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Optimization Scheme for Power Transmission in Wireless Sensor Network

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***Abstract*—Wireless Sensor Networks (WSNs) are networks of sensors that can sense a dynamic process and send the measured data over a common channel to a central base station. As the number of devices increases exponentially, the energy efficiency of WSN clusters needs to be considered. The transmission power refers to the total allowable output power of the sensors to send information packets. Consider the power transmission problem for a fully connected cluster, with the goal of finding the minimum transmission power for each node in a given cluster without disrupting the network. In order to obtain a more effective optimal solution for the mentioned problem, ten different cases are studied using five optimization algorithms. The optimization algorithm is repeatedly tested to find the global minima of the fitness function. The study emphasises that the artificial ecosystem optimizer is the best fit for the mentioned model in all 10 cases. The average energy saved in transmission by the best performing algorithm is about 6.4 dBm.**

***Index Terms*—Wireless Sensor Network, Optimization algorithm, Power transmission, artificial ecosystem optimizer.**

I. Introduction

The ability to interact with an environment makes wireless sensor networks (WSNs) distinct from wired networks. Contrary to conventionally networked systems, WSNs are a new kind of real-time embedded systems with diverse communication requirements. It is demarcated as an auto-configured, foundation-less wireless network that inspects the environmental and physical conditions [1]. Data aggregation techniques are employed in WSNs to gather the sensor node-generated data sample at the sink through multiple cluster heads. To make an interface between the network and the user, the sink comes in handy for data analysis. A sink is a massive information centre from which required data or data-related information, such as hop numbers, can be traced. An astronomical number of sensor nodes can be present in clustered WSNs. Sensor nodes are fabricated with computing and sensing devices and power components. Sensor nodes use radio signals to communicate with each other. WSN has gained attention in many domains that include military, transport, health, agriculture, industry, and the environment [2]. The term "Internet of Things" (IoT) refers to any device linked to the internet. These connected gadgets can control or gather data regarding the tasks assigned. Sensors and actuators frequently exchange data using the same Internet Protocol (IP) that connects the internet. For the purpose of continuous monitoring and data accumulation, IoT sensors and actuators are deployed into various objects or locations. All devices are interconnected and "speak" with one another, from one's home to the entire city. As a result of this interconnection, a highly connected environment is created that will aid in better planning and adaptation by the gadgets that surround us. The recent advancements in the IoT field will make our lives more comfortable. IoT, considered only a concept a few years ago, has quickly evolved into a practical application that already has an impact in the present scenario. IoT has a broader use than just homes and cities, including consumer equipment, supply chain management, inventory tracking, production, and food supply chain management [3]. The main limitation in the research progress of WSNs is their limited energy capacity. The field of research on the energy savings of a fully connected cluster network is more than a decade old. Different methods have been proposed to improve energy efficiency. Sensor nodes are still evolving and maturing by acquiring new technology, so a lot of research is required in this field. The primary causes of energy waste are packet overhead, idle listening, overhearing, over-emitting, collisions, and state transitions [4]. Duc Chinh Hoang [5] presented a framework to use Harmony Search Algorithm for construction of centralised cluster-based protocol to save energy by reducing distances within a cluster, between its members and its cluster heads (CHs). In another research by Duc Chinh Hoang [6] utilized Fuzzy C-means (FCM) to obtain better energy efficient routing than K-Means clustering. Similar way, FCM was used to balance energy usage of each sensor nodes within each cluster [7]. Sandeep [8] proposed the use of hybrid algorithm containing particle swarm optimization and K-Means algorithm for data clustering. The hybrid algorithm was able to provide better solution by overcome local minima, improving clustering of the network.

The remainder of this work is organized as follows; Section II describes the problem statement. Section III presents the results attained by the optimizer and its analysis. Section IV concludes the study.

II. Problem Statement

As mentioned earlier, increasing the energy efficiency and lifetime of WSN requires more work in other areas such as proper clustering and power transmission. The communication range and the clustering of the network are predefined in all cases. The sensor nodes are placed in a cluster with each other, and the sink is relatively L-shaped. This is done to increase the likelihood of obtaining a fully connected cluster during the testing phase. The node transmits the data packets through the given mesh network to the sink located at the edge of the range. Fig.1 presents the location of nodes in one of the test cases. Table I present the coordinates of nodes of all the cases.

A. Model description

For modelling, the sensor nodes are considered as identical, energy-restricted, and static. The transmission power refers to the total permitted output power of a trans-receiver and amplifier (EIRP). Optimizing the transmission power of each node will lead us to the minimum transmission power necessary to get a fully connected cluster of sensors.

1) Neighbourhood matrix: The first step of the process is to get a cluster neighborhood matrix. The neighborhood matrix contains information regarding the nodes which are in range with each other, for the given transmission power. The matrix Θ_y is a function of the necessary power vector y according to equation. (1):-

$$\Theta_{(y)} = \begin{cases} 0 & if \rho_j < \rho_{th} \\ 1 & if \rho_j \geq \rho_{th} \end{cases} \tag{1}$$

where ρ_j is the power received by node j from i which transmitted the information packet with power vector y. The sensitivity of the node's antenna is represented by ρ_{th}. The sensitivity of the node's antenna indicates the minimum necessary power received by the node to accurately read the information packet. Fig.2 illustrates the sensitivity of a node. The boundary line around indicated range from where the necessary power to transmit data to the sensor is ρ_{th}. In other words, sensor j will be able to receive the signal from sensor i if and only if sensor j lies within the area enclosed by the antenna. The Friis equation [9] connects the model to the physical world.

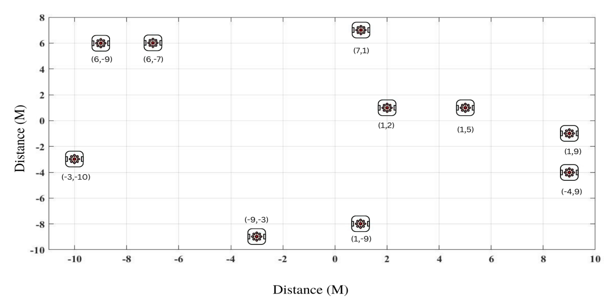


Fig. 1: Position of Nodes

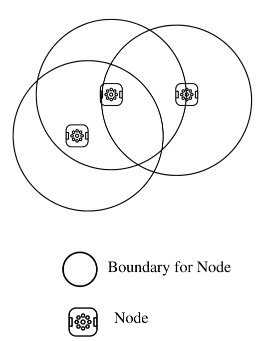
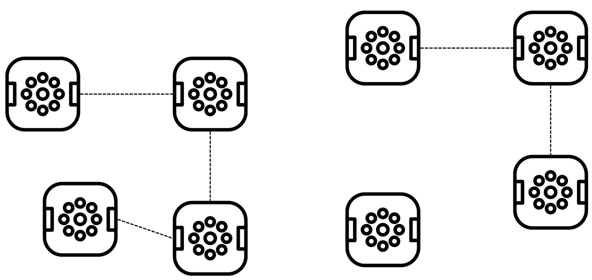


Fig. 2: Sensitivity Boundary

TABLE I: Coordinates of Sensors in all 10 cases.

Case 1		Case 2		Case 3		Case 4		Case 5		Case 6		Case 7		Case 8		Case 9		Case 10	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
-3	-10	6	-2	-3	7	3	-3	6	-2	3	-3	-9	-5	-10	5	-9	-5	-10	1
6	-9	-5	-2	2	1	7	1	-5	-2	7	1	6	-10	0	0	6	-10	8	4
6	-7	-8	-8	9	-4	-3	9	-8	-8	-3	9	9	5	8	2	9	5	-7	-3
7	1	9	10	5	5	8	1	9	10	8	1	0	2	2	8	0	2	-1	10
1	2	2	-9	-3	1	3	2	2	-9	3	2	-6	-1	6	2	-6	-1	-7	7
-9	-3	-6	-3	-9	-9	-6	-4	-6	-3	-6	-4	10	1	-7	-5	10	1	3	-3
1	-9	7	-10	1	6	-1	-6	7	-10	-1	-6	0	-6	8	-10	0	-6	-6	-2
1	5	-10	-7	9	-8	7	-6	-10	-7	7	-6	0	3	0	-7	0	3	0	-8
1	9	3	5	1	-1	-6	-7	3	5	-6	-7	4	-2	10	4	4	-2	2	-6
-4	9	3	-1	-10	-3	-6	-1	3	-1	-6	-1	-3	10	0	-1	-3	10	-2	2



(a) Network connected (b) Network disconnected

Fig. 3: Network analogy

The advantage over other formula is lack of numerical coefficients multiplier. It is used to calculate the received power ρ_j. It relates the physical distance between the multiple nodes and the transmitted power under idealized condition. The Friss equation is given by:-

$$\frac{P_r}{P_t} = \frac{A_r A_t}{d^2 \lambda^2} \tag{2}$$

where P_r represents the received power by destination node, P_t represented the transmitted power by sender node, A_r represents the destination node antenna effective area, A_t represents the sender node antenna effective area, d representing the distance between the destination and sender node, λ is the wavelength of the signal. The choice of WSNs antenna have significant affect on model. Based on the direction, the three major types of antenna are Omni-directional antenna, semi-directional antenna, and directional antenna. The direction of transmission by nodes are not fixed, we considered a simple isotropic Omni-directional antenna, which can send a signal in any direction with the same amount of power. The effective range of the isotropic antenna at each node is given by:-

$$A_{isotropic} = \frac{\lambda^2}{4 \times \Pi} \tag{3}$$

Using the equation equation. (3), making A_r=A_t=$A_{isotropic}$, the Friss formula (equation. 2) has been simplified as:-

$$\frac{P_r}{P_t} = (\frac{\lambda}{4 \times \Pi \times d})^2 \tag{4}$$

After the construction of neighborhood matrix using equation. (1), another section of code is used to determine whether the network is connected or not.

2) Connectivity of the network: The WSNs model employs spectral graph theory to determine the connectivity of the cluster. The study of graphs, which are mathematical frameworks, used to represent pair-wise relationships between objects with the help of eigen vectors, is known as Spectral graph theory [10]. The cluster is considered fully connected when it can form a path connecting all the N sensors. The connection is shown in Fig.3.

Considering the ineffective and complex process. Clustering is one of the methods employed where a cluster head is assigned to a group of sensor, task is to collect the real-time stream of data and transmit it to data centers for further investigation. The model here focuses on the working of such clusters. The first step toward determining the connectivity is to calculate the Laplacian Matrix [10] of the neighborhood matrix. The Laplacian Matrix (L_{ij}) is given by

$$(L_{ij})_{n \times n} = \begin{cases} deg(n_i) & if \;\; i = j \\ -1 & if \;\; i \neq j \;\; and \;\; \Theta_{ij} = 1 \\ 0 & otherwise \end{cases} \tag{5}$$

where n is the total number of nodes and $deg(n_i)$ contain the number of nodes connected to node n_i. The equation. (5) can be further simplified as following:

$$L = D - A \tag{6}$$

where D is the degree matrix and A is adjacency matrix of the cluster. The degree matrix contains information about the sum of connection each node have while the adjacency matrix store information about inter-connectivity of nodes. The second step involves finding the Fiedler value (Fv), which is the second-smallest eigenvalue of calculated Laplacian matrix (L_{ij}). The cluster is fully connected if the Fv is greater than zero. If Fv is less than zero, it shows that the cluster is incomplete and some nodes are separated from each other, forming a subgroup.

3) Fitness function: The fitness function passed to the optimizer after the Fv is greater than zero is mathematically expressed as:-

$$f_{obj} = 10 * log_{10} \frac{\sum_{n=1}^{N} Y_n}{1e^{-3}} \tag{7}$$

where Y_n is randomly generated transmission power for node n_i using optimizer, n is number of nodes.

III. Results and discussions

The performance of the optimizers has been evaluated using cluster's transmission power magnitude, convergence rate and Box plot. The algorithms are implemented using MATLAB 2022 scripts with ryzen 7 4000 series cpu. on the basis of fitness function developed in the previous section, and by considering the randomness exist in optimizers, The model performed 25 optimization runs with 500 iteration per run. For the sake of clarity, we are reporting the best results obtain in 25 optimization runs by each optimizer. In real-world applications, the minimal transmission power typically used is around -17dBm. To justify the 500 iterations, the search space was increased to - 30dBm [11]. The frequency of operation of the sensor was set at 915 MHz for the worst attenuation possible for a WSN application. The algorithm used for comparison are Ant Lion Optimization (ALO) [12], Grey Wolf Optimization (GWO) [13], Sine Cosine Algorithm (SCA) [14], Artificial Ecosystem Optimization (AEO) [15] and Arithmetic Optimization Algorithm (AOA) [16]. The objective function consists of three steps.

- Building a neighbourhood matrix.
- Determining whether the nodes are connected in a cluster or not by using spectral graph theory.
- Calculating the cluster's transmission power.

A. Objective function optimal value analysis

The optimal value attained is presented in the form of a bar graph. The AEO optimizer, highlighted in green in Fig.4, provides the optimal solution in all ten cases. It was observed that the energy savings were greater in the case of AEO compared to the other algorithms. The AEO capability of optimization is superior to all others due to the fact that the production step guides the population fragments from one region to the best obtain region with greater speed as iterations increase. Some algorithms provided a positive value for power transmission while others provide a negative value. The negative value arises because the value of power here is less than 1 milliwatt. The results obtained are shown in Table II. The simplistic method (SM) is a method where all the nodes were assigned same transmission power [4]. This method provided a base cluster transmission power to judge optimizers performance. The average energy saved by AEO compared to the SM was around 6.4 dBm. While ALO was the second-best algorithm in terms of obtaining an optimal solution saving 5.66 dBm. AOA was the worst-performing algorithm out of all 5 optimizers.

TABLE II: Optimal cluster transmission power by the SM and 5 optimizers.

Case No.	Ant-lion	GWO	SCA	**AEO**	AOA	SM
1	-4.253	-4.655	3.943	**-5.043**	5.538	2.808
2	-6.966	-7.307	2.414	**-7.680**	5.039	-2.76
3	-4.329	-4.651	1.276	**-5.042**	5.380	2.791
4	-5.568	-5.894	3.265	**-6.258**	3.393	3.851
5	-6.914	-7.253	2.725	**-7.680**	4.364	-2.786
6	-5.493	-5.938	2.288	**-6.258**	1.590	3.867
7	-4.386	-4.655	3.613	**-5.043**	6.898	-1.329
8	-6.621	-6.971	0.750	**-7.287**	5.155	-2.753
9	-4.627	-4.788	4.135	**-5.042**	3.815	-1.313
10	-3.838	-4.232	3.083	**-4.505**	7.231	1.235

B. Box plot analysis

The box plot [17] analysis is a standard way to demonstrate the distribution of the optimal value over multiple runs of summarising and comparing the groups of optimal data. The analysis has been carried out from Fig.5. For all the test scenarios, the box plots for AEO are very narrow, the median lies lower as compared to other optimizer with no outliers. It is possible to conclude that AEO's value over 25 runs is very consistent. In Fig.4, AEO and ALO was observed as competitive with each other having little difference in optimal cluster transmission power. The box plot analysis depicts that when consistency is taken into account, ALO's medium is significantly higher than AEO's. ALO's Interquartile Range (IQR) is also high compared to AEO meaning more dispersion of optimal value. GWO IQR is large implying the value obtained over multiple runs is very inconsistent. Box plot analysis of shows, GWO, SCA and AOA are not even competitive to AEO and ALO.

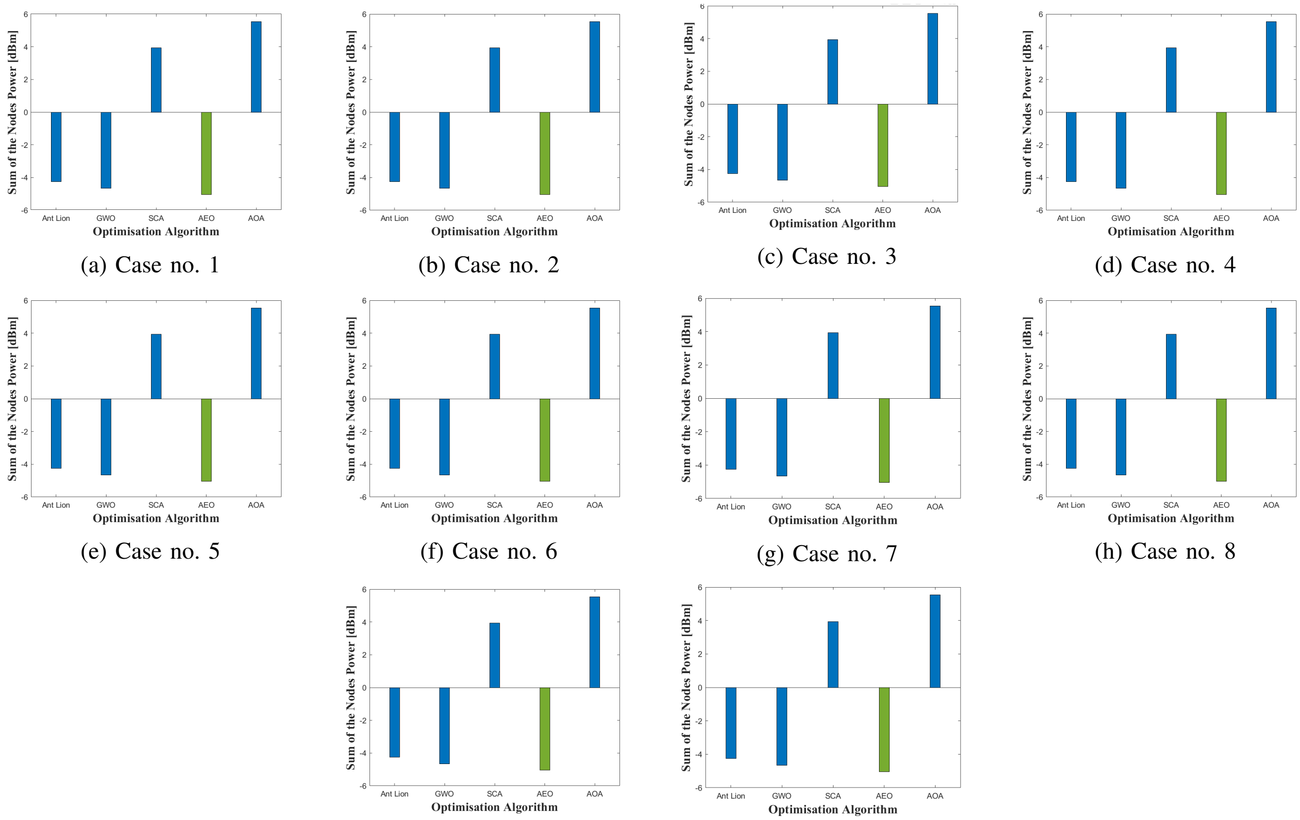
C. Convergence curve analysis

The convergence curve analysis shows which optimization algorithm faster to reach the optimal solution graphically. Convergence is a very important criterion in WSNs. Even a small change in the optimal value can lead to huge differences in power consumption. The convergence curves are shown in Fig.6. The convergence curve was selected randomly out of 25 run performed. AEO maintains a higher convergence value than other algorithms. It shows better exploration and exploitation capability than other optimizers in all 10 cases. On the contrary, despite providing a better solution, ALO has an inferior convergence rate, which leads to high transmission power. It clearly shows optimizer is lacking in exploitation capabilities. The convergence curves of ALO, GWO, and AOA reached the same solutions in all ten cases.

IV. Conclusion

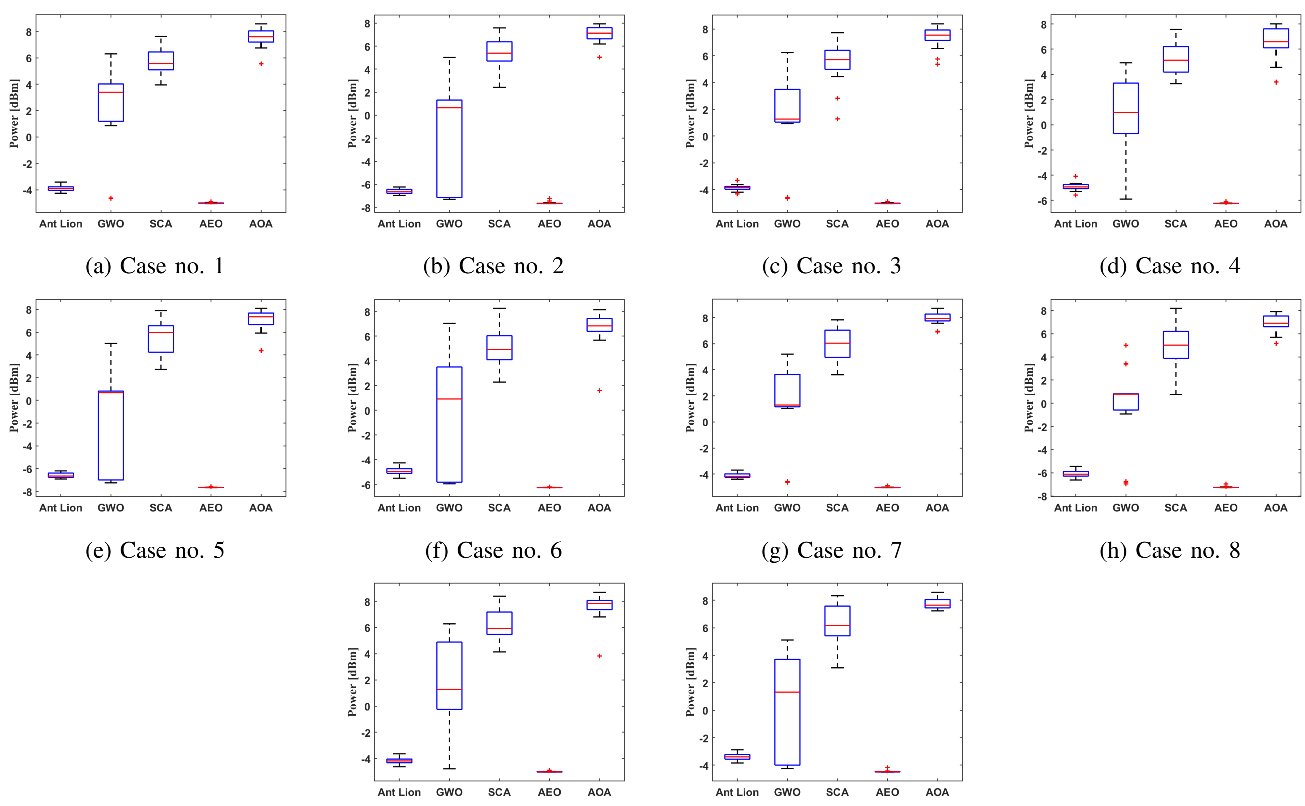
In this study, five optimization algorithms are used to calculate the minimum cluster transmission power from multiple nodes while keeping the network connected. The AEO algorithm gave the best result out of AOA, GWO, SCA, and ALO. Compared to simplistic method, average energy saved by AEO is 6.4 dBm. The superiority of the AEO optimizer for the mentioned model has been demonstrated using optimal value attained, box plots, and convergence curve analysis.

Modeling different types of antennas other than a simple isotropic antenna can be used to further investigate the brief model. To make it even more complicated, things like energy use, transmission rates,



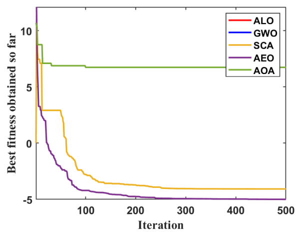
(a) Case no. 1 (b) Case no. 2 (c) Case no. 3 (d) Case no. 4
(e) Case no. 5 (f) Case no. 6 (g) Case no. 7 (h) Case no. 8
(i) Case no. 9 (j) Case no. 10

Fig. 4: Optimal value for each model cases.

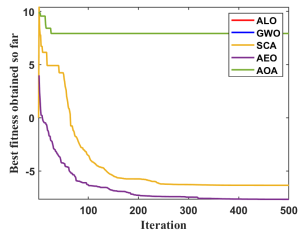


(a) Case no. 1 (b) Case no. 2 (c) Case no. 3 (d) Case no. 4
(e) Case no. 5 (f) Case no. 6 (g) Case no. 7 (h) Case no. 8
(i) Case no. 9 (j) Case no. 10

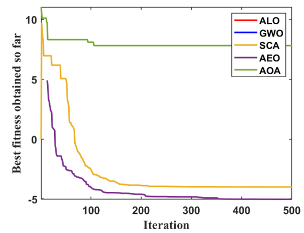
Fig. 5: Box plot for each model case



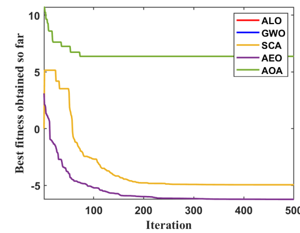
(a) Case no. 1



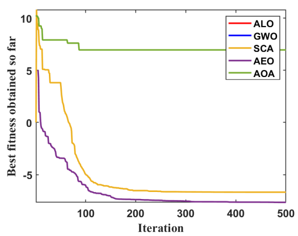
(b) Case no. 2



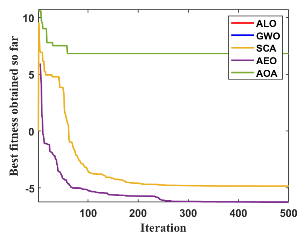
(c) Case no. 3



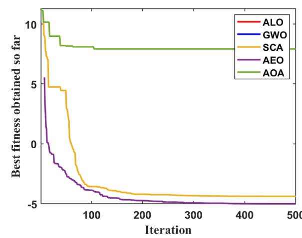
(d) Case no. 4



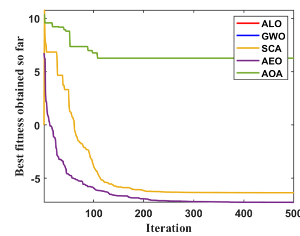
(e) Case no. 5



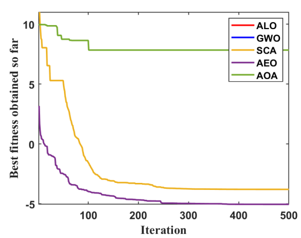
(f) Case no. 6



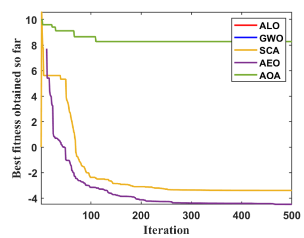
(g) Case no. 7



(h) Case no. 8



(i) Case no. 9



(j) Case no. 10

Fig. 6: Convergence Curve for each model case

power use, security, and the differences between physical and medium access protocols could be taken into account.

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