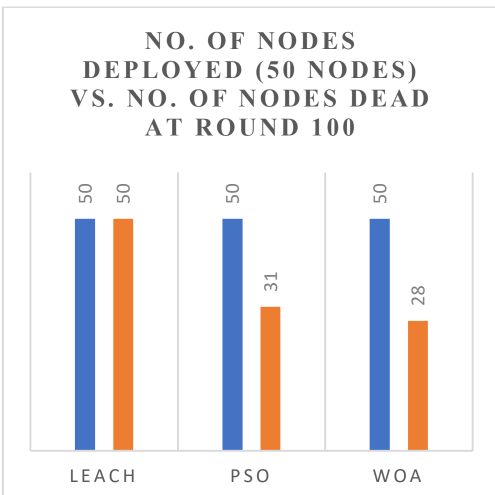
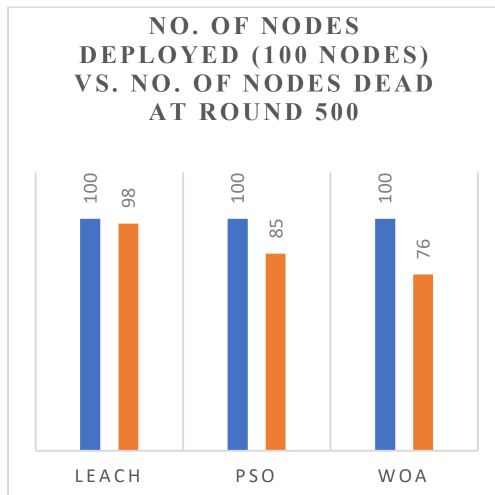


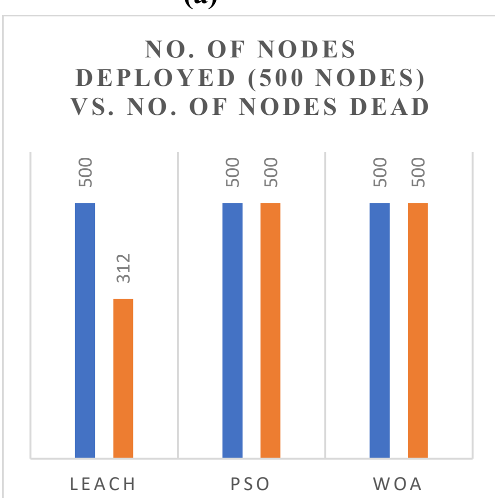
Figure 4.3 No. of Nodes vs. Rounds for WOA algorithm



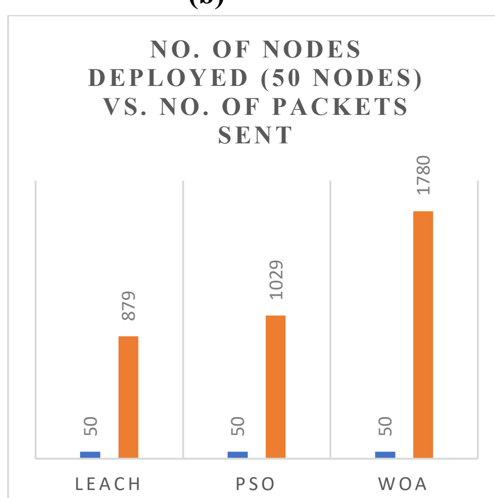
(a)



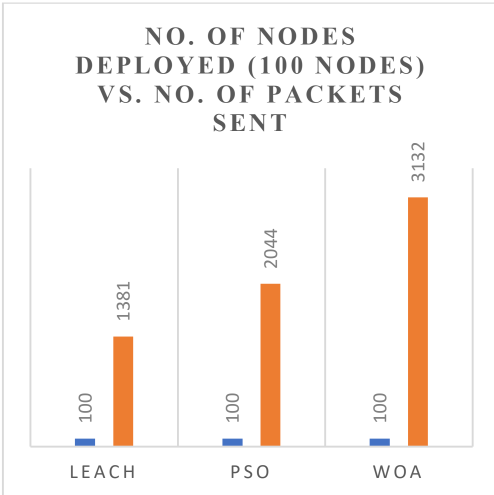
(b)



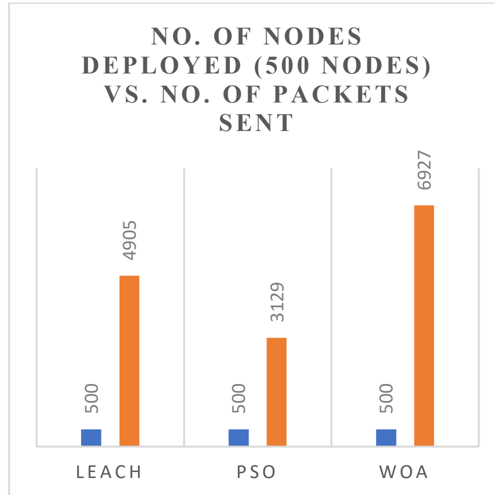
(c)



(d)



(e)



(f)

Figure 4.4 Comparative analysis of various parameters for LEACH, PSO and WOA algorithms

The analysis of the Number of Nodes deployed vs. Number of nodes expired are compared with a graphical representation in the Figure 4.4 (a), (b), (c). Figure 4.4 (a) represents the comparison for the 50 nodes deployed in to the network and at the end of round 100 WOA algorithm shows prominent improvement. Figure 4.4 (b) shows comparison of 100 nodes deployed for an iteration of 500 rounds. PSO and WOA showed a near equal performance, at the end WOA shows better results. Figure 4.4(c) represents 500 nodes deployed and observed that 312 nodes are dead at the end of round 1000 by using LEACH algorithm, whereas by using PSO and WOA, all the 500 nodes are dead at the end of iteration 20189 and 2258 respectively. This again shows a significant improvement in Network Lifetime.

Number of packets sent for the number of nodes deployed is represented in the Figures 4.4(d), (e), (f). In all the three scenarios, WOA showed significant improvement in the total number of packets sent which is 1780, 3132, 6927 for the number of nodes deployed 50, 100, 500 respectively. From the analysis done so far will give a brief idea about the comparative analysis of implementation of algorithms for a Wireless sensor networks with its parameters.

CONCLUSION:

This paper analyzes the three algorithms used to implement and optimize Wireless sensor networks. The three algorithms are LEACH, PSO and WOA. The efficiency of LEACH in terms of its Network Lifetime, Number of Packets transferred are significantly low. By introducing a swarm-based Nature inspired Metaheuristic algorithm such as PSO, WOA shows significant improved in the same parameters. In comparison to PSO and WOA, the WOA shows improvement in its network lifetime, activity of the nodes for longer periods of time, a greater number of packets transmission, which shows there is a improvement in the energy efficiency in the network. By the implementation of WOA algorithm, network lifetime, coverage performance to a certain extent is optimized. For the future improvements, the clusters are not evenly distributing, as there is a random deployment of the nodes in the network. So, by making an evenly cover and reduce the area where nodes gather more, one can achieve further improvements.

REFERENCES:

[1] S. Thilagavathi and C. G. Priya, "Study on Wireless Sensor Networks – A Comprehensive Approach," 2018 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2018, pp. 0710-0714, doi: 10.1109/ICCSP.2018.8524174.

[2] M. Gheisari et al., "A Survey on Clustering Algorithms in Wireless Sensor Networks: Challenges, Research, and Trends," 2020 International Computer Symposium (ICS), Tainan, Taiwan, 2020, pp. 294-299, doi: 10.1109/ICS51289.2020.00065.

[3] http://dx.doi.org/10.1016/j.advengsoft.2016.01.008

[4] Holland JH . Genetic algorithms. Sci Am 1992;267:66–72 .

[5] Kirkpatrick S , Gelatt CD , Vecchi MP . Optimization by simmulated annealing. Science 1983;220:671–80 .

[6] ˇCernýV . Thermodynamical approach to the traveling salesman problem: an efficient simulation algorithm. J Opt Theory Appl 1985;45:41–51 .

[7] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 2000, pp. 10 pp. vol.2-, doi: 10.1109/HICSS.2000.926982.

[8] J. Xu, N. Jin, X. Lou, T. Peng, Q. Zhou and Y. Chen, "Improvement of LEACH protocol for WSN," 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery, Chongqing, China, 2012, pp. 2174-2177, doi: 10.1109/FSKD.2012.6233907.

[9] C. Pankaj, G. N. Sharma and K. R. Singh, "Improved Energy Lifetime of Integrated LEACH Protocol for Wireless Sensor Network," 2021 International Conference on Disruptive Technologies for Multi-Disciplinary Research and Applications (CENTCON), Bengaluru, India, 2021, pp. 265-269, doi: 10.1109/CENTCON52345.2021.9688050.

[10] J. Kennedy and R. Eberhart, "Particle swarm optimization," Proceedings of ICNN'95 - International Conference on Neural Networks, Perth, WA, Australia, 1995, pp. 1942-1948 vol.4, doi: 10.1109/ICNN.1995.488968.

[11] T. M. Shami, A. A. El-Saleh, M. Alswaitti, Q. Al-Tashi, M. A. Summakieh and S. Mirjalili, "Particle Swarm Optimization: A Comprehensive Survey," in IEEE Access, vol. 10, pp. 10031-10061, 2022, doi: 10.1109/ACCESS.2022.3142859.

[12] Andranik S. Akopov, Levon A. Beklaryan, "Traffic Improvement in Manhattan Road Networks With the Use of Parallel Hybrid Biobjective Genetic Algorithm", IEEE Access, vol.12, pp.19532-19552, 2024.

[13] Jing-Yu Ji, Zusheng Tan, Sanyou Zeng, Man-Leung Wong, "An ε-constrained multiobjective differential evolution with adaptive gradient-based repair method for real-world constrained optimization problems", Applied Soft Computing, pp.111202, 2024.

[14] Andronie, Mihai, George Lăzăroiu, Mariana Iatagan, Cristian Uță, Roxana Ștefănescu, and Mădălina Cocoșatu. 2021. "Artificial Intelligence-Based Decision-Making Algorithms, Internet of Things Sensing Networks, and Deep Learning-Assisted Smart Process Management in Cyber-Physical Production Systems" Electronics 10, no. 20: 2497. https://doi.org/10.3390/electronics10202497

[15] Seyedali Mirjalili, Andrew Lewis, The Whale Optimization Algorithm, Advances in Engineering Software, Volume 95, 2016, Pages 51-67, ISSN 0965-9978, https://doi.org/10.1016/j.advengsoft.2016.01.008.

[16] International Journal Of Engineering Technologies-IJET Alrubaye and Myderrizi, Vol.8, No.1, 2023, 49 Improvement of Cluster Head Selection in LEACH for Reducing Energy Consumption in Wireless Sensor Networks, Ali Qasim Alrubaye*, Indrit Myderrizi**
[17] A.S. Sai Puneeth Theja et. al., 2024, Network Lifetime Comparative Analysis in Wireless Sensor Networks, Manuscript accepted to Control and Information Sciences (Lecture Notes in Electrical Engineering), ISSN 1876-1100
[18] Yousefi, Marziye & Omid, Mahmoud & Rafiee, Sh & Ghaderi, S.F.. (2013). Strategic planning for minimizing CO2 emissions using LP model based on forecasted energy demand by PSO Algorithm and ANN. International Journal of Energy and Environment. 4. 1041-1052.