Journal of Network Intelligence ©2019 ISSN 2414-8105(Online)
Taiwan Ubiquitous Information Volume **4**, Number **1**, February **2019**

Node Coverage Optimization Strategy Based on Ions Motion Optimization

Trong-The Nguyen[1,2], Jeng-Shyang Pan[1], Tsu-Yang Wu[1]

[1]Fujian Provincial Key Lab of Big Data Mining and Applications,
Fujian University of Technology, Fujian, China
jvnthe@gmail.com, jengshyangpan@gmail.com, wutsuyang@gmail.com

Thi-Kien Dao[2], Trinh-Dong Nguyen[2]

[2]Department of Information Technology,
Haiphong Private University, Vietnam
vnthe@hpu.edu.vn, dongnt@hpu.edu.vn

Received December, 2018; revised January, 2019

Abstract. *This paper proposes a novel coverage strategy approach based on Ions Motion Optimization (IMO) for optimal coverage problem in the wireless sensor networks (WSN). In specific arear, how to reasonably arrange the sensor nodes to achieve the best coverage is the key to improving whole network performance. The node-coverage of the monitored area is modeled for objective function by the probability of each node to pixel and the joint coverage of each pixel point into the region for a whole network coverage optimization. Simulations of the coverage strategy are implemented in different scenario densities for optimal coverage. The results compared with the other approaches in the literature shows that the proposed approach can provide the effectively improving convergence speed and coverage rate of nodes, so leading to whole network coverage effect and prolonging network lifetime.*

Keywords: Ion motion optimization, Network coverage, Wireless sensor networks.

1. **Introduction.** Sensor nodes layout generally are deployed randomly by using the method of tossed in the air that then causes the whole area of ranging nodes to make the network performance inefficiently. So, the node coverage issue in the wireless sensor work (WSN) plays important role in improving entire network performance [1]. Under the premise of ensuring the performance of network services, it mainly addresses how to use the least nodes to cover the maximum area that WSN can provide accurate data collecting information and target tracking services [2].

The traditional way had used the static deploying nodes on a large scale, however, the static nodes would lead to communication conflicts. Therefore, mobile nodes can be used to improve that situation. However, how to optimize the mobile node coverage that has raised more challenge with becoming one of the hot topics in current research [1][3][4].

As optimizing the location of mobile nodes, the network performance also increases arranging the mobile nodes effectively, improving the service quality and prolonging the network monitoring time, because the efficient algorithm can allocate the resources of the whole WSN reasonably [5] [6].

There was a proposed method of maximum coverage of the mobile node by establishing the models of using the distance between nodes to adjust the node position, however, this method existed the disadvantage is a relatively large computation [7]. The cellular structure, additionally, was used to calculate the mobile node candidate target location, to repair loopholes, and to improve network coverage [8], but it faced to heavily computation if the scale network is large. Moreover, the network coverage problems also have been dealt with optimization by the swarm algorithms: such as the artificial fish algorithm (AFA) use animal autonomy to improve whole coverage area with the optimization effective algorithm [9], ant colony optimization algorithm (ACO) to optimize the network coverage problem[10] , particle swarm optimization (PSO) algorithm based on improved inertia weight coefficient to the wireless sensor network coverage optimization [11]. However, these methods have the drawbacks such as the latter search blindness, easy to lead to stagnation phenomenon and the slower rate of convergence, and dropped in locally optimal solutions.

Ion motion algorithm (IMO), a recent meta-heuristic is a kind of physical heuristic group intelligence optimization algorithm which simulates the movement rules of anions and cations [12]. IMO algorithm has several advantages such as simple operation, few parameter setting, and easy programming implement. While evolution processing development of the algorithms, the IMO algorithm also has not been paid much attention by scholars in various fields. In this paper, the nodes coverage strategy is considered by being put forward to IOM for optimization locations in wireless sensor networks to improve the network performance.

2. **Related Work.**

2.1. **Ion Motion Optimization (IMO).**

IMO simulated two sets of ion included Anion (negative ion charge) and Cation (positive ion charge) set[12]. Two sets perform different evolutionary strategies in the liquid phase and the solid phase. The movement of ions in the algorithm can guarantee the improvement of all ions over the course of iterations. The amount of the force specifies momentum of each ion. The process of the algorithm is represented as.

Initialization: population is randomly generated according to a uniform distribution within the lower and upper boundaries with D dimension.

Liquid phase: the anion group *(A)* and the cation group *(C)* are updated according to the following patterns, respectively.

$$A_{i,j} = A_{i,j} + AF_{i,j} \times (Cbest_j - A_j)\,, \tag{1}$$

$$C_{i,j} = C_{i,j} + CF_{i,j} \times (Abest_j - C_j)\,, \tag{2}$$

where C_{best} and A_{best} are cation and anion optimization respectively. Subscript $i = 1, 2, 3, ...NP/2$, (NP/2 is the size of ions population), and $j = 1, 2, 3..D$. The resultant of anions attracted force $AF_{(i,j})$ and $CF_{I,j}$ are mathematically modeled as follows:

$$AF_{i,j} = \frac{1}{1 + e^{-0.1/AD_{i,j}}} \tag{3}$$

$$CF_{i,j} = \frac{1}{1 + e^{-0.1/CD_{i,j}}} \tag{4}$$

where $AD_{I,j}$ and $CD_{i,j}$ are the distances of i^{th} anion from the best cation, and cation from the best anion in in jth dimension respectively. $AD_{i,j} = |A_{i,j} - Cbest_j|$, and $CD_{i,j} = |C_{i,j} - Abest_j|$.

Solid phase: this phase was set for breaking the phenomenon of excessive concentration, and also providing diversity for the algorithm in case of over-concentration of ions to make the algorithm fall into a local optimum. The process of recrystallization was simulated in IMO was known as a solid phase.

$$A_j = \begin{cases} A_j + \varphi_1 \times (Cbest - 1)\,, & if\ rand > 0.5 \\ A_j + \varphi_1 \times (Cbest)\,, & otherwise \end{cases} \tag{5}$$

$$C_j = \begin{cases} C_j + \varphi_2 \times (Abest - 1)\,, & if\ rand > 0.5 \\ C_j + \varphi_2 \times (Abest)\,, & otherwise \end{cases} \tag{6}$$

Termination condition: conditions include the presupposition accuracy, the number of iterations, and so on. If it is reached, the optimal ion is directly output; otherwise, the anions and cations are returned to the liquid phase from the solid phase and continue to be iterated.

2.2. **Network Model.** A supposing network with N sensor nodes is randomly dispersed in two-dimensional space of a monitoring region. Assumed its network is as follows:
(1) The coordinates of each node are known.
(2) Node density is large enough in a network with redundancy.
(3) These sensor nodes are isomorphic. The sensing radius of each mobile node is r and communication radius is R. In order to ensure the entire network connectivity and prevent wireless interference that set $R = 2r$.

Setting the location of the mobile node s_i in the network is (x_i, y_i) for $i = 1, \ldots, N$. The set of all sensors is denoted with $S = \{s_1, s_2, \ldots, s_N\}$. The probabilistic model is used for network monitoring model by the binary model version. In which r_i represents events that can be covered by sensor nodes. The $P\{r_i\}$ is the probability that the point $p(x, y)$ is covered by all the sensor points s_i in the region. The binary model [13] is as follows:

$$P(r_i) = \begin{cases} 1 & \text{if } d(s_i, p) < r \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

where p is pixel point of the location (x, y). By changing the location of the mobile node achieves the maximum coverage of the network area. Monitoring area S is digital discreted into a pixel of $m \times n$ and p represent pixel point. The euclidean distance between target pixel p and each sensor node is as follows:

$$d(s_i, p) = \sqrt{(x_i - x)^2 + (y_i - y)^2} \tag{8}$$

The sensor node monitoring model in fact should use the probability model because of the surrounding environment and the noise of the monitored area.

$$P(s_i, p) = \begin{cases} 1 & d(s_i, p) \le r - r_e \\ e^{(\frac{-\lambda_1 \alpha_1^{\beta_1}}{\alpha_2^{\beta_2} + \lambda_2})} & r - r_e < d(s_i, p) < r + r_e \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

where r is the sensing radius, $r_e (r_e < r)$ represents the measure of uncertainty in detection, and λ_1, λ_2, β_1, β_2 are parameters which depend on physical characteristics of sensors and $d(s_i, p)$ is euclidean diatance. α_1 and α_2 represent input parameter. The formula is as follows:

$$\begin{aligned} \alpha_1 &= r_e - r + d(s_i - p) \\ \alpha_2 &= r_e + r - d(s_i - p) \end{aligned} \tag{10}$$

In the monitoring area, when all nodes monitor the pixel p, the joint coverage rate is as follows:

$$P(S,p) = 1 - \prod_{i=1}^{n} [1 - P(s_i, p)] \tag{11}$$

The ratio of the size of effective coverage area by the N mobile nodes and the total size of the limited area.

3. **Network Coverage Optimization Strategy.** In IMO algorithm coverage optimization, it is assumed that there are M agents in the population, each agent contains N nodes, and each agent represents a node placement scheme. The position of the agent is denoted by X: $X_i = (x_{i1}, y_{i1}, x_{i2}, y_{i2}, \cdots, x_{iN}, y_{iN})$, where (x, y) represents the position coordinate of each sensor.

Supposing the WSN monitoring area is $L \times W\,\mathrm{m}^2$ (in which L and W units of length and width). The location of the mobile nodes are distributed mobile, represented "o" point is for movement node.

The coverage calculation process is outlined as follows: (i) the coverage probability of each mobile node is computed as in Eq. (9) to a pixel; (ii) joint coverage of each pixel point is calculated as in Eq. (11); (iii) joint coverage of all pixels in the region are summarized for an entire network for monitoring area.

Different agents have different location for the mobile node location information that is the input value for IMO algorithm based on the ions movement. The coverage ratio of the monitored region is constructed as the fitness function of the whole network coverage optimization.

The coverage rate of the WSN is as the fitness function as follows:

$$P\_\{area\} = \frac{\sum P(s,p)}{m \times n} \tag{12}$$

The workflow diagram of the coverage strategies optimization based on IMO algorithm is shown in Fig. 1.

The specific steps are as follows:

Step 1: Generate M agents (including the position and speed information) randomly, and then assign the fitness function with a big value.

Step 2: Compute distances the anion and cation as Eq.(3) to Eq.(6).

Step 3: If ($random \leq 1/2$)

update the anion position of the agents in the region as Eq.(1),

Else

update the cation position of the agents in the region as Eq. (2).

Step 4 Calculate their fitness values;

Step 5: Compare the best value of the agents before and after the update A_{best}, and the best value of the whole group, C_{best}, and replace it with a large value instead of a small value.

Step 6: If k reaches the maximum number of iterations, the algorithm will stop; otherwise it returns to Step 2.

4. **Simulation results.** .

***Simulation settings*:**

Supposing there are N mobile nodes that are placed arbitrarily in the area of $L \times W\,\mathrm{m}^2$ (the case $N = 15$ and $L = W = 20$. The sensing radius of all mobile nodes is the same. The sensing radius is $r = 3\,\mathrm{m}$, the communication radius is $R = 6\,\mathrm{m}$; In probability model,

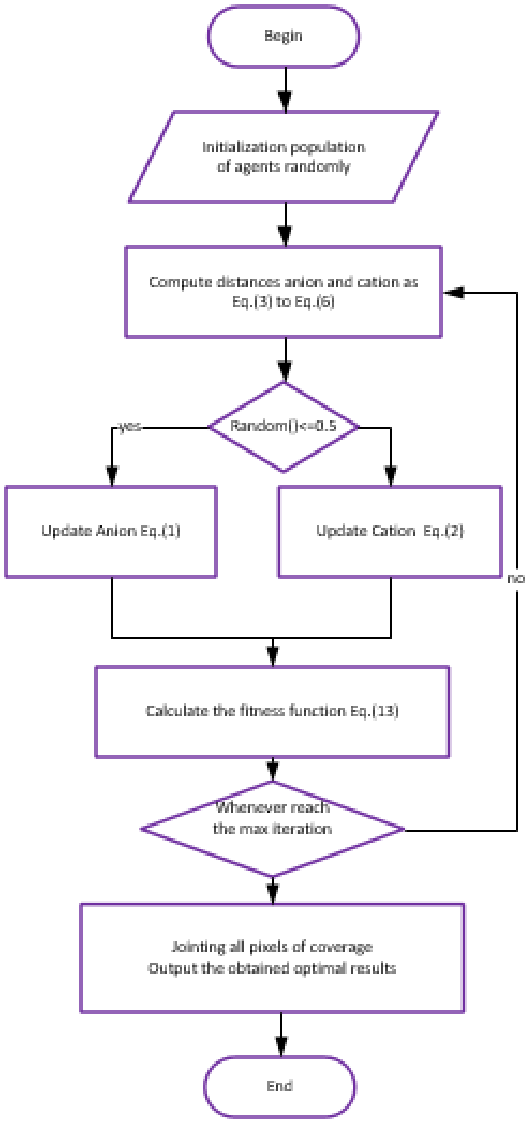

FIGURE 1. Flow chart of IMO algorithm for optimal node coverage

$\lambda_1 = 1, \lambda_2 = 0, \beta_1 = 1, \beta_2 = 1$; The reliability measurement parameters is $r_e = 0.5r = 1.5\,\mathrm{m}$; The maximum number of iterations $Iter_{\max} = 400$; At the same time.

A consistent simulation condition used to compare the algorithms performance. The initial location of the mobile node is randomly generated in the monitored area and as shown in Fig. 2. A red 'o' is the position of the mobile node in the region, and the circle is the size of the mobile node's perceived range.

The simulation results of the proposed approach are compared with the other methods such as the ant colony optimization algorithm (ACO) [10], and the particle swarm optimization (PSO)[11] for the mobile node position layout optimization respectively.

Table 1 shows the comparison of the proposed method with PSO and ACO methods. Clearly, the proposed approach has a higher network coverage rate than PSO and ACO approaches.

Fig. 3 – Fig. 5 illustrate the optimized mobile node position layout respectively by PSO, ACO, and IMO algorithms respectively.

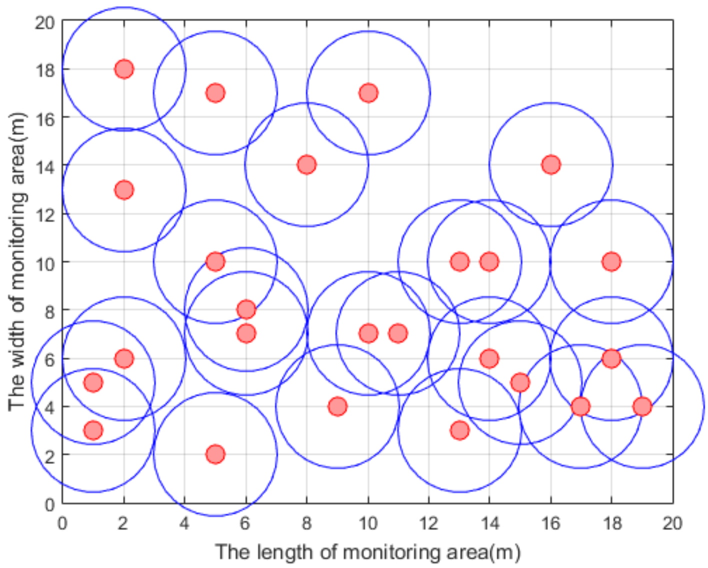

FIGURE 2. Initial nodes distribution

TABLE 1. Comparison of the proposed method with PSO and ACO methods for statistical coverage

Methods	IMO algorithm	ACO algorithm	PSO algorithm
Coverage rates	81.8%	79.3%	80.8%

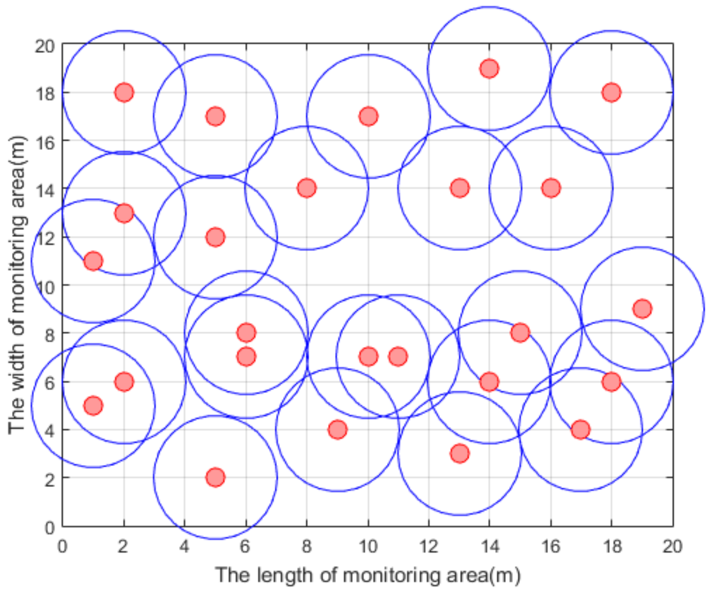

FIGURE 3. PSO algorithm optimized node distribution

Observedly, the PSO and ACO algorithms optimized mobile node distribution are not very uniform, some areas are covered repeatedly. The main reason is that the algorithms fall easily into a local optimum in the search and difficult to find the global value. In contrast, the nodes distribution of the proposed approach in Fig. 5 is more uniform and

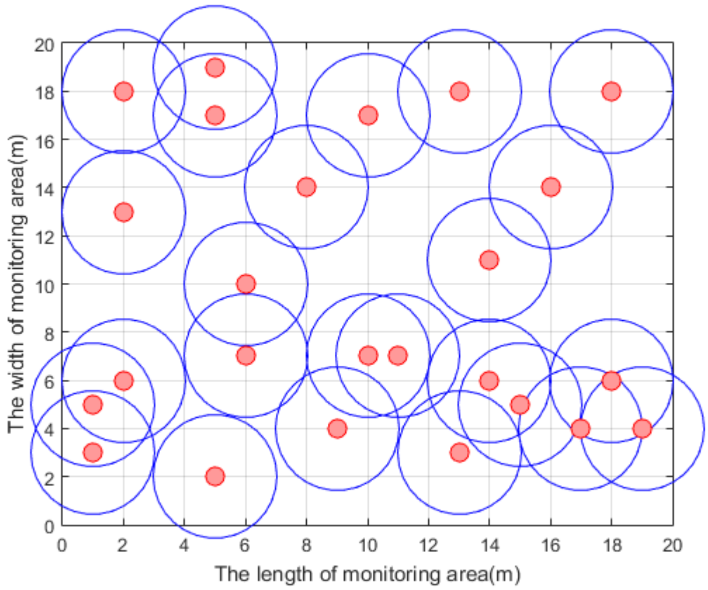

FIGURE 4. ACO algorithm optimized node distribution

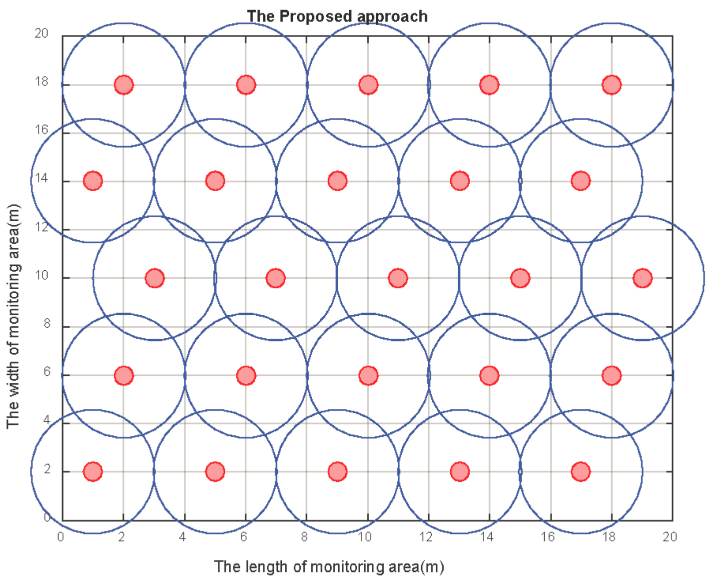

FIGURE 5. IMO algorithm optimized node distribution

less overlap. Therefore, the IMO algorithm optimized mobile node layout is the best coverage area.

TABLE 2. Different algorithm run time statistics

Methods	IMO algorithm	ACO algorithm	PSO algorithm
Running time(second)	4.689 122	5.831 005	4.826 707

Table 2 lists the comparison of the proposed approach with PSO and ACO approaches for the in terms of the running times. It can be seen the concluded for IMO approach requires a relatively shorter operating cycle over the other two methods.

Furthermore, the different size of monitoring areas and densities are used to conduct the network coverage optimization. Table 3 shows comparison the proposed method with the other methods as PSO and ACO in the different situation of monitoring area sizes.

TABLE 3. Three algorithms for different regions of the coverage optimization performance

Coverage area	Number of mobile nodes	IMO algorithm		ACO algorithm		PSO algorithm	
		Coverage rate	Number of convergent iterative	Coverage rate	Number of convergent iterative	Coverage rate	Number of convergent iterative
20×20	15	81.8%	87	77.3%	21	78.8%	90
30×30	20	84.1%	148	77.4%	120	70.8%	136
40×40	30	80.9%	164	72.9%	135	68.1%	88

It can be seen from Table 3 that compared with the PSO algorithm and ACO algorithm, the IMO algorithm can achieve the global optimal solution regardless of the coverage area is $20 \times 20\,\mathrm{m}^2$, $30 \times 30\,\mathrm{m}^2$ or $40 \times 40\,\mathrm{m}^2$. The IMO algorithm can cover the entire monitoring area with the best layout of the nodes.

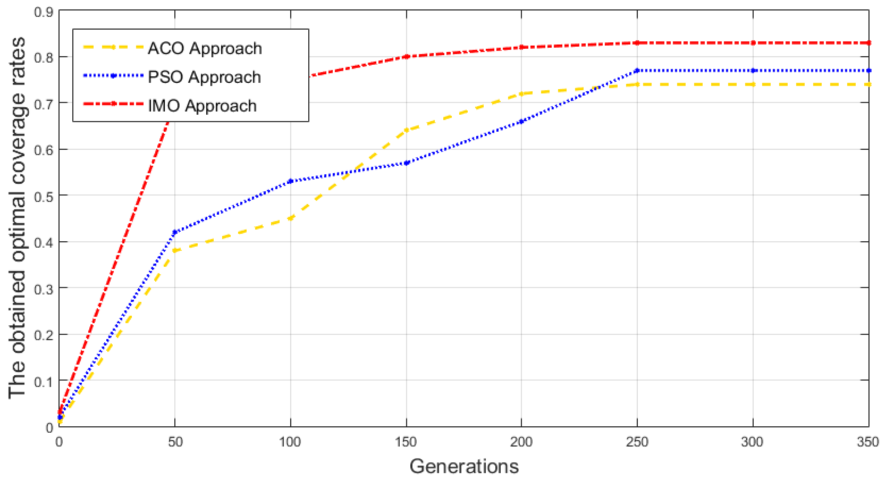

FIGURE 6. Comparison of the obtained coverage optimization curve of the IMO with PSO and ACO approaches

In Fig.6 indicates three the coverage rate of IMO, PSO, and ACO approaches. Simultaneously, the proposed approach for the coverage optimization in WSN based on IMO algorithm can provide the accurate data collection information and target tracking services. IMO algorithm can avoid premature phenomenon, so the coverage rate is a relatively large and less overlapping area so that it can more effectively adjust the mobile node layout and enhance the network coverage of the monitoring area.

5. **Conclusion.** In this paper, a new nodes coverage optimization in Wireless Sensor Network (WSN) was proposed based on Ion Motion Optimization (IMO). Sensor nodes layout generally made efficiently the network performance. So, the node coverage issue in WSN is paid attention for deployment of monitoring and tracking applications. The probability perception and regional coverage rate are used to model as objective function

of changing node location to achieve the maximum coverage. The node density cases were conducted to evaluate the proposed approach for experiments of optimal coverage in WSN. Experimental results show that the proposed approach provides the effectively improving convergence speed and coverage rate of nodes, so leading to whole network coverage effect and prolonging network lifetime.

REFERENCES

[1] C. Zhu, C. Zheng, L. Shu, and G. Han, A survey on coverage and connectivity issues in wireless sensor networks,*J. Netw. Comput. Appl.,* vol. 35, no. 2, pp. 619 - 632, 2012.

[2] G. Fan, S. Jin, and D. Processing, Coverage Problem in Wireless Sensor Network: A Survey,*J. Networks*, vol. 5, no. 9, pp. 1033 - 1040, 2010.

[3] M. A. Guvensan and A. G. Yavuz, On coverage issues in directional sensor networks: A survey,*Ad Hoc Networks*, vol. 9, no. 7, pp. 1238 - 1255, 2011.

[4] T. K. Dao, T. S. Pan, T. T. Nguyen, and S.-C. Chu, A Compact Artificial Bee Colony Optimization for Topology Control Scheme in Wireless Sensor Networks,*J. Inf. Hiding Multimed. Signal Process.* , vol. 06, no. 3, pp. 297 - 310.

[5] J. S. Pan, T.-K. Dao, T. S. Pan, T. T. Nguyen, at el., An Improvement of Flower Pollination Algorithm for Node Localization Optimization in WSN, *J. Inf. Hiding Multimed. Signal Process* vol. 08, no. 02, pp. 500 - 509, 2017.

[6] T. Dao, T. Pan, and T. Nguyen, A Compact Artificial Bee Colony Optimization for Topology Control Scheme in Wireless Sensor Networks,*J. Inf. Hiding Multimed. Signal Process.* , vol. 6, no. 2, pp. 297 - 310, 2015.

[7] A. Ghosh, Estimating coverage holes and enhancing coverage in mixed sensor networks,*Innull 2004 Nov IEEE*, pp. 68 - 76.

[8] J. A. Torkestani, An adaptive energy-efficient area coverage algorithm for wireless sensor networks,*Ad hoc networks*, vol. 11, no. 6, pp. 1655 - 1666, 2013.

[9] L. Li, H. Li, T. L. Zhang, B. Tao, and W. Zhang, Stratege of WSN Coverage Optimization by Improved Artificial Fish Swarm Algorithm,*Microelectron. Comput.*, vol. 33, no. 2, pp. 83 - 86, 2013.

[10] J.-W. Lee, B.-S. Choi, and J.-J. Lee, Energy-efficient coverage of wireless sensor networks using ant colony optimization with three types of pheromones, *IEEE Trans. Ind. Informatics*, vol. 7, no. 3, pp. 419 - 427, 2011.

[11] N. A. B. Ab Aziz, A. W. Mohemmed, and M. Y. Alias, A wireless sensor network coverage optimization algorithm based on particle swarm optimization and Voronoi diagram,*in Networking, Sensing and Control, 2009. ICNSC09. International Conference on* , 2009, pp. 602 - 607.

[12] B. Javidya, A. Hatamloua, and S. Mirjalili, Ions motion algorithm for solving optimization problems, *Appl. Soft Comput. J.,* vol. 32, pp. 72 - 79, 2015.