A Coverage Algorithm based on Key Node Scheduling

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***Abstract*—Network coverage rate is a key standard of measuring the quality of network coverage. This thesis aims at solving the differences between node energy and task, which causes coverage holes and blind spots of Wireless Sensor Network, and proposes a coverage algorithm, based on key node scheduling, divides node subsets, and adjusts the states of individual nodes according to node energy and coverage rate. This algorithm ensures network connectivity while reducing coverage holes and redundancy. Simulation results show that, the proposed algorithm can effectively reduce failure nodes, energy consumption, improve network coverage rate, and demonstrates network convergence and stability.**

***Index Terms*—Wireless Sensor Network; network coverage rate; energy loss, coverage adjustment, node scheduling.**

I. INTRODUCTION

Network coverage rate is an important technical index indicating completeness and availability of information by Wireless Sensor Network. It indicates the sensing ability of Wireless Sensor Network to the physical world and usually describes quality of service (QoS). To fully cover the sensor filed, dense deployment is exercised to increase the coverage rate of Wireless Sensor Network. However, there is some overlapping between sensor nodes in the network, which produces redundant data and interferes with wireless channels. Once channels are in conflict, over-consumption will emerge [1, 2]. In addition, given the input-output ratio, with limited investment, dense deployment is always put aside.

Among existing studies on network coverage, literature [3] studied the coverage correlation between nodes. Without accurate position, errors are produced and a blind area of coverage is created, making the monitored data inaccurate. Literature [4] proposed a distributed scheduling algorithm. Network nodes can calculate shared area with neighboring nodes within its coverage according to geographical position, from which coverage correlation is clear. However, this algorithm fails to notice that a sensing area of nodes can be overlapped, thus mobilizing too much working nodes and wasting energy. Liu C [5] divided sensor nodes into k random subset. In each subset, sensor nodes practice mission periodically. But the free division of subsets makes it impossible to predict the coverage rate. Literature [6] combined two ways of coverage control. So the coverage rate can serve as an index to measure quality of service. Select several nodes randomly as master node and divide the monitored area into several Voronoi polygons. 8 fixed point away from the master node are regarded as the best places for hole repairing. Look for nodes that are closest to 8 fixed points in the subset and put them into operation so as to increase the coverage rate. The requirement of network coverage differs with circumstances. But it works as long as the network has a reasonable coverage rate [7-9] for the sensor filed.

More and more researches on coverage control are done recently, such as the research node scheduling strategy, which puts redundancy nodes take turns into dormant state; The other is research network coverage hole detection and repair strategy, which imagine the sensor node perception range as a circle and divided monitoring area into multiple area according to sensor node location information.There are related method has incorporates two kinds of coverage control strategies, which is a research trend in the future. But it set the same network attribute to every nodes, which can't get accurate network holes information, existing a lot of redundant area, so the method can't maximize coverage rate. This thesis presents the key nodes, meanwhile, designs a covering algorithm based on key node scheduling. The proposed algorithm selects key nodes and distribute nodes into different node subsets while not undermining the monitor quality. According to network condition, adjust nodes and change their working conditions to reduce coverage holes and redundancy and energy consumption, increase network coverage and prolongs network survival.

II. NETWORK MODEL

Supposing a node set S which containing N non-overlapping wireless sensor nodes is randomly deployed in a 2-D monitoring region A. After deployment, the position of each node is fixed. All nodes have a perception radius of Rs and a communication radius of Rc. To any node Si (Si∈S), as the center of a circular perception area. Supposing the node has the following properties:

1) The wireless sensor nodes are randomly deployed in the monitoring region. After deployment the node location is fixed, and a wireless network is building up.

2) Network nodes are isomorphic. Their initial energy is W and they have synchronous clock.

3) The coverage sensing area is $\xi = \pi R_s^2$. When P in the sensor filed meets $\| S_i \cdot p \| \leqslant R_s$, P is covered by node S_i .

4) The position of sensor node is available. Meanwhile, a node can obtain relevant information within effective communication range, including battery and node position.

5) The border effect of sensor filed is negligible and the node density is larger.

III. NETWORK COVERAGE STRATEGY

To balance energy consumption and given that network nodes differ from each other in energy supply after a time of working, this thesis proposes a covering algorithm based on key node scheduling. Two questions are bore in mind. One is how to judge the nature of the node according to network condition, node type and position [9], namely whether the node is a key node. The other question is how to adjust node, if the node is an ordinary node and when two or more ordinary nodes share the same electric quantity, which can prolong network lifetime [10-12] according to network redundancy while ensuring the quality of network coverage and saving energy.

A. Selection of key nodes

N sensor nodes are distributed randomly in sensor filed A to construct wireless Sensor network. According to existing studies, in Wireless Sensor Network, energy consumption during information transmission has something to do with Euclidean distance. The total energy consumption W from source node a to target node b is described by expression (1):

$$W = \sum_{\substack{i=a \\ j=a}}^{b} \left[\alpha Q_{a\to ai} \cdot d(a,a_i) + \gamma Q_{ai\to aj} \cdot d(a_i,a_j) + \beta Q_{ai\to b} \cdot d(a_i,b)\right] + n\tau \quad (1)$$

where α , β and γ are energy factor of node. d(ai ,aj) refers to Euclidean distance between node ai and node aj. τ is a variable. $Q_{ai\to aj}$ is data volume of transmission from node aj to node aj node. The unit is bit. ai is the information-related neighbor nodes of the target node and the source node.

Only when the residual energy of any sensor node and the monitored area in the sensor field reach a balance can the effective coverage meet the threshold Θ, where n is node number, A is the sensor filed area, and $\Theta \le Cov_{max} \le A$.

$$Cov_{max} = f\left(\sum_{i=1}^{i=n} cov_i\right) \quad (2)$$

cov_i is the effective coverage area of node,When cover function f is close to the coverage threshold , the Purpose is to deal with non-linear multi-target optimization. According to expression (1) and (2), it is known that key node set that meets the coverage threshold in area A is S{k_1,k_2…..k_n}:

$$S = \arg k_i \in A \quad (3)$$

According to real situation, key node set is computed based on expression (3). In a given sensor field, to reach the anticipated the coverage rate, key nodes should become main working nodes during transmission, as shown in Fig.1:

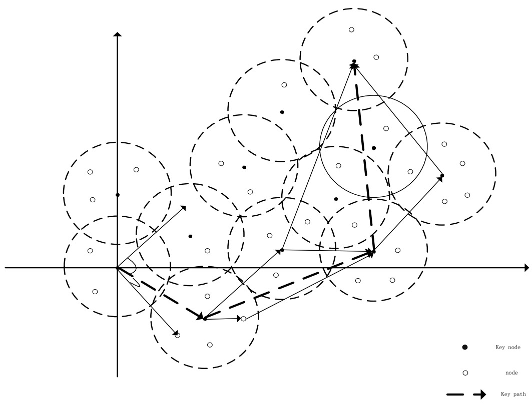

Figure 1. The selection of key nodes

B. Coverage adjustment

Based on network key node sets S, ordinary working nodes are adjusted according to residual energy of network nodes and network coverage, so as to reduce network holes and redundancy, as described below:

Step 1 Select key node set S={k_1,k_2…..k_n} in sensor field A. Node members are relevant to each other. Any member can acquire the information about its neighboring nodes, such as relative position and surplus electricity quantity.

Step 2 Select a key node key nodes si from S and divide the coverage area M. local areas mi are independent. Key nodes receive information from neighbor nodes and the other way round. Information acquired by the key node composes a fully connected member node set E.

Step 3 When members in node set E are determinate, activate member nodes. It is necessary to consider the change of energy and coverage of node. If the energy is smaller than energy threshold W0, the node should be taken to dormant. And a node sub-graph G connected to this node is established. Activate nodes in G and repair the blind area in the network.

Step 4 Calculate the network coverage with current working nodes and its coverage correlation. Make choice between the node and node subgraph G and bring to dormancy nodes of small coverage. By doing so, network redundancy can be reduced and "dead" node can be avoided. Network lifetime is prolonged to the maximum without undermining network connectivity.

Step 5 When key nodes are low in energy, bring them to dormancy. In the fully connect member nodes set E. repeat abovementioned steps to find key nodes and adjust network holes and redundancy so that the network will have favorable connectivity. As shown in Fig.2 and Fig.3:

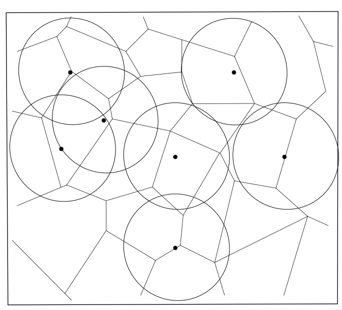

Figure 2. network coverage before adjustment

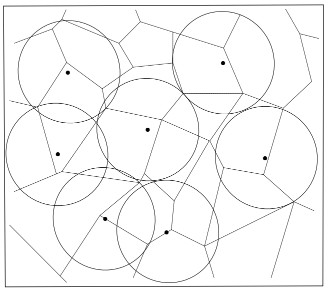

Figure 3. network coverage after adjustment

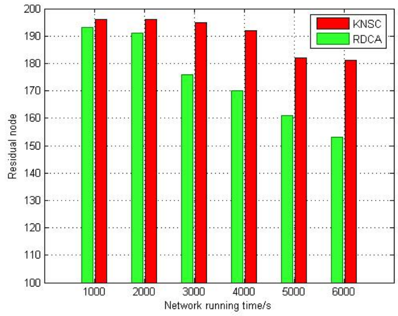

Figure 5. network residual node

IV. ANALYSIS OF SIMULATION EXPERIMENT

This thesis measures performance of the algorithm through simulation experiment and comparison. The settings: in $100\times100\text{m}^2$ sensor field 200 sensor nodes are placed, the radius of which is 15m. The initial electric quantity is 200J. The algorithm this paper proposed is named after KNSC (a coverage algorithm based on key node scheduling) for convenient. To evaluate the performance of KNSC algorithm, this paper will compare it with the RDCA (the random distribution algorithm.). KNCS is compared with RDCA, the random distribution algorithm. Working condition of nodes in different time period is sampled in the wireless operation. Three aspects are analyzed with priority: (1) energy consumption (2) the number of failure nodes and (3) network coverage rate.

Network residual energy is an important index to measure network performance. It reflects the speed of energy consumption in the whole network. Network residual energy ratio is total residual energy against initial energy. From Fig.4 it is seen that in the initial stage, there is little network energy loss. As time goes by, the gap in energy consumption appears gradually. This thesis takes key node as master node and adjust other nodes according to working condition of the network. And the algorithm brings nodes whose energy is lower than the threshold to dormancy and activates relevant nodes. It is more advantageous in terms of saving energy.

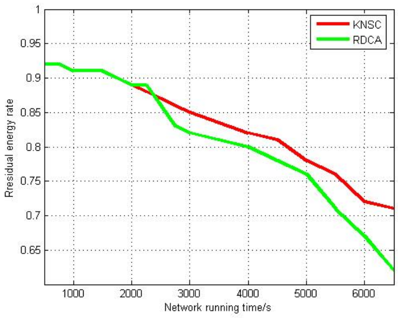

Figure 4. network energy consumption

The number of failure nodes indicates network connectivity and distribution of energy consumption. From Fig.5, it is shown that there are less failure nodes in the proposed algorithm than in the random algorithm. As time goes by, failure nodes take a leading position in deciding the distribution of whole networks. The proposed algorithm prolongs network lifetime successfully.

The coverage rate is the proportion of effective coverage area to overall sensor field in a given time. It is also important to measure network coverage performance. Fig.6 presents the change of network coverage rate with network holes and redundancy in the initial stage of the network. The difference in coverage rate begins to appear. Though there is much energy consumption in node subset division and network node transmission, the overall performance of network coverage has been enhanced, which extends network lifetime. At the same time, the coverage rate curve of the proposed algorithm is more stable than the other one, indicting that it has good convergence.

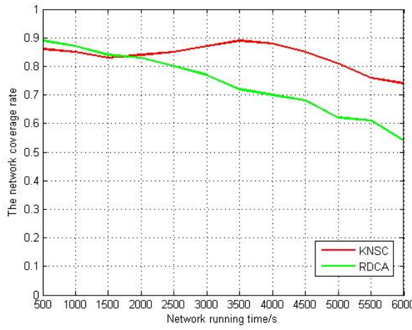

Figure 6. network coverage rate

V. CONCLUSION

Wireless Sensor Network have some features, such as dynamic and randomly distributed. These features are source of network holes in the sensor field. The holes not only produce blind area and lower the monitoring quality, but also influence the performance of the network. Thus, this thesis proposes a coverage algorithm based on key node scheduling. By dividing nodes into different working node sets, it adjusts working condition of nodes and repairs network holes and redundancy. Results show that the proposed algorithm sheds off monotony in selecting the best nodes and realizes even distribution of working nodes. As a result, network holes and redundancy are reduced, the coverage rate reaches the requirement and the network lifetime is prolonged. With redundant nodes removed, the monitoring cost is also taken under control.

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