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A Maximum Lifetime Coverage Algorithm Based on Linear Programming

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Abstract. *In order to ensure coverage of wireless sensor networks, sensor nodes within the monitoring area are densely deployed, thereby increasing the energy consumption of the network. To solve this problem, we propose a method based on linear programming, we use the least number of working nodes as the objective function, and we restrain decision variables by diving the monitoring area as grids. Our proposed method can resolve the contradiction between increasing network coverage and reducing the number of working nodes. The experimental results show that our method can guarantee minimal node in working condition, and to ensure the effective coverage of the network, thus saves energy and extends life cycle of the network.*
Keywords: Wireless Sensor Network, Coverage, Linear Programming

1. **Introduction.** Wireless sensor network is a network with a large number of inexpensive sensor nodes formed by self-organization, capable of sensing, computing and wireless communication capabilities. Sensor nodes are powered by batteries, so the network has a limited amount of energy, under normal circumstances, the sensor nodes are randomly deployed, especially in harsh environments and military applications, battery replacement is unrealistic, so energy conservation has become an important issue in wireless sensor networks.

In order to obtain accurate monitoring information, network coverage problem becomes a fundamental problem to be solved in most applications of wireless sensor networks. A number of algorithms about network coverage problems have been proposed[1-21. [1,8] use mobile nodes to dynamically deploy wireless sensor networks, this method can effectively improve the coverage rate, but a lot of energy of the node will be consumed to move to the definite destination and the complexity of the algorithm increases[2]. Some people use all kinds of heuristic approaches, such as Genetic Algorithm, Particle Swarm Optimization and Ant Colony Algorithm to address the problems. These algorithms can improve the network coverage effectively and save the energy, but they also have some problems which cannot be avoided by themselves. For instance, in [9], it uses Genetic Algorithm to solve the problems, it needs to perform three genetic operators and confirm many parameters which can affect the network optimization if the parameters are not inaccurate. In addition, the process is very complex. [10] use Particle Swarm Optimization to schedule states of nodes. PSO is easily trapped in the local optimum and reaches premature convergence which can influence coverage optimization. Ant Colony Algorithm is used in [11-13] to solve the effective energy coverage problem. Although ACO is well suited in local searching, it is slow in solving problem at first which has a bad effect on real-time network coverage as was shown in [14]. There are also some other methods to deal with this problem. For example, in [15], several independent sets are built, every set can monitor all the examination area, a weight is also set for each set and the size of the weight is used to decide whether the set is suitable for performing the monitoring task. According to [16], nodes scheduling scheme caused by energy is proposed, it is based on original topology whose redundant nodes are judged by several restricted conditions. A grouping nodes scheduling scheme is considered in [17-19].

In this paper, we are concerned with making the least nodes in working station while preserving maximum coverage and we use linear programming to solve this coverage problem. The rest of this paper is organized as follows: Section 2 describes linear programming briefly. Section 3 introduces the central problem of this paper and fixed the notations. In section 4, we describe our proposed algorithm. In section5, we report some experimental results. We then conclude with some remarks.

2. **Linear Programming.** In linear programming, the goal is to minimize some linear function subject to a set of linear constraints. In linear programming, we have the decision variables, objective function and constraints. Decision variables are selected by the designer to select the appropriate value based on the problem under consideration, the objective function is a function of the decision variables, it is used to represent the function to be minimized, the constraints are the restrictions for the decision variables. The canonical form of the linear programming is as follows:

$$Minimize\ f(x_1, ..., x_n) = c_1x_1 + ... + c_nx_n \tag{1}$$

$$Subject\ to\ \sum_{i=1}^{n} a_{ij}x_i \leqslant b_j\ j = 1, ..., m \tag{2}$$

$$x_i \geqslant 0\ i = 1, ..., n \tag{3}$$

Where m, n are given natural numbers, c_i, b_j, a_{ij} are constants, x_i are decision variables.

Each linear programming problem has a number of decision variables (x_1, x_2 ... x_n), the set of values of all the decision variables represent a set of feasible solutions (the set of values of the decision variables satisfying all the constraints). Expression (1) is the objective function to be minimized, (2) and (3) are constraints, they constitute a polyhedron which is the feasible region, the decision variables value in the feasible region, the set of values of decision variables which make the value of the objective function minimum is the optimal solution.

A linear programming problem is set up using the following steps:

Step1. Determine the decision variable based on relevant factors;

Step2. Set up the objective function according to the relationship between the decision variables and objectives to be achieved;

Step3. Set up the constraints according to the restrictions on the decision variables.

When all of the decision variables are integers, the problem is known as integer linear programming, 0-1 programming is a special case of integer programming, i.e., the decision variables can be either 0 or 1. Both the general integer programming and the 0-1 programming are NP-hard problems.

3. **The problem of minimizing the number of working nodes.** In order to improve the coverage of the network, usually a large number of sensor nodes are deployed to increase the density of the deployment of the sensor nodes. However, it causes a lot of redundant nodes to deploy the sensor nodes densely, thereby consumes a large amount

of network energy, decreases network life cycle, in addition, sensor nodes breaks down due to the energy depletion may bring down the entire network. The node scheduling mechanism can solve this conflict between increasing the network coverage and reducing network energy consumption effectively. Redundant nodes whose whole sensing range can be detected by their neighbour nodes turn low-power sleep state, while keeping few nodes in working state. On the premise of ensure the network coverage, the less nodes are in working state, the more energy can be saved.

Here is our problem to be solved: given a two-dimensional region D, in which m sensor nodes are randomly deployed, i.e.,N = N_1, N_2,... N_m, (x_i, y_i) represents the coordinates of the node Ni. Each node has a certain coverage radius r (For simplicity, we assume that all nodes have the same coverage radius), the transmission radius are R.

Each sensor node has two states: working or sleep. We use the vector X = (X_1, X_2, ..., X_m) represents the control vector of sensor nodes, X_i can take the value 0 or 1 only, which means that if $X_i = 1$, N_i is in working state, if $X_i = 0$, N_i is in sleep state. Our goal is: Find out X such that coverage is preserved and the number of working nodes is minimized. In other words, we want to figure out the state of each individual nodes, while preserving network coverage and minimizing energy consumption.

4. **Coverage optimization algorithm based on linear programming.** Making the least nodes in working station while preserving maximum coverage is a combinatorial optimization problem. Suppose that there are n sensor nodes, some of which are selected to be in working state, the remaining nodes are in sleep state, there are 2^n possible combinations, the challenge is to find the combination with the lowest energy consumption. This problem is known as NP-hard as was shown in [20]. Linear programming is widely used in solving combinatorial optimization problems.

We reduce the problem of minimize the number of working nodes to 0-1 programming problem. The following is our proposed algorithm:

Step1. Divide the monitored region D into w subareas: D_1, D_2, ..., D_w, we use (Px_i, Py_i) represents the coordinates of P_i, which is the center of D_i.

Step2. Let Q_i be the set of subscripts of nodes which are able to cover area D_i. So

$$Q_i = \{j \mid d(N_i, P_i) \leqslant r\}, (1 \leqslant i \leqslant w)$$

, where d (N_i, P_i) is defined as follows:

$$d(N_i, P_i) = \sqrt{(Px_i - x_i)^2 + (Py_i - y_i)^2} \quad (4)$$

Step3. Set up the following objective function and constraints:

$$Min = \sum_{i=1}^{m} X_i \quad (5)$$

If Q_i is not empty set, then:

$$\sum_{i \in Q_1} X_i \geqslant 1 \quad (6\text{-}1)$$

$$\sum_{i \in Q_2} X_i \geqslant 1 \quad (6\text{-}2)$$

$$\cdots$$

$$\sum_{i \in Q_w} X_i \geqslant 1 \quad (6\text{-w})$$

$$X_i \in 0, 1 \quad (7)$$

Step4. Use lingo solver to solve the above 0-1 programming problems, the resulting vector X is the final result.

The above algorithm can find out X such that coverage is preserved and the number of working nodes is minimized. The objective function (5) to ensure that the number of working nodes is minimized, (6-1) $\cdots$ (6-w) ensure that if a sub-region can be covered by some sensor node, then after let some nodes go to the sleep state, the sub-region can still be covered by at least one sensor node.

5. **Experiments and results analysis.** We use a wireless sensor network to monitor a region of 20×20 square area, and divide it into grids of 10 *times* 10, the sensing radius of sensor nodes are 2.5m, the communication radius are 5m. Deploy 100 nodes randomly in the monitoring area. We apply our algorithm in section 4 on this problem.

The results show that the minimal number of working nodes is 25. The network coverage is 98%. We use MATLAB to simulate the results, which are shown in Figure 1 and Figure 2.

As we can see from Figure1, the original coverage with up to 98%, but there are a large number of redundant nodes which can consume a large amount of energy. These nodes can be turned off because they detect and send the repeat messages with their neighbour nodes. According to our algorithm, only a few nodes need to be in working condition and at the same time, the coverage rate is not reduced, it is still reach 98% as was shown in Figure2.

In [21],an algorithm was proposed to minimize the number of the on duty nodes as well as maintain the original sensing coverage, a rule is proposed to determine whether the node should be turned off or not, the specific strategy is that the node can get other nodes information and it only can be turned off when the whole area monitored by the node can be detected by its neighbors, a back off-based schedule is also used to delay nodes decision with random time to avoid blind point. In order to compare with this algorithm, we do the experiment at the same environment with it. Deploying 100 nodes in a region of 50*50 square areas, the range of the sensing radius of sensor nodes is from 8m to 12m as was used in [21]. The result is shown in Figure 3 and Figure 4.

We can see from the result that when the number of the nodes is not enough and they are not deployed uniform, most areas can not be monitored, the less sensing radius is, the more number of nodes is needed to make sure the coverage rate, so dense deployment of the nodes can improve the sensing coverage effectively. As was shown in Figure 3 and Figure 4, when the number of node is big enough, it can ensure effect coverage and our algorithm can select best strategy with least nodes, the comparison is shown in Figure 5 and Figure 6.

Both of the algorithm in [21] and this paper can maintain the coverage rate as the same with original coverage, but the number of working nodes increase with the number of deployed nodes in [21]. It is because the edge nodes which is located at the boundary of the monitoring area are raised due to the increasing number of deployed nodes and these edge nodes can not be turned off according to the algorithm in [21]. There is no such problem in our algorithm and we can make better choice which can let less nodes in working condition with the number of deployed nodes increasing as was shown in Figure 6. In addition, we just use one third nodes in working condition compared with the number of working nodes in [21] but maintain the same coverage rate.

6. **Conclusion.** Energy and coverage are important in wireless sensor network, it has been a challenging task to ensure effective coverage as well as maximize energy saving. This paper proposes to use linear programming to solve the optimization problem. We

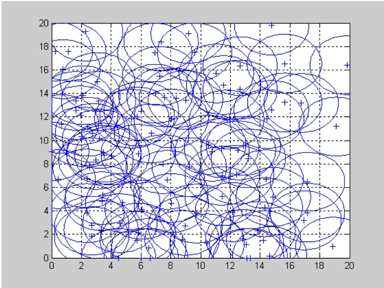

FIGURE 1. Nodes distribution

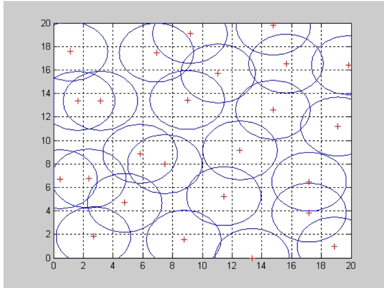

FIGURE 2. Working nodes distribution

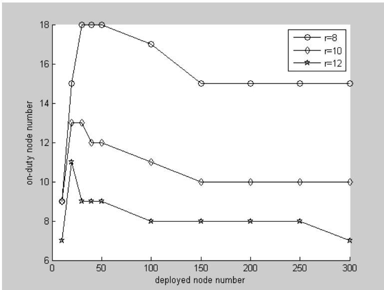

FIGURE 3. Working nodes number

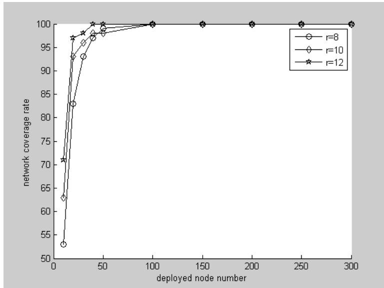

FIGURE 4. Network coverage rate

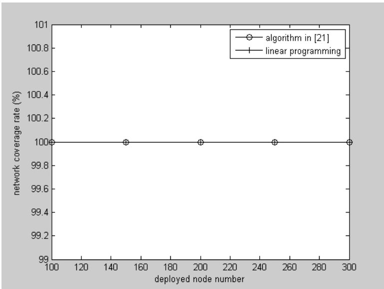

FIGURE 5. Comparison of coverage rate

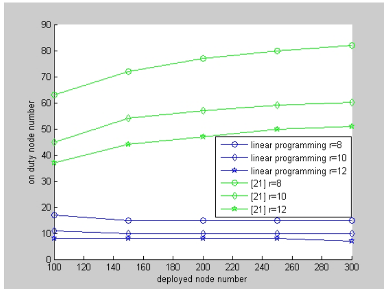

FIGURE 6. Comparison of working nodes number

compare our proposed algorithm against other algorithms. Our experimental results show that linear programming can make the fewest number of nodes in working condition and achieve maximum network coverage. Our method saves a lot of network energy, thereby effectively extend the life cycle of networks.

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