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An Optimized Wireless Sensor Network Deployment Using weighted Artificial Fish Swarm (wAFSA) Optimization Algorithm

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***Abstract*—This paper presents an improved method for deployment of wireless sensor networks using weighted Artificial Fish Swarm Algorithm (wAFSA). In wireless sensor networks, optimal deployment of sensor nodes is a very critical and important factor in obtaining efficient and reliable quality of service. An improved approach called inertial weight is first introduced into the standard artificial fish swarm algorithm to adaptively select the visual and step sizes of the artificial fishes before the preying, swarming and chasing behaviours of wAFSA were used to randomly and optimally deploy a total of sixty sensor nodes in a network coverage area of 60 square meters. The proposed method was evaluated using some performance metrics such as network coverage and mobile node, network coverage and iteration. The method was also compared with results obtained using standard AFSA which showed that wAFSA performed better and can be used to adequately improve the scalability of wireless sensor networks.**

Keywords-wireless sensor network; artificial fish swarm algorithm; inertial weight

I. INTRODUCTION

The deployment of sensor nodes is a very important factor which affects the quality of wireless sensor networks (WSN). Poor deployment of sensor modes in WSN could lead to low mode density which in turn causes communication gap and high node density which causes message collision and retransmission, signal intrusion and cramming, huge energy consumption, etc. thereby leading to challenges in scalability, stability, distributed architecture, energy consumption, and autonomous operation of the WSN [1]. The introduction and development of Artificial Intelligence (AI) has been given significant research attention in engineering and related disciplines. These artificial intelligence (heuristic and metaheuristics) algorithms have shown robustness and strong ability in solving problems such as WSN deployment and target tracking as shown in [2-4] and [1]. These algorithms include Particle Swarm Optimization (PSO) [5], Artificial Bee Colony (ABC) [6], Ant Colony Optimization (ACO) [7], Firefly Algorithm (FA) [8], Bacterial Foraging Optimization (BFO) [9], Artificial Fish Swarm Algorithm (AFSA) [10] and so on. Several modifications of these algorithms have also been presented by different researchers in order to improve their performance and address some of their challenges when solving several optimization problems.

The Artificial Fish Swarm Algorithm (AFSA) has been widely adopted in solving various optimization problems because of its numerous advantages such as; ease of implementation, adaptive search ability, high convergence speed, ability to effectively acquire global solutions while avoiding local extreme solutions [11-13]. These advantages are due to a combination of chasing, preying and swarming behaviour of the artificial swarm of fish while searching for the global solution in multi-modal complex optimization domain problems.

II. LITERATURE REVIEW

The AFSA has been used by several authors in the deployment and tracking of WSN and a significant performance when compared with other algorithms have been observed. The paper presented in [14], proposed the use of AFSA for wireless network deployment but did not consider network energy efficiency based on node delivery time. In 2012, Ma and Pu [15] used niching Particle Swarm Optimization technique for energy distance aware clustering protocol with dual cluster heads in wireless sensor networks. The research in [16] used artificial fishes based AFSA for cooperative search and rescue in underwater wireless sensor nodes. However, effective coverage area utilization, while optimally deploying mobile nodes in WSN still remains a major concern for researchers in the area of wireless sensor networks. In this paper, we present a modified AFSA called weighted Artificial Fish Swarm Algorithm (wAFSA) for deployment of sensor nodes in WSN. As presented in [11, 13] an inertial weight was first introduced into the AFSA to adaptively select its parameters before it is used for the deployment of WSN so as to obtain a maximized value of the objective function. The results obtained were then compared with that of standard Artificial Fish Swarm Algorithm.

III. WIRELESS SENSOR NETWORK MODEL

For the essence of simplicity and easy applicability, this paper considers a wireless sensor network having fixed and mobile sensor nodes. Sixty (60) random nodes were generated in a square coverage area of $60m \times 60m$. This number of fixed and mobile sensor nodes are represented as N and D for easy adaptability into the optimization algorithm that would be used for deployment of these sensor nodes.

The significance and important of doing this is to create a matrix search space which is equivalent to the network coverage area for the sensor nodes to be deployed. N represents the population of sensor nodes to be deployed while D represents the dimension of deployment which can be termed as the search space usually in an optimization problem. Therefore, the combination of all nodes in their respective location within the coverage area can be represented as:

$$N = \{n_{1,1}, n_{1,2}, ...n_{i,j}\} \quad (1)$$

Where $n_{i,j}$ represent the ith node in the network, in the jth location of the network. In this case, *i* has the same size as N and *j* has the same size as *D*. where *N* is the number of sensor nodes and D is the dimension of deployment. Given a random node M with a position (x, y) in the network coverage area and a specific node Q having a position x_i, y_i within the monitored or specified area, the distance between the nodes can be calculated as [1]:

$$X(M,Q) = \|Q - M\| = \sqrt{(x_i - x)^2 + (y_i - y)^2} \quad (2)$$

The detection probability of any node Q by another node M can be calculated based on the probability measurement model adopted from the work of [14, 1]. This can therefore be obtained as:

$$P_p(Q_i) = \begin{cases} 0 & R_s + R_e \le X(M,Q) \\ e^{-\alpha\lambda^{\beta}} & R_s - R_e < X(M,Q) < R_s + R_e \\ 1 & R_s - R_e \ge X(M,Q) \end{cases} \quad (3)$$

Where R_s is the perceived radius of various elements in the network, R_s is the uncertainty factor within the measurement range of the nodes for $0 < R_e < R_s$, α & β are measured parameters with respect to the physical devices being used and λ is the input parameters which can be defined as [1]:

$$\lambda = X(M,P) - (R_s - R_e) \quad (4)$$

Therefore, the joint detection probability of multiple sensor nodes when conducting simultaneous measurement simultaneously can be obtained using [1]:

$$P_p(Q) = 1 - \prod_{w_i \in W} (1 - P_p(Q,M)) \quad (5)$$

IV. NETWORK COVERAGE AREA

The Network Coverage Area (NCA) is one of the important indices used to measure the strategy of the wireless sensor network deployment. The network coverage area we considered in this work was the ratio of the whole area that can be covered by the nodes in the total node-aware region and the total area of the monitoring region. Due to the fact that monitoring the environment can be quite complicated, the probability measurement model described in equation (5) was adopted. In order to minimize energy consumption, the following assumptions were made:

- Network nodes are ideal (i.e. nodes in the network have the same communication radius R_C and the same sensor radius R_S while $R_C > R_S$ because when the communication radius between the nodes is greater than two times the sensor radius of nodes, then the current networks are connected).
- Coverage is considered as a metric for the measurement of quality of service of a sensor network.
- At the initial stage of network deployment, all nodes are randomly distributed in a square monitoring area whose length is N, while the coordinate range of the monitoring area is from (0, 0) to (N, D) whereby the D is the dimension of the coverage.
- Every node obtains the coordinate position information of itself and its neighbouring nodes.
- In order to reduce energy consumption, the movement of nodes is virtual when running the algorithm until after the end of the algorithm, when nodes move to the best location based on the physical location for a single time period.
- The model and physical structure of every node is the same and similar.

V. WEIGHTED ARTIFICIAL FISH SWARM ALGORITHM

The Artificial Fish Swarm Algorithm (AFSA) was developed based on the intelligent random behaviours of school of fish which are preying, swarming and chasing behaviours. It has been established that certain parameters of AFSA such as visual distance and step size have critical influence on the performance of the algorithm. For example, when the visual distance is very large, the algorithm has a strong ability in obtaining a near optimal global solution and when the visual distance is small, the algorithm has a strong local solution searching ability. Furthermore, the bigger the step size, the faster the speed of convergence of the algorithm and vice versa [11, 13]. This property of the artificial fish swarm algorithm necessitated us to employ the use of weighted Artificial Fish Swarm Algorithm (wAFSA) [11, 13] in which an inertia weight was introduced to adaptively select the visual distance and step size of the AFSA to suite our problem formulation at every iteration

The ultimate goal of every fish in water is to discover available regions with more food either by vision or by sense through intelligent behaviours such as preying, swarming and chasing. This idea was used in modelling the behaviour of artificial fishes such that the environment where an artificial fish lives is mainly the solution search space of the optimization problem and this defines the state of the fishes.

The basic idea of AFSA is to imitate the preying, swarming and chasing behaviour of fishes. These individual behaviours of AFSA can be represented based on the following rules:

- Synergic rule: Here, a basic communication is maintained between each individual artificial fish. If an individual fish in the searching swarm receives a call sent by another individual, it moves forward to the calling individual's position by a step with a certain probability
- Reconnaissance move rule: If the individual artificial fish does not receive a call, it implements reconnaissance (surveying) according to its own swarm historical experience. If it however finds a better goal, it then moves forward to that position by a step using its respective probability.
- Stochastic rule: For this rule, if the searching individual fish does not receive a call or does not find a better goal, it moves in steps randomly such that if it then finds a better goal during the step movement, it sends a call to the entire fish swarm.

For any optimization problem, the objective function under consideration can be said to have a solution space Dimension-D and the swarm is initialized with P-population of artificial fishes, such that the state of one artificial fish can be formulated accordingly. Detail description and relevant mathematical model for the implementations of wAFSA can be found in [11, 13].

The flowchart of the weighted Artificial Fish Swarm Algorithm (wAFSA) as implemented in this paper is shown in Figure 1.

VI. PROBLEM FORMULATION

The problem formulation was done based on the network area. Here, $N.H$ and H' represent a set of total nodes and a set of active nodes respectively. These constitute the total number of nodes that can be represented as randomly generated artificial fishes within the solution search space. The inspection region of H and H' are correspondingly G and G' in which G_i is the inspection region of the ith artificial fish (node). The network coverage area is formulated as follows [17]:

$$\omega(H') = \frac{H'}{N} \tag{6}$$

The quality of the network coverage area is then defined as:

$$C(H') = \frac{\bigcup_{i=1,2,\ldots N} G_i}{G} \tag{7}$$

The objective function of the coverage quality which was formulated using equation (7) can be defined as:

$$f(c) = \max[\mathrm{C}(H')] \tag{8}$$

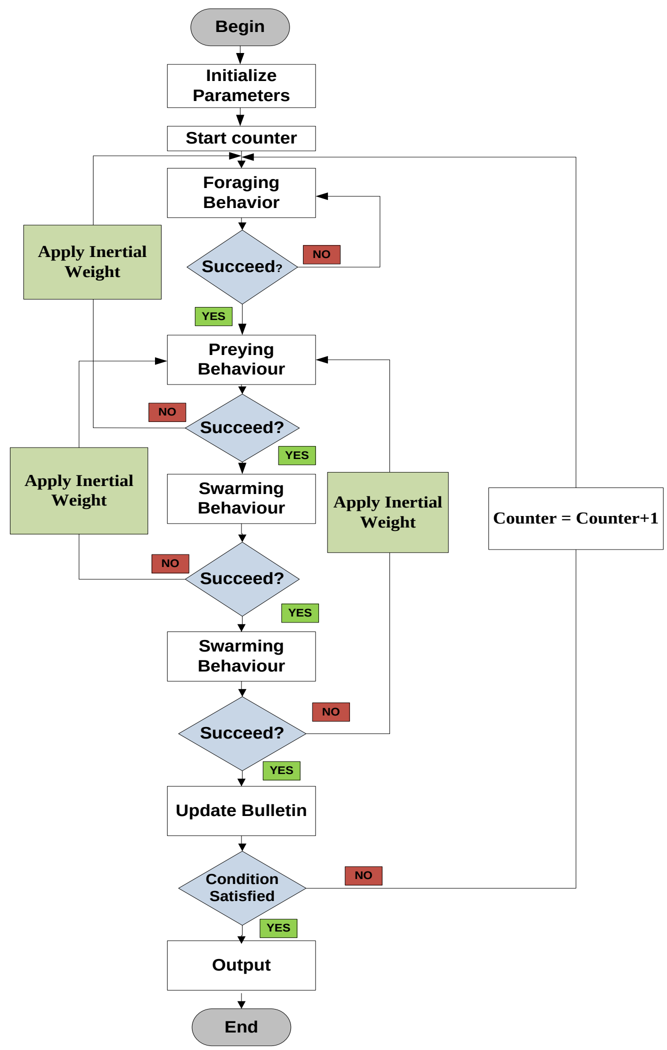

Figure 1. Flowchart implementation of wAFSA

Equation (8) represents a maximization objective function which was formulated as a function of network region optimization. The best solution of this objection function returns the optimum value of the network coverage area in which the location of all the sensor nodes are optimized in terms of deployment while consuming minimal energy in the process.

VII. SIMULATION APPROACH

The wAFSA which was previously described was used to optimize the objective function shown in equation (8). Here, mobile sensor nodes are represented as artificial fishes in a cluster form and the cluster head node travels based on the nature of the objective function while following the inertial preying, swarming and chasing movement behaviour. The step by step procedure of the proposed method which is represented in Figure 1 is as follows:

- Initialize all the parameters for wAFSA;

- Initialize the wireless nodes and population of wAFSA to be deployed within the coverage area's dimension;
- Initialize iteration start point $itr = 0$;
- Calculate the fitness based on the current locations of the nodes in the coverage area and update the score board with the best individual;
- Select a new state randomly and evaluate its fitness
- Evaluate the best fitness based on inertial preying, swarming and chasing behaviour of wAFSA;
- Evaluate the current fitness of the population (nodes) and compare with previous fitness and then update;
- If the stopping criteria is met, output the current best fitness, else increase iteration by 1 and go back to step (5) until best solution is obtained.
- Display best solution and configuration.

The details of the parameters used for simulation is presented in Table 1. Since the coverage area under consideration is 60 X 60 square metres, 60 wireless sensor nodes were also considered to be deployed randomly and thus, the problem dimension of 60 was used.

TABLE I. PARAMETERS SETTINGS FOR NETWORK COVERAGE SIMULATION USING WAFSA

S/N	Parameters	Description	Values
1	Visual	Visual Distance	20m
2	Step	Step Size of AF	10m
3	Crowd	Crowd factor of AF	0.6
4	N	Number of Nodes	60
5	R_S	Sensor Radius	4m
6	R_C	Commutation Radius	15m
7	R	Uncertain Factor	2m
8	Try_num	Number of trial	100
9	K_{min}	Cessation Value	40
10	K	Current Value	Iterative
11	K_O	Initial Value	200
12	R	Attenuation Constant	0.95
13	P_m	Measured Probability	0.8
14	K	Actuation Constant	0.4

VIII. RESULTS AND DISCUSION

Simulations were carried out on MATLAB R2015b and the results are presented based on the performance of the model. The performance evaluations carried out were to check the relationship between network coverage certain parameters such as network node and number of iteration. Readers should note that, the best of every twenty (20) run of the model were presented. The Figure 2 shows the superimposed result obtained for the network coverage against the number of iteration for both the weighted wAFSA and the standard AFSA.

It can be observed from Figure 2 that, the performance of the network coverage increases as the number of iteration is increased from 0 in a step of 5 to 50 iterations. It can be deduced that the wAFSA attained the highest network coverage of about 77.95% which occurs when the number of iterations is 25. At this point, increase in number of iteration appears to have little or no significant effect on the performance of the algorithm. Also, for the standard AFSA, the network attains it maximum coverage of about 75.9% when the number of iteration is 20, thereafter, increase in iteration also, appears to have no significant effect on the network. it can be concluded that, even though the wAFSA performed much better in terms of coverage area, the standard AFSA attains it maximum much faster. The improvement of wAFSA over AFSA can be attributed to the adaptive behaviour of the inertial weight which enables to explore larger solution space before it converges. The figure showing the performance evaluation using the coverage area and number of mobile nodes is given in Figure 3.

From Figure 3, it can be observed that, the network coverage increases with increase in number of mobile nodes. For the weighted AFSA, the network coverage attains a maximum of 80.20% at mobile nodes of 50 and then, tends towards stability. Also, for the standard AFSA, a maximum network coverage of about 79.9% was obtained at the same network nodes with similar network behaviours. The insignificant different in the network using both weighted AFSA and standard AFSA indicates the scalability of the network using both approach.

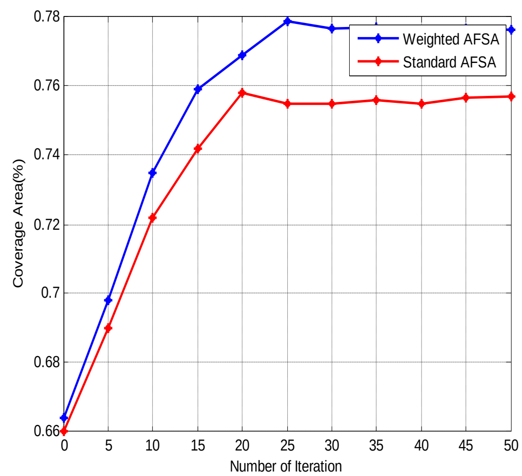

Figure 2. Network Performance Against Number of Iterations

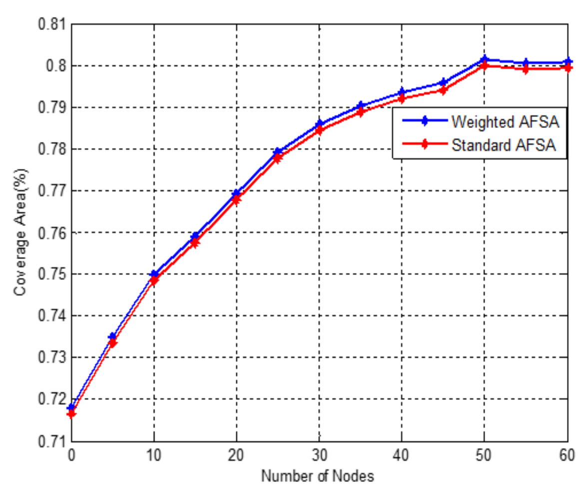

Figure 3. Network Coverage Performance Against Number of Nodes

IX. CONCLUSION AND FUTURE WORK

This paper presents an optimized deployment of WSN using a modified artificial fish swarm optimization algorithm (wAFSA). The model was simulated in MATLAB R2015a simulation environment and results show the superiority of the modified algorithm over the standard AFSA. The superiority of the modified algorithm is attributed to the adaptive and dynamic behaviour of the modified algorithm in comparison the original AFSA. In our next research work the performance of the wAFSA will be evaluated on different target tracking and other optimization problems such as data clustering, colour quantization, distributed generation etc.

REFERENCES

[1] S. A. Lawal, S. Garba, A. D. Usman, M. B. Mu'azu, and A. T. Salawudeen, "Optimal Deployment of Wireless Sensor Networks (WSN) Based on Artificial Fish Swarm Optimization Algorithm," *International Journal of Science and Engineering Investigations,* vol. 4, pp. 45-51, 2015.

[2] T. Yang and T. Yong, "Short Life Artificial Fish Swarm Algorithm for wireless sensor network," in *Computational Problem-solving (ICCP), 2013 International Conference on*, 2013, pp. 378-381.

[3] Z. Li, H. Zhang, J. Xu, and Q. Zhai, "Recognition and localization of harmful acoustic signals in wireless sensor network based on artificial fish swarm algorithm," *Journal of Theoretical and Applied Information Technology,* vol. 49, 2013.

[4] Y. Wang and L. J. Li, "An Improved Intelligent Algorithm based on the Group Search Algorithm and The Artificial Fish Swarm Algorithm," *international Journal Optimization, Civil Engineering,* vol. 1, p. 15, 2015.

[5] R. C. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *Proceedings of the sixth international symposium on micro machine and human science*, 1995, pp. 39-43.

[6] D. Karaboga, "An idea based on honey bee swarm for numerical optimization," Technical report-tr06, Erciyes university, engineering faculty, computer engineering department2005.

[7] M. Dorigo, V. Maniezzo, and A. Colorni, "Ant system: optimization by a colony of cooperating agents," *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on,* vol. 26, pp. 29-41, 1996.

[8] X.-S. Yang, "Firefly algorithm, stochastic test functions and design optimisation," *International Journal of Bio-Inspired Computation,* vol. 2, pp. 78-84, 2010.

[9] K. M. Passino, "Biomimicry of bacterial foraging for distributed optimization and control," *Control Systems, IEEE,* vol. 22, pp. 52-67, 2002.

[10] L. X. Lei., Z. J. Shao, and J. X. Qian, "Optimizing method based on autonomous animats: Fish-swarm Algorithm," *Xitong Gongcheng Lilun yu Shijian/System Engineering Theory and Practice,* vol. 22, p. 32, 2002.

[11] M. B. Mu'azu, A. T. Salawudeen, T. H. Sikiru, A. Muhammad, and A. I. Abdu., "weighted Artificial Fish Swarm Algorithm with Adaptive Behaviour Based Linear Controller Design for Nonlinear Inverted Pendulum," *Jounal of Engineering Research JER,* vol. 20, pp. 1-12, March, 2015 2015.

[12] A. T. Salawudeen, "Development of an Improved Cultural Artificial Fish Swarm Algorithm with Crossover," Masters Electrical and Computer Engineering, Ahmadu Bello University Zaria, 2015.

[13] A. T. Salawudeen and M. B. Mu'azu, "Stabilization of Inverted Pendulum System using Intelligent Linear Quadratic Regulator Controller," in *IEEE-Trans of 7th International Joint Conference on Computational Intelligence* , Lisbon Portugal, 2015, pp. 325-333.

[14] W. Yiyue, L. Hongmei, and H. Hengyang, "Wireless sensor network deployment using an optimized artificial fish swarm algorithm," in *Computer Science and Electronics Engineering (ICCSEE), 2012 International Conference on*, 2012, pp. 90-94.

[15] D. Ma and P. Xu, "An Energy Distance Aware Clustering Protocol with Dual Cluster Heads Using Niching Particle Swarm Optimization for Wireless Sensor Networks," *Journal of Control Science and Engineering,* vol. 2015, 2015.

[16] W. Zhao, Z. Tang, Y. Yang, L. Wang, and S. Lan, "Cooperative search and rescue with artificial fishes based on fish-swarm algorithm for underwater wireless sensor networks," *The Scientific World Journal,* vol. 2014, 2014.

[17] H. A. Hashim, B. Ayinde, and M. Abido, "Optimal placement of relay nodes in wireless sensor network using artificial bee colony algorithm," *Journal of Network and Computer Applications,* vol. 64, pp. 239-248, 2016.