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Optimal Coverage of Wireless Sensor Networks Based On Artificial Algae Algorithm (AAA)

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Abstract
In the past few years, the demand for wireless sensor networks has increased significantly due to its small size, low cost and high efficiency. It has been used in many applications and in multiple fields. Owing to the ever-increasing number of applications using the wireless sensor network, it was necessary to find solutions to the problems and challenges faced by the wireless sensor network. One of the important challenges faced by Wireless Network Sensor is coverage. The nodes bear the actual liability to cover the pre-defined region. That's means the sensor nodes is placed in such a way as to achieve the maximal coverage of the area. Artificial alga algorithm (AAA), which is a very effective optimization method, has been used to find the suitable solutions for the coverage problem. The results were compared with the results of three algorithms (Artificial bee colony algorithm (ABC), particle swarm optimization algorithm (PSO) & Differential evolution Algorithm (DE)) to address the coverage problem. AAA proved to be more effective in solving the coverage problem. The simulation of the algorithms is performed by MATLAB and the results are analyzed to show the effectiveness of the proposed algorithm.

Keywords: Artificial algae algorithm; Coverage Problem; Wireless Sensor network.

1. Introduction

With the world's great technological revolution, methods aiming to solve the problems encountered in the real world are developing rapidly and continuously. One of the most promising technologies in the future is wireless sensor networks (WSN). That is because it has many advantages, the most important is small size, inexpensive, smart and easy to deploy. [1].In recent years, there was great interest worldwide in the WSN. It is consider as one of the most researched subjects in the last decade.
The wireless sensor network can be define as a network of small devices (sensor nodes) deployed in a specific area to obtain information about the area, all devices work collaboratively, collect information and send it via wireless links. Each node sends the data collected to a sink where the data is used either locally or sent to another network. [1]
The WSN technology offers multiple features through traditional networking solutions, like the lower costs, accuracy, scalability, flexibility, reliability, and ease of use that allows the possibility of deployment and use in many different applications such as military, environment, healthcare, and security. In military, sensor nodes can be used to adjust, locate or the enemy movements. In status of natural disasters, sensor nodes can predict disasters before they happen. In healthcare, sensor nodes use to help in monitoring a patient’s case. In the area of security, sensors can provide caution and increased vigilance for possibility terrorist attacks. WSNs will enable the automatic surveillance of forest fires, hurricanes, avalanches, floods, traffic

problems, hospitals and health centres, etc. With the continuous technological development, we have billions of wireless sensors spread over many different applications. Therefore, the standards and techniques of wireless sensor networks should be continuous developed to support new applications. [2].

There are many challenges that limit the efficiency of wireless sensor networks such as Energy usage, Security and Coverage. One of the important problems that occur in a wireless sensor network is the coverage area besides to location pinpointing, tracking, and a deployment. As the sensor nodes is actually responsible for coverage of the area specified, so the coverage depends on the manner of publishing the sensor nodes in the region to ensure that the maximal network coverage is accomplished [3]. The optimal deployment of the sensor nodes leads to optimum coverage, which is a key factor increase the lifetime of the network.

The optimal Deployment locations can be calculated in many ways. Such as using the physical properties of the node or using the artificial intelligence algorithms. The bio-inspired metaheuristic optimization algorithms is very efficient for solving the optimization problems. In this paper, we used AAA to achieve to the maximize coverage and minimum sensor range. The performance of the AAA method was compared with the successful optimization methods Artificial Bee Colony (ABC), Differential Evolution (DE), Particle Swarm Optimization (PSO) [3]. In the experimental study, various numbers of sensors were placed on 4 different terrain. The obtained results and the convergence of the methods to the solution were analyzed.

2. Related work

In the past few years, a lot of research has been done on the subject of coverage and sensor deployment in wireless sensor networks. Different methods and algorithms are used for optimal coverage and sensor distribution. For example, the impact of the coverage area on wireless sensor networks, their types and their impact on other performance standards such as connectivity and life time were discussed in [4]. In the paper, the best and worst case of coverage of a wireless sensor network are evaluated and calculated. In addition, a set of algorithms that were used in deployment and achieved their goals well are represented. In [5], it has been proposed to develop a consecutive form of the particle swarm optimization for the application of maritime surveillance. The objective is to determine the perfect location for the sonar sensors so that the coverage is maximized at a constant size representing a maritime area. The article explains that the proposed method has achieved better results in coverage than the standard PSO. In [6], Aziz et al. proposed a two-phase PSO algorithm for maximum coverage and energy saving for mobile WSN. The proposed method handled the maximization of coverage in the first stage and energy saving in the second stage. In (Singh and Lobiyal 2012) and (Latiff et al. 2007), they used the PSO to optimize the cluster heads location selection between normal sensor nodes and did not pay attention to the formation of clusters. In (Liu 2012), ant colony optimization with three categories of ant transitions to increase search speed and improve the quality of solution space is proposed to achieve the least deployment cost and ensure the coverage of the entire network. In [7], a heuristic method was proposed to schedule the work of the sensor nodes to obtain the maximum lifetime of the network. The method was theoretically proven highly efficient in all experimented cases. Lu et al. are proposed a polynomial-time constant-factor approximation algorithm to solve the scheduling problems for the data collection and the coverage in wireless sensor networks with the target of maximizing network lifetime. [8] In the study, it has been suggested that it is very difficult to reach the maximum lifetime scheduling of data collection and coverage in the wireless sensor network. In (Mini et al. 2014), a two-part method was proposed the first section is deploy the sensor nodes in an optimal way to reach the upper limit of coverage. The second section includes the scheduling of these nodes after distribution at optimal locations to reach the maximum lifetime of the network. ABC and PSO are used to sensor deployment problem in the paper. The ABC was more effective than the PSO. In [9], It proposed a method to reach the maximum lifetime of the wireless sensor network through a method called a Multi round Distributed Lifetime Coverage Optimization protocol (MuDiLCO), which divides the interested area into a group of regions. Then the protocol deploy the sensor nodes in these regions and scheduling the work of these sensor nodes and that is achieve to increases the wireless sensor network lifetime. In [10], the study proposed using a column generation algorithm to reach the longest life time of the wireless sensor network which contains different types of sensor nodes, which ensures the continuity of all the different nodes in the minimum coverage. The algorithm was also guided by a genetic algorithm, which proved a high speed to reach the target. In [11], Sangwan and Singh presented a survey on the problem of coverage in wireless sensor networks in terms of its importance in the lifetime of the network and discussed the effecting of the Computational Geometry in the coverage strategies, as well as discussing several strategies affecting the coverage of wireless sensor networks. In [12], the article proposes a centralized plan for managing a large set of deployed sensor nodes in a particular area by dividing the nodes into groups. All groups are scheduled so that each group is active within a specific period. The article proposes the column generation (CG) method to find an effective solution to the problem of the maximum lifetime coverage. In [13], Carrabs et al. suggested an efficient test for the operation of a wireless sensor network in a specific area, which includes the speed of performance and quality of work at any time as well as the calculation of energy consumption, where the article suggested an exact column generation algorithm that includes the metaheuristic genetic sub-problem. Where the results showed the success of the proposal.

3. Problem Formulation

An area to be covered is represented by a set of location point P_i denoted by coordinate (x_i, y_i), where *i* is a point in the terrain of size *m*x*n*, with *m* number of rows and *n* number of columns. The each location of sensor node is assumed to be a centroid of the location point's they must be covered.
Each centroid is found by calculating the mean value (*M*) of location points (X_i, Y_i) within the sensing range so the mean value is represented by (*mx*, *my*) when the location points (x_i, y_i) for *i=1, 2, 3 ... M*. *mx* and *my* are calculated by Eq. 1 and 2.

$$mx = \frac{\sum_{i=1}^{M}(x_i)}{M} \tag{1}$$

$$my = \frac{\sum_{i=1}^{M}(y_i)}{M} \tag{2}$$

When the sensor node located in a location point (x_1, y_1) the sensing range *r* can cover the location point (x_2, y_2), the distance between these two points is calculate by Euclidean distance expressed in Eq. 3.

$$\sqrt{(x_1 - x_2) + (y_1 - y_2)} \leq r \tag{3}$$

So, if the location point located within the sensing range it can be said it's covered. The location point (P_i) is closest to the centroid (S_c) if the distance ((P_i, S_c) ≤ distance (P_i, S_j)) $\forall_j$, $j = 1, 2 . . . R$ the cluster centroids.

By decrease the Euclidean distances between the location points and their nearest centroid. It divides the entire location area (A) into regions (R) which represent the number of sensor nodes. the sensor coverage problem can be formulated as an optimization problem in Eq.4 and processed as follows: a set of location points 'P' with fixed number of sensors 'R' are got, being deployed all the sensors by finding the optimum location So that all location points are covered.

$$F = \forall_R, \forall_j (\max(distance(S_R, P_j))) \quad (4)$$

Whereas SR is referring to the sensor deployment point P_j refers to the location point and the distance, which are calculated through the Euclidean distance shown in eqn. (3). [14]

the Proposed Scheme in the beginning, the algorithm initializes the centroids randomly in the region. After that, each location point is assigned to a cluster containing the nearest centroid. In the next step, the centroids are recalculated for all clusters by calculating the mean value of the location points allocated to them. The target is to lessen the objective function defined in eqn. (4), such that the sensors deployment is optimal to cover all the location points and the required sensing range is minimum. The problem is assumed as a data clustering problem, and each location point coordinates it represent a data point/ object, the centroid of the cluster represents the position of a sensor nodes, the cluster is considered the sensor node and the sensing range is the distance between the centroid and the farthest location point in the same cluster.

4. Artificial Algae Algorithm

Artificial algae algorithm developed by Uymaz et al. Artificial algae deals with any solution found in the research area by taking advantage of the properties of algae.

Like real algae in nature, artificial algae usually move helically to the light source and can adapt to the environment and reproduce by mitotic division. Each algal colony represents a solution. The algal colony consists of a set of algal cells living jointly. When the cell of the algae is divided, two new cells are produced and live together. The Algal colony works such a one cell, moves jointly, and under inappropriate life circumstance the cells might die. If the colony is exposed to an external force like a shear force may be divided into groups and each group become a new colony like a life produce. The colony called the colony of optimum if existent at the ideal point and it is consisting of the optimum algal cells. [15]. AAA is consisting of three parts (Evolutionary Process), (Adaptation) and (Helical Movement).

4.1 Evolutionary process

The algal colony grows and proliferate if it has get sufficient light, under enough nutritious conditions. The proliferate process results in two new cells, in time t, like the genuine mitotic division.

Otherwise, the algal colony dies when it does not get enough light.

4.2 Adaptation

When the algae colony cannot grow enough in an environment, it will try to adapt itself to the environment by resembling the dominant species.
The definition of adaptation is the process in which a colony of non-developing algae attempts to resemble itself in the largest algae colony in the environment. When the starvation level changes in the algorithm the Adaptation process will stop.

4.3 Helical movement
In nature, algae cells and colonies live in water move by swimming. In order to survive they try to remain close to the surface of the water to get the light. The algae cells swim in the fluid in a helical manner with their flagella, which provides movement forward, but they are restricted through the gravity and sticky drag. The movement of algae cells is different. The algae cells in the friction surface grow bigger, the helical motion frequency increases with increased the local search capability. The algae cell moves according to its energy. The energy of algal cell at time t is directly proportional to the quantity of nutrient uptake at the same time. Therefore, closer the algae cell is to the surface, the greater their energy and get additional chances of moving in the liquid. Otherwise, their movement space in the liquid it will be longer if the friction surface is few. Thus, the capability of global search it will be more. Its movement can be less according its energy. Like the real life, the motion of algal cell is helical.

The algorithm works can be illustrated in the following steps:
The first step (Initialization): the problem Parameters (number of dimension 'D', the maximum values for each dimension (upper bound (UB)), and the minimum values for each dimension (lower bound (LB)), the algorithm Parameters (energy loss 'e', Shear force 'Δ', adaptation 'Ap'), number of population 'N', the maximum fitness evaluations number 'MaxFES', and Initialize the algal colonies with random solutions.

- Determine the size for each algal colony

$$X_{ij} = LB_j + (UB_j - LB_j) \times Rand \quad i = 1, 2, \dots, N; j = 1, 2, \dots, D \qquad (5)$$

- For each algal colony is evaluate the fitness
- evaluate the size (G) of the algae colony

$$\mu_i = S/(K_s + S) \qquad (6)$$

- μ is the specific growth rate, the growth rate at half nutrient conditions of algal colony in time t is K, and S is the nutrient concentration.

$$G_i^{t+1} = \mu_i^t G_i^t \qquad i = 1, 2, \dots, N \qquad (7)$$

- Evaluate the friction surface 'τ' for the algal colonies

$$\tau(x_i) = 2\pi\left(\sqrt[3]{3G_i/4\pi}\right)^2 \qquad (8)$$

- Evaluate the energy 'E' of the algal colonies.

$$G\ E^{t+1} = norm\left(\left(rank(G^t)\right)^2\right) \qquad (9)$$

The second step (Main department): This department it will be iterate until reach to the MaxFES. Consist of:

a- the Helical motion phase for all algal colonies :

- Choose other algal colony with a tournament chooses.
- Randomly choosing three algal cells (k, l & m) of the colony.
- Modification of the colony.

$$X_{i_m}^{t+1} = X_{i_m}^{t} + \left(X_{j_m}^{t} - X_{i_m}^{t}\right)\left(\Delta - \tau^{t}(X_i)\right)P \quad (10)$$

$$X_{i_k}^{t+1} = X_{i_k}^{t} + \left(X_{j_k}^{t} - X_{i_k}^{t}\right)\left(\Delta - \tau^{t}(X_i)\right) \cos\alpha \quad (11)$$

$$X_{i_l}^{t+1} = X_{i_l}^{t} + \left(X_{j_l}^{t} - X_{i_l}^{t}\right)\left(\Delta - \tau^{t}(X_i)\right) \sin\beta \quad (12)$$

- Decrease the energy be caused by movement.
- If the new solution is better then move to new location and starvation is false, else less the energy by metabolism.
- If the colony didn't get better solution then increase starvation of the colony.

b- cloning phase :

- Choose the smallest & the biggest colonies.

$$Biggest^{t} = max\, G_i^{t} \quad i = 1, 2, 3 \ldots\ldots N \quad (13)$$

$$Smallest^{t} = min\, G_i^{t} \quad i = 1, 2, 3 \ldots\ldots N \quad (14)$$

- Select the algal cell randomly (m).
- Algal cell is proliferate from the biggest to the smallest.

$$Smallest_m^{t} = biggest_m^{t} \quad m = 1, 2, 3 \ldots . D \quad (15)$$

c- Adaptation phase :

- Select the hungriest colony.

$$Starving^{t} = max\, A_i^{t} \quad i = 1, 2, 3 \ldots\ldots N \quad (16)$$

- Amendment the colony .

$$Starving^{t+1} = starving^{t} + (biggest^{t} - starving^{t}) \times rand \quad (17)$$

The final is report the best solution. [15].

5. Results and Discussions

In this paper, MATLAB 2016a version is used in the conducted of the experiments. Experiments on four different terrains structures were performed; the first structure was regular, shown in Figure 1 and the other structures were irregular, as shown in Figure 2, 3, 4. The terrains were drawn using the image-editing program and converted into binary images. The size of each image was 100 X 100 pixels. The black pixels in the figures indicate the points where the sensor can be placed.

Fig. [illegible] (Terrain 1)

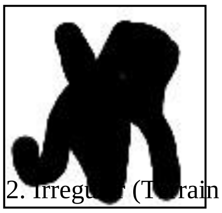


Fig. 2. Irregular (Terrain 2)

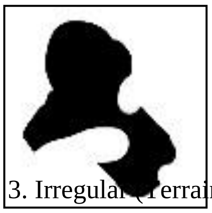


Fig. 3. Irregular (Terrain 3)

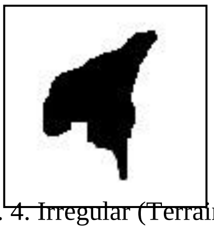


Fig. 4. Irregular (Terrain 4)

The experiments were simulated with 4, 8, 16 and 32 sensor nodes, to be deployed in the terrain. In this work ABC, DE and PSO are selected for comparison with AAA. Since each sensor location is expressed by the x and y coordinate, the dimension size of the individuals for the 4, 8, 16 and 32 sensors is 8, 16, 32 and 64 respectively. For all algorithms, the population size is 20. The minimum and maximum range of individuals in each dimension is determined as [0, 100]. All specific parameters of the algorithms are depicted in Table 1.

Table 1. Parameters of algorithms

Algorithm	Parameter
AAA	ShearForce (Δ)=2, LossOfEnergy (e)=0.3, AdaptationParameter (Ap)=0.5
ABC	Limit parameter = round(0.6*dimension*popsize)
DE	CR=0.9, F=1, Strategy is DE/Best/1
PSO	c1=c2=2.05

Four tests performed for each train. The tests were carried out with 20 runs and 150,000 maxFEs parameters. The average range and standard deviation values obtained for 4, 8, 16 and 32 sensors deployment in each terrain are shown in Table 2.

Table 2. Test results for 4, 8, 16 and 32 sensors in terrains

Terrain	Number of Sensor	AAA		ABC		DE		PSO	
		Avg. Range	Std. Dev.	Avg. Range	Std. Dev.	Avg. Range	Std. Dev.	Avg. Range	Std. Dev.
1	4	**55.9017**	0	**55.9017**	0	**55.9017**	0	**55.9017**	0
	8	35.28535	0.221325	35.29666	0.225737	**34.65545**	7.49E-15	35.43098	0.401819
	16	**27.05917**	0.578442	28.1444	0.570368	27.42192	0.697911	28.51565	1.397498
	32	19.9557	0.434796	21.4311	0.34602	**19.89459**	0.670952	20.10182	0.892521
2	4	**43.41659**	7.49E-15	**43.41659**	7.49E-15	**43.41659**	7.49E-15	**43.41659**	7.49E-15
	8	**29.15476**	0	**29.15476**	0	**29.15476**	0	29.7019	1.153463
	16	**19.25293**	0.37203	20.53138	0.920475	21.38528	1.876664	19.49676	0.866941

	32	14.88303	0.325757	16.36919	0.526651	18.46664	0.304119	**14.38164**	0.275599
3	4	**40.22437**	7.49E-15	**40.22437**	7.49E-15	**40.22437**	7.49E-15	40.269	0.094078
	8	22.70325	0.424593	22.54406	0.269621	22.56951	0.361225	**22.06319**	0.132536
	16	**16.24938**	0.713117	17.13723	0.6794	17.8888	1.449417	16.72045	1.014599
	32	12.56469	0.503987	13.8126	0.485473	15.50219	0.449655	**12.16873**	0.684815
4	4	**31.89044**	3.74E-15	**31.89044**	3.74E-15	**31.89044**	3.74E-15	**31.89044**	3.74E-15
	8	**19.25828**	0.492807	19.72921	0.254108	19.76531	0.508233	19.25946	0.43852
	16	13.102	0.390901	14.72879	0.425066	14.53794	1.433042	**12.7916**	0.441018
	32	10.02096	0.447636	11.70347	0.504278	12.29302	1.096316	**9.340961**	0.227164
Total Average		**25.68266**	0.306587	26.376	0.32545	26.56053	0.552971	25.71568	0.501286

For 4 sensors deployment, all methods except the PSO at the terrain 1 had the best range value. For 8 sensor deployment, the AAA method achieved the best results in two terrains (terrain 2 and terrain 4), the DE method in two terrains (terrain 1 and terrain 2), and the PSO method in terrain 3. For 16 sensors deployment, the AAA method achieved the best results in all terrain except terrain 4. The best result in terrain4 was achieved by the PSO method. For sensor placement 32, the PSO method achieved the best results in all terrain except terrain 1. Overall, AAA achieved the best results in 9 out of 16 test studies. PSO, DE and ABC obtained the best results in 8, 7 and 5 of 16 test studies, respectively.

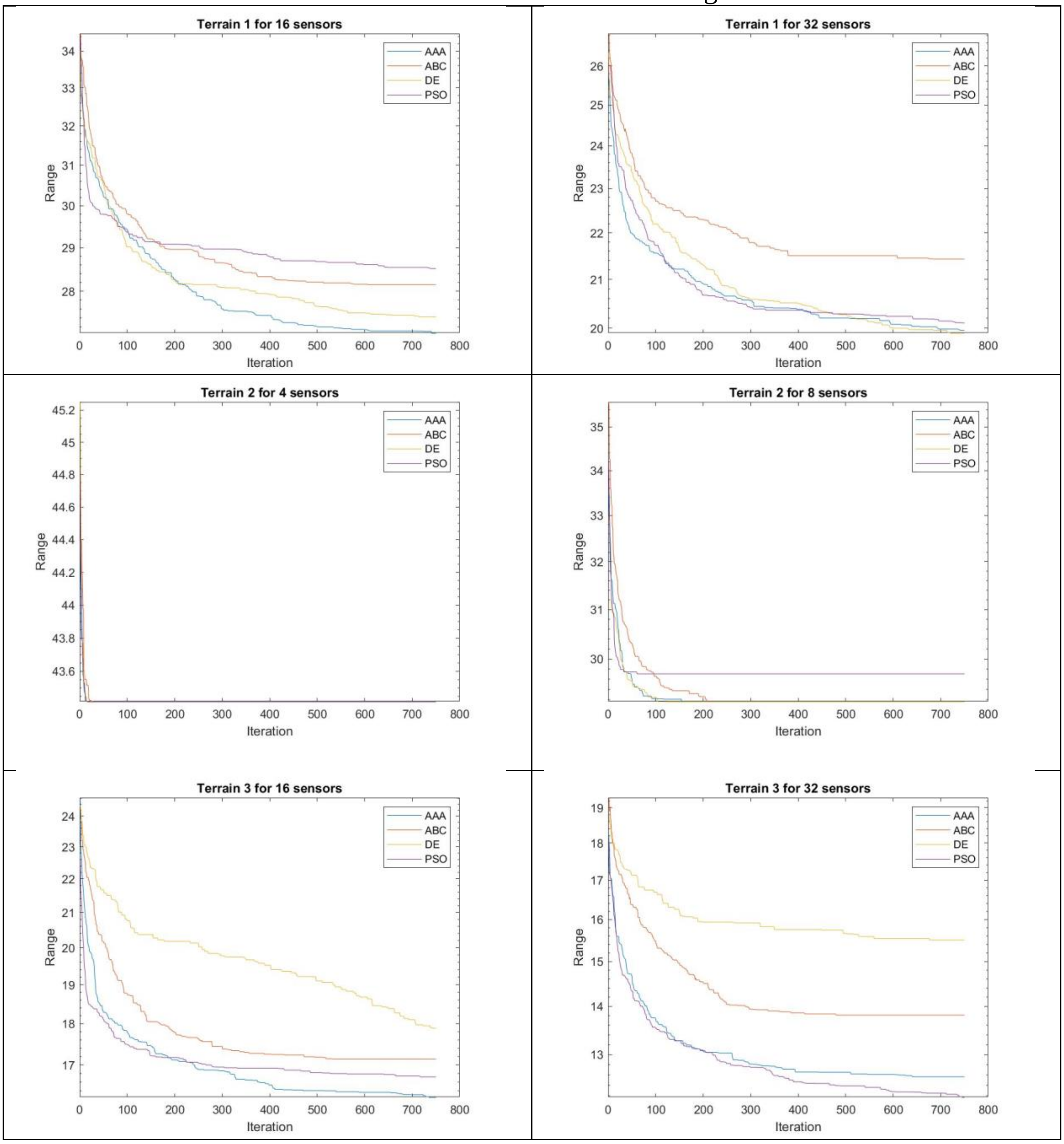
The average ranking method is a method used to compare the results of more than one method from different experiments and to determine which method is more successful. The results of the average ranking of the experimental study are in Table 3. The total number of tests was 16 and the ranking was as follows: The AAA algorithm got the first rank 4 times, got the second rank 8 times, got the fourth rank once and the equal condition 3 times. The ABC algorithm got the second rank 3 times, got the third rank 8 times, got the fourth rank 2 times and the equal condition 3 times. The DE algorithm got the first rank 2 times, got the second rank 3 times, got the third rank 2 times, got the fourth rank 6 times and the equal condition 3 times. The PSO algorithm got the first rank 5 times, got the second rank 3 times, got the third rank once, got the fourth rank 4 times and the equal condition 3 times. According to Table 3, the average ranking method shows that the AAA method is more successful than other methods.

Table 3. the ranking of algorithms according to simulation results

Terrain	Number of Sensor	AAA	ABC	DE	PSO
1	4	2.5	2.5	2.5	2.5
	8	2.0	3.0	1.0	4.0
	16	1.0	3.0	2.0	4.0
	32	2.0	4.0	1.0	3.0
2	4	2.5	2.5	2.5	2.5
	8	2.0	2.0	2.0	4.0
	16	1.0	3.0	4.0	2.0
	32	2.0	3.0	4.0	1.0
3	4	2.0	2.0	2.0	4.0
	8	4.0	2.0	3.0	1.0

	16	1.0	3.0	4.0	2.0
	32	2.0	3.0	4.0	1.0
4	4	2.5	2.5	2.5	2.5
	8	1.0	3.0	4.0	2.0
	16	2.0	4.0	3.0	1.0
	32	2.0	3.0	4.0	1.0
Average		**1.97**	2.84	2.84	2.34

For demonstrating the convergence characteristic of the algorithms, the convergence graphs of the selected tests including terrain 1 for 16 and 32 sensors, terrain 2 for 4 and 8 sensors, terrain 3 for 16 and 32 sensors and terrain 4 for 8 and 16 sensors in Figure 5



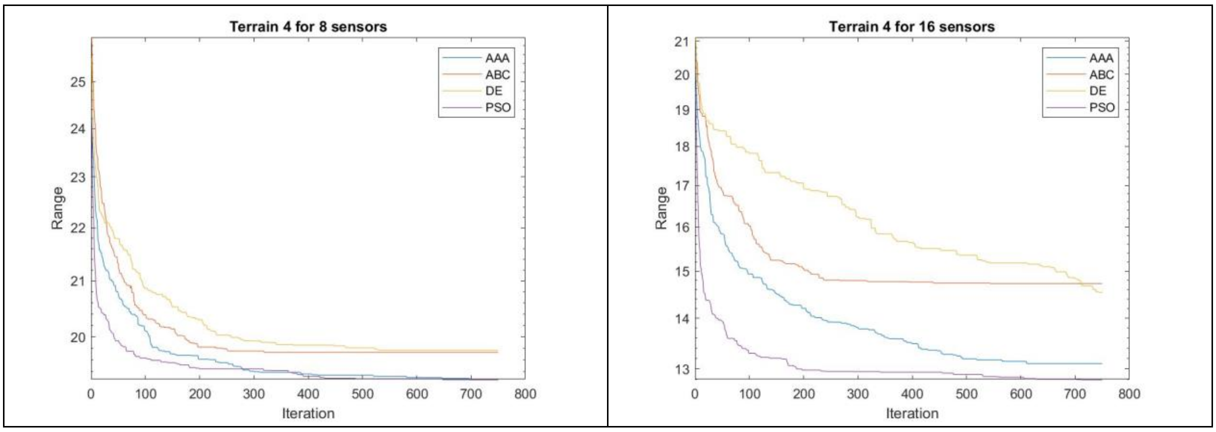


Figure 5. Convergence graphs of test (terrain 1 for 16 and 32 sensors, terrain 2 for 4 and 8 sensors, terrain 3 for 16 and 32 sensors and terrain 4 for 8 and 16 sensors).

When convergence graphs are examined, convergence of AAA and PSO methods to optimum solution is better than DE and ABC methods. In tests with 4 sensors, all methods have almost the same convergence characteristic. In tests with 8 sensors, convergence character of AAA method is better than other methods. In tests performed with 16 and 32 sensors, DE and ABC suffer from avoidance of local minimum points, whereas AAA and PSO methods have a good convergence characteristic. As a result, the convergence characteristic of the AAA method to the optimum solution is better than the other methods.

5. Conclusion

In this paper, due to the importance of coverage in the performance of the WSN, proposed this approach to optimal coverage by using AAA. it simulated a varying number of sensor nodes in four different terrain area and located the minimum sensing range requirements Which help to know the number of sensor nodes needed to cover the area. also used the same inputs with three algorithms (ABC, DE and PSO) to make a comparison between the performance of the algorithms. The artificial algae algorithm proved more efficient and more capable of reaching the optimal solution than the other algorithms.

Our proposal for the future is the use of artificial algae algorithm to address the energy consumption in wireless sensor network. In addition, AAA method can be designed as multi-objective and a multi-objective approach for solving WSN problems can be presented.

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