Coverage Control in Wireless Sensor Network Based on Improved Ant Colony Algorithm

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***Abstract*—The problem of computing such minimal active sensor which can cover the target region completely is NP-hard. This paper designs a novel method, in which the detection area is divided into lots of virtual grid. So area coverage can approximately be considered as point coverage. Then the problem of area coverage turns into set covering problem. An improved ant colony algorithm is proposed for the minimal set covering. Experimental results show that the lever of algorithmic complication is depressed and the searching time is reduced, and the proposed algorithm outperforms the other algorithm in terms of the constructed cover set.**

***Keywords*—wireless sensor networks; coverage control; improved ant colony algorithm; set covering**

I. INTRODUCTION

How wireless sensor networks to maximize network coverage, and provide a reliable monitoring regional and tracking services become a main topics about control coverage study at present. Many solutions have been proposed in recent years. In literature [1], monitoring regional was divided into a number of regional grids, which covered the entire region can be regarded as similar point coverage, so as to change the issue of regional coverage into the set covering problem (SCP).By using improved ant colony algorithm this paper solved the minimum set covering, designed for a minimum set of nodes the algorithm. The simulation results show that the algorithm proposed in this paper can be less working nodes than the other algorithms.

II. PROBLEM DESCRIPTION

WSN has high nodes density, a point or a region usually covered by multiple nodes. In order to prolong survival time of network, optimize control for random deployment of network topology is needed, and reduce the number of work nodes under the premise of performance in maintaining coverage.

To select the least working nodes monitoring regional will be divided into a number of interval virtual grids [1], mesh vertices known as mesh grids, also called sampling points. Use the grid as a approximation of target region, mesh size and accuracy of coverage are closely related.

The literature [1] deduced an error formula to compute the relationship between grid size and the coverage accuracy.

$$\varepsilon = 1 + \frac{d}{\pi r}\sqrt{1-(\frac{d}{2r})^2} - \frac{2}{\pi}\arctan\sqrt{(\frac{2r}{d})^2 - 1} \ (d < 2r^2) \quad (1)$$

Thereinto, r denotes detection radius of sensor node. d denotes gridding margin. ε is error, which is rapid descending when r/d is augmenting. ε is less than 0.1% when r/d $\geqslant$800. Gridding dimension may be selected according to r and cover precision.

There are many method of seeking the least set covering. It is the least set covering problem, which selecting the least number of working node cover the all sampling points in inspected region. In literature [1], greedy algorithm was used to seek the least set covering. But, greedy algorithm cannot obtain approximate optimal solution. In this paper, we used improved ant colony algorithm to obtain approximately optimal solution, namely the least working node set.

III. IMPROVED ANT ALGORITHM SOLVE SET COVERING

Ant colony algorithm is more robust and the ability to search better solutions, provide a new way to solve NP-hard problem.

A. Minimal Set Covering Problems

Define Minimal set covering problem (SCP): S is a set, $S_1, S_2, \cdots, S_m$ are subsets and coverages of S, namely, $\bigcup_{i=1}^{p} S_i = S$ ($p \in m$), solve the minimal covering.

B. The Basic Ant Colony Algorithm Model for Set Covering

Ramalho [2] and others first used ant colony algorithm to solve the SCP. The basic ant colony algorithm model for set covering is as follows:

At the initial moment, all subsets $S_1, S_2, \cdots, S_m$ are selected; Ant will be randomly placed on the m-subsets, assuming that the initial information of each subset is $\tau_j(0) = C$ (constant). In order to meet the ants through different subset, each ant possess a taboo list. The probability $p_{ij}(t)$ of ant k transfer from the subset i to the subset j is:

$$p_{ij}(t)=\begin{cases}\dfrac{\left[\tau_j(t)\right]^{\alpha}\times\left[\eta_{ij}\right]^{\beta}}{\sum_{l\in N_i^k}\left[\tau_l(t)\right]^{\alpha}\times\left[\eta_{il}\right]^{\beta}} & ,if\ \ j\in N_i^k \\ 0, & otherwise\end{cases} \tag{2}$$

Among them, k is the ID($k=1,2,3,\cdots,m$)for the ants; t is the cycles; N_i^k representatives the next subset allowed to select for ant k ; τ_j said the pheromone strength of subset j ; η_{ij} is the inspired degree of ant k shifted from subset i to the subset j ,this volume is changeable in the operation system of Ants; These two parameters α and β , are accumulation of information and inspired information in the process of ant's sports, reflects the relative importance of ants to choice the next subset.

According to equation (2), the inspired degree $\eta_{ij}^k(t)$ of ant k shifted from subset i to the subset j defined as follows:

$$\eta_{ij}^{k}(t)=\frac{|U_i^k(t)\bigcap S_j|}{M} \tag{3}$$

Where, M is the number of elements in the S. $U_i^k(t)$ said the element sets not covered after ant k select subset i in the cycle t; S_j said the number of not covered elements in subset j after ant k select subset i in the cycle t; It is worth noting that ant k will not choose all the subsets. After select subset p , Ant will stop when the elements that the selected subset contained meet $\bigcup_{i=1}^{p}S_i=S$, this will mark the end of the cycle. Then the taboo list was empty, and ants are free to choose.

After all the Ants have completed a cycle, the pheromone of the subsets adjusted according the under equation:

$$\tau_j(t+1)=\rho\tau_j(t)+\sum_{k=1}^{n}\Delta\tau_j^k \tag{4}$$

$$\Delta\tau_j^k=\begin{cases}Q/J^K, if\ ant\ k\ though\ subset\ j\ in\ this\ cycle \\ 0, \quad otherwise\end{cases} \tag{5}$$

Among them, $\Delta\tau_j^k$ is the pheromone increment of ants k released in the subset j ; $(1-\rho)$ is the attenuation coefficient of the pheromone, usually installed $\rho<1$ to avoid unlimited accumulation of informational on subset; J^k said the number of subset ant k selected in this cycle; Q is the pheromone strength, it affected the convergence speed of algorithm in a certain extent.

C. *Improvement of Ant Algorithm*

At present, many improved ant colony algorithm can not be used to solve minimal SCP. By analysis we know that when increasing the number of ants, the number of sets and the number of elements set contained larger, complexity of the algorithm is high, and the question of the length for search time appear to be particularly prominent. This will be too heavy a burden of calculation for WSN nodes, resulting in network bottlenecks. The main cause of flaw is that all subset selected will be update by basic ant colony algorithm, subset can only be fixed to select one in each cycle, and the closer possibility of transition probability of different subset are greater with the increase of solution space, which reduces the efficiency of search for optimal results, making search act of the ants can not quickly concentrated in the areas of the optimal solution, and increase the search time accordingly.

Therefore, we make improvements on the ant colony algorithm: Initially, placing ants on the limited subset which random selected, after each cycle, only the subset secled by the optimal solution ants make pheromone increase, makes the ants tend to choose the subset which can pose a minimal set covering so as to enhance the search capabilities of the ants. Repeated cycle of the implementation of the process, when the cycles to meet the conditions the number of minimum set will output. Algorithm process is as follows:

Step 1 Initialize parameters α,β,ρ,Q etc.

Step 2 $NC=0$ (NC is the cycle number), initialize $\tau(j)$ and $\Delta\tau(j)$, ants will be randomly placed on the limited subset;

Step 3 Ants transfer to the next subset j by probability p_{ij} , place j on the current solution set, and joined the taboo list. When the elements contained in a subset of the solution set meet $\bigcup_{i=1}^{p}S_i=S$ and put an end to this cycle;

Step 4 After the end of a cycle, updated the pheromone of subset ant selected. Then order $\Delta\tau(j)=0$, $NC=NC+1$, empty taboo table;

Step 5 $NC>NC_{\max}$ ($NC_{\max}$ is the largest cycles), withdraw from circulation; otherwise transfer to Step 2.

By compare the experimental results (see Experiments), the performance of the improved algorithm is significantly improved, and can achieve the smaller set of nodes than greedy algorithm. From the above, we can see that the number of subset an ant traversing each time is not more than m , after NC times cycles, the time complexity of the whole process not exceed $O(m^2 \bullet NC)$.

D. *Approximate Minimum Set of Nodes Produced*

In practice, the nodes were randomly thrown in monitoring the region. The number of nodes is large, each node with

Global Positioning System (GPS) is impossible. Generally only 5%~10% of the nodes can be identified with its own positioning system location, known as the reference node. Ordinary nodes estimate of their position through the exchange of data with reference node (assuming that each node known location information in algorithm) to determine their own coverage of sampling information, we called this stage pretreatment stage, using distributed computing. Then node sent its own coverage of sampling information to central node. Central node using the algorithm derived approximate minimum set of nodes, decided which nodes in the network to work in the state, which nodes in a low-power state of dormancy, completed the work node selection.

IV. THE EXPERIMENTAL RESULTS AND ANALYSIS

In the simulation experiments, let M = 100. It is said that one hundred sensor nodes were deployed in the target region of 50m × 50m square region, the detection radius of node is R_S =10m, gridding density d = 0.5 m. All experiments are achieved on the PC of memory 256M, Celeron 1.5G by using MATLAB7.0.

We take compared test on greedy algorithm (GA), the basic ant colony algorithm (BACA) and improved ant colony algorithm (IACA), running time of algorithm is T. The default value of ant colony algorithm parameters set to α =4, β =1.5, ρ =0.8,Q=30, the number of ants set 20. Found through experiments: the improved algorithm iteration to 8 can get around approximate optimal result (OR).

The reason in the less number of iterations get better solution is the worst value 18 is not much below the optimal result 30. The basic ant colony algorithm needs to iterate about 30 times to achieve the approximate optimal solution. Experimental results from 20 times average, as shown in table Ⅰ.

TABLE I. THE EXPERIMENTAL RESULT COMPARISON

BACA		IACA		GA	
OR	T(s)	OR	T(s)	OR	T(s)
18	1219	18	269.3	26	7.131

Clearly, under the same solution effect, the optimizing speed of IACA is faster than BACA, improving the search efficiency of the algorithm.

A. Impact of the Number of Nodes in Initial Deployment on the Selection of WNs

The number of nodes of initial deployment M calculate from 10 to 300, from the results such as Figure 1, when the total number of nodes deployed up to a certain value, WSN will not increases with and the number of nodes deployed, but maintained a stable value. Among them, WNs represents the number of working nodes. In Figure 2 and 3, we compare on the selection of working node and network coverage of the proposed algorithm in this paper (Simple Points Covering) and the Sponsor Area [3], GAF [4] and PEAS [5] in different initial deployment of the number of nodes. Under the deployment of a certain number of nodes, the algorithm in this paper can achieve over 98 percent of the coverage in the needs of only 18 working nodes; PEAS needs more the number of working nodes about 40% than the algorithm in this paper; GAF can provide a good quality of the coverage, but the number of elected working nodes is almost two times more than the algorithm in this paper; Sponsor Area did not consider the excessive overlapping of coverage areas, leading to excessive number of nodes, increases with the deployment of the number of nodes. This algorithm is obviously superior to the other three algorithms in performance.

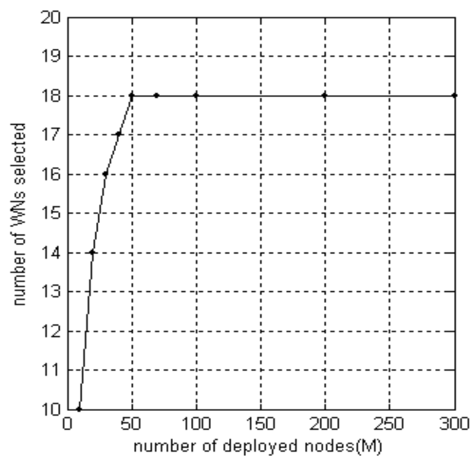

Figure 1. Nnumber of WNs Under Different deployed nodes

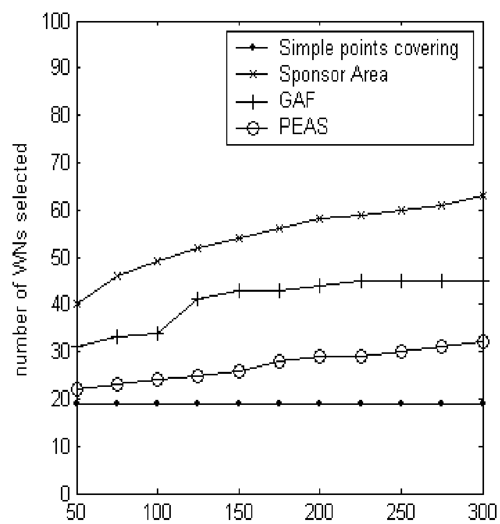

Figure 2. Nnumber of WNs Under Different Algorithm

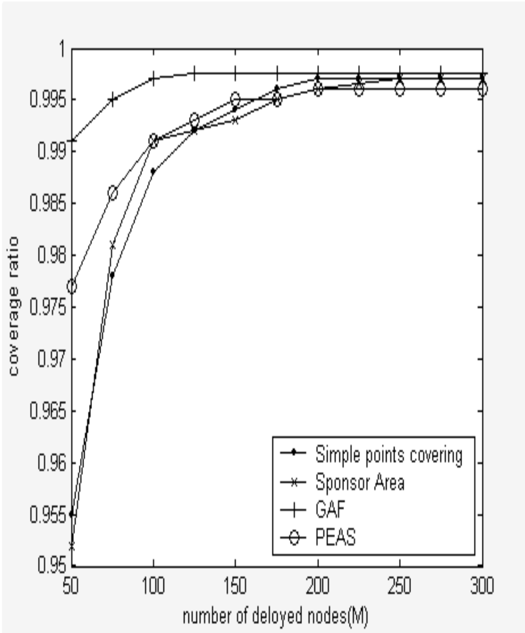

Figure 3. Comparison of Different Algorithms in Network Coverage

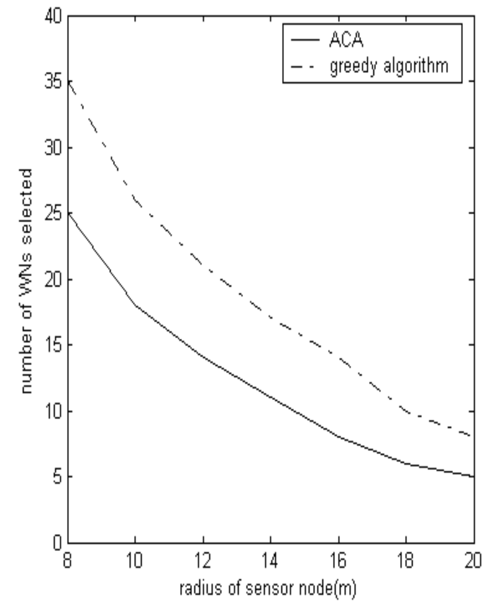

Figure 4. Nnumber of WNs Under Different Detection Radius

B. Impact of Mesh Density on the Selection of WNs

In order to observe the impact of mesh density on the selection of WNS, we have done the experiment the same as literature [1], get the same results. Assume the initial deployment location of nodes unchanged, the value of mesh side d take from 0.3m to 2m, we found that the final number of working nodes set maintains between 18 and 22, but not tend to a stable value, which is due to different d resulted in a different outcome of error ε .

C. Impact of Radius of Sensor on the Selection of WNs

The radius of sensor nodes impact the number of WNs selected. We will compare the WNs achieved in ant colony algorithm and the greedy algorithm in *Fig 4.*

When the radius of sensor node R_S decreased, the number of WNS will increase faster, but the ant colony algorithm always be able to find fewer WNS than the greedy algorithm. In the actual network, select the appropriate R_S should be based on various factors.

V. CONCLUSIONS

This paper improved the ant colony algorithm about SCP, have been made optimize speed significantly improved and effective to overcome the slow convergence flaws of the algorithm. And applied the improved ant colony algorithm to WSN coverage control problems, monitor the entire region with approximate the least nodes. Simulation results show that the reliability and validity of the algorithm.

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