Patching Method for Coverage Holes with Distance-Assistant in Wireless Sensor Networks*

Zhengwei Guo[1], Lin Zhu[1,2]

[1]Department of Computer and Information Engineering, Institute of Image Processing and Pattern Recognition Henan University Kaifeng, Henan Provice 475001, China

[2]Department of Computer and Information Technology Shangqiu Normal University Shangqiu, Henan Provice 476000, China

zhulinjulie@126.com

Abstract - An effective approach for coverage holes was proposed, called Distance-assistant Coverage Hole Parching (DACHP) strategy. DACHP strategy would achieve the purpose of patching coverage holes using redundant sensor nodes within the wireless sensor networks. Simulation results show, compared with DFNFP and random algorithm, for the same size and shape coverage hole, DACHP can awaken five redundant nodes to patch 92.19% of hole, yet DFNFP needs awaken nine redundant nodes and just patch 90.28%. It can be seen that DFNFP not only awaken four extra nodes, but also is lower 1.19% in patching rate of hole than DACHP. In addition, DACHP is more stable in utilization of redundant nodes and does not produce additional cost.

Index Terms - wireless sensor networks; coverage holes; patching holes; nodes utiliza

1. Introduction

The wireless sensor network is an important network technology in the harsh conditions and special requirements. Different applications require different degrees of sensing coverage [1]. In practical application of wireless sensor network, it requires available network coverage, thus often throws a mass of redundant nodes in the monitoring region. In the monitoring of region of wireless sensor networks, some nodes which suffer from attack or imbalance of receiving and transmitting data volume are premature death. Since that, the original coverage range appears certain areas which can not be monitored caused coverage holes [2]. As a result, how to detect and patch of coverage holes is an important element.

Recently, many researchers have focused on the development of patching coverage holes by using mobile sensor nodes. For example, SOI algorithm [3] figures out the optimal inner nodes, and then moves mobile sensor nodes to the new position. Or to deploy new sensor nodes on the hole-boundary bisectors [4] patch coverage holes. In [5], it adopts the basic principle that the static sensor nodes guide mobile sensor nodes to reach the optimum position and recover the coverage holes. Although the cost of mobile sensor nodes is gradually reducing, the dense networks are limited by resources and cost.

In order to avoid the phenomenon of coverage holes, multi-coverage [6] is more common solution, and the wake-up scheme [7] based on multi-coverage can save the consumption of resources. Thus, it is effective that using remaining redundant nodes patch coverage holes [8-10]. In [10], the authors propose the DFNFP strategy, but this strategy has the disadvantage of utilization of resource and redundant nodes while it is applicable on large-scale coverage holes. In this paper, based on current hole detection algorithms, we propose the distance-assistant coverage holes patching (DACHP) strategy to patch coverage holes. On the basis of network which meets multi-coverage and existence of coverage, compared with DFNFP and random algorithm holes, DACHP performs more superior.

2. Preliminaries

A. Assumptions

In this paper, we assume that all of sensor nodes in the monitoring region are stationary after deployment. These nodes are assumed to be homogenous, with the same communication and sensing range, and data processing capacity. When the ratio of communication range and sensing range is no lower than 2, and the network meets coverage, it is a connected network [1]. Thus we assume that each sensor node in wireless sensor network has a limited communication and sensing range and the ratio of them is 2. In addition, coverage holes are closed in the monitoring range.

Each sensor node communicates with its neighbors and not has GPS device, but it can receive relative position information of its adjacent nodes by adopting directional antenna and the associated wireless locating arithmetic. Since the network meets multi-coverage, calculate the number of neighbors of each sensor node and set the threshold of number that sensor nodes becomes redundant nodes. If the number of neighbors of one sensor node reaches the threshold, it is a redundant node.

B. Problem Description

The major consideration of this paper is how to patch coverage holes by using redundant nodes in the case of existing coverage holes in the wireless sensor networks. As shown in Fig. 1, the known coverage hole is an irregular region. A 、B 、C 、D 、E 、F 、G 、H 、I and J are hole boundary nodes, and interconnect to form a hole range. a 、b 、c 、d 、e 、f 、g 、h 、i and j are hole boundary intersections [12]. In addition, as we can see node O

* This work is supported by National Natural Science Foundation of China (NO.61202098)

completely covers the hole boundary arc [12] of *B*. Thus, node *O* is the optimal redundant node to patch coverage hole, called virtual redundant node.

As a result, how to determine the optimal location of *O* has two factors to be considered:

1) The distance between node *O* and node *B* is optimal to cover hole boundary arc of *B* for as much as possible.

2) The direction of node *O* should be moderate and generate repeated coverage for as little as possible.

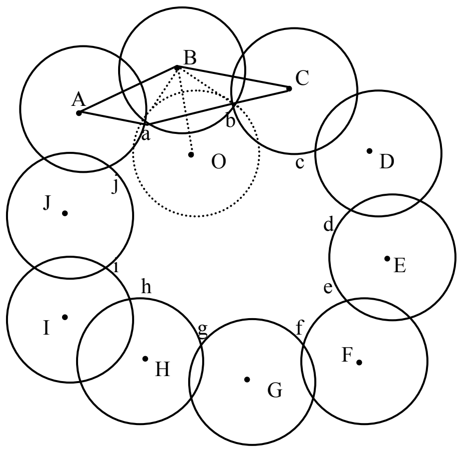


Fig. 1 Distance-assistant coverage holes patching strategy mode

3. Patching Method for Coverage Holes with Distance-Assistant in Wireless Sensor Networks

A. Coverage Hole Detection

During patching coverage hole, for providing conditions of patching hole, the first step is to detect coverage hole [4, 11] to accurately determine the direction and size of the hole. In this study, we adopt a hole detection algorithm [4] to achieve the boundary of hole.

B. DACHP Algorithm

As shown in Fig. 1, assumed that the distance between *O* and *B* denoted as d_0, and *AB* 、*BC* represent the distance of hole boundary node *B* with *A* 、*C*, respectively. Node *B* communicates with *A* 、*C* and then obtain $\angle ABC$, denoted as φ. If $\varphi < \pi$, calculate the length of *AB* 、*BC* by the associated wireless locating arithmetic. Otherwise, any of hole boundary neighbor nodes [11] of *B* has priority to patch. Since hole boundary nodes of coverage hole are interconnected to form a closed polygon, as long as coverage hole exists, there must be the angle that is less than π, thus be able to find a node that meet the requirement [2].

In the ΔABa 、ΔBab and ΔBbC, the following can be formulated mathematically through trigonometric function:

$$\begin{cases} \cos\angle BCb = \dfrac{BC}{2r} \\ \cos\angle BAa = \dfrac{AB}{2r} \\ \cos\angle OBb = \dfrac{d_0}{2r} \end{cases} \quad (1)$$

$$\cos\varphi = \cos(\angle BCb + \angle BAa + 2\times\angle OBb)\,. \quad (2)$$

Since φ is known, using (1) and (2), we can obtain $\angle OBb$ and approximate optimal solution of d_0. Then the next is to find out the optimal redundant node.

If node *Q* is any one of neighbor redundant nodes of hole boundary node *B*, *B* communicates with it and other hole boundary neighbor nodes, and calculates the length of *QB* and $\angle QBC$. Then the error *k* is calculated as a foundation which redundant node is to be awakened. The error *k* is defined as:

$$k = |\angle QBC - \angle OBC| \times |QB - d_0|$$

Overall, the proposed DACHP algorithm is divided into three steps as following:

1) Running the hole detection algorithm [4] determines the number of coverage hole and each hole-boundary node.

2) For any hole boundary node, determine the optimal relative position information of its virtual redundant node.

3) Figure out the redundant node which has the minimum *k* and awaken it to patch coverage hole.

Repeat the previous steps until coverage hole is completely covered.

C. Process of Patching

Assumed that hole boundary node *B* firstly receives the patching command, and then communication with the left and right hole boundary neighbors to obtain φ. If $\varphi < \pi$, *B* figure out location information of its virtual redundant node, and awaken redundant node that has the minimum *k* in its communication range. Thus, this redundant node becomes a new hole boundary node and sends its boundary information to all its neighbors. While its hole boundary neighbors receive its boundary information, they replace location information of *B* with its location information. And then *B* sends the patching command to the next hole boundary node that has not received the patching command. If $\varphi >= \pi$, *B* directly sends the patching command to the next hole boundary node that has not received the patching command. While all hole boundary nodes have received the patching command, and then running hole detection algorithm recalculate hole boundary nodes.

4. Simulation

In this section, simulations show that the proposed DACHP experiments in a randomly deployed network. In a 50x50 m^2 rectangular region, we randomly deploy 300 sensor nodes, and set the sensing range and communication range at 4 and 8, respectively. The threshold of redundant nodes is set at 8. For one coverage hole, DACHP compares the performance at two aspects that is the area of patching coverage hole and the utilization of redundant nodes with DFNFP [10] and random algorithm. As shown in Fig. 2, the blank range in the rectangular area is uncovered area by sensor nodes, called coverage hole. As we can see, there are a lot of redundant nodes within the coverage hole, thus we can awaken some redundant nodes to patch the coverage hole.

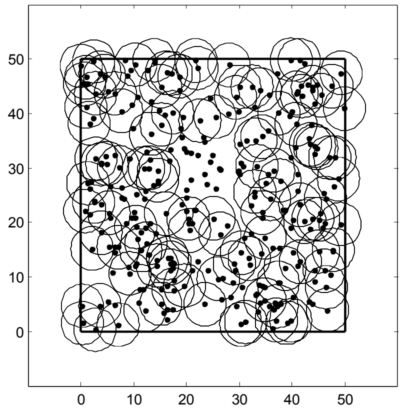
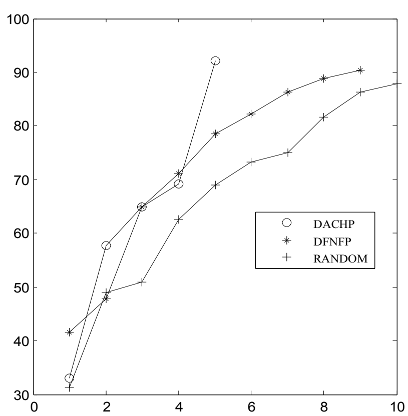


Fig. 2 Coverage hole in the wireless sensor network

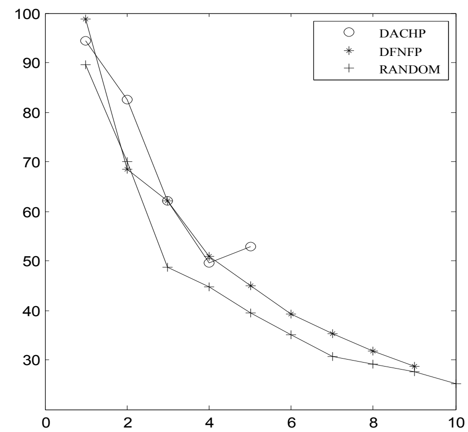
Fig. 3 shows, for the same size and shape coverage hole (Fig. 2), the relationship between the number of awakened redundant nodes with patching rate of coverage hole. After running three hole patching algorithms, with the increasing of the number of awakened redundant nodes, the area of the coverage hole is reducing. DACHP awakens five redundant nodes to patch 92.19% of hole, and DFNFP needs awaken nine redundant nodes and then just patch 90.28%. Thus it can be seen that DFNFP not only awaken four extra nodes, but also is lower 1.19% in patching rate of hole than DACHP. Compared with random algorithm, DACHP and DFNFP are more superior in the patching rate of coverage hole.



Number of Awakend Redundant Nodes

Fig. 3 Changes of patching rate of hole with the increasing number of awakened redundant nodes

After patching the same coverage hole (Fig. 2), the comparison of average utilization of awakened redundant nodes is shown in Fig. 4. As we can see, in the most cases, average utilization of redundant nodes of DACHP algorithm is higher than DFNFP and random algorithm. However, if the length of hole-boundary arc is too long, it exists that a single redundant node utilization of DACHP is less than DFNFP. When the number of awakened redundant nodes is one, its utilization of DACHP and random algorithm are 94.50% and 89.64%, respectively, and that of DFNFP is 98.79%. Compared with DACHP as a whole, DFNFP and random algorithm need to awaken more redundant nodes, and easily lead to more repeated covered area in the coverage hole, thereby reduce the average utilization of awakened redundant nodes. As described in Fig. 4, after completely patching the coverage hole, the average utilization of DACHP is 52.82% and rises 23.84% from DFNFP and 27.4% from random algorithm. Therefore, DACHP algorithm can effectively patch coverage holes, and reduce the waste of resources.



Number of Awakend Redundant Nodes

Fig. 4 changes of average utilization of awakened redundant nodes

5. Conclusion and Future Work

The coverage problem is important research issues for wireless sensor networks. The paper proposes a solution for patching coverage holes, called DACHP. In the process of patching, this algorithm can effectively solve the problem of coverage holes, and improve the quality of network coverage, take into account the costs and the efficient use of resources. However, due to all of sensor nodes in the monitoring range are stationary after deployment, and using redundant nodes to patch coverage holes has some limitations. So the future work is to research that adds mobile sensor nodes or static sensor nodes to achieve the redeployment of the network.

6. References

[1] G.L. Xing, X.R. Wang, et al, “Integrated Coverage and Connectivity Configuration for Energy Conservation in Sensor Networks,” ACM Transactions on Sensor Network, vol. 1, no. 1, pp.36-72, August 2005.

[2] L.M. Wang, F. Li, Y. Qin, “Resilient Method for Recovering Coverage Holes of Wireless Sensor Networks by Using Mobile Nodes,” Journal on Communications, vol. 32, no. 4, pp. 1-8, 2011.

[3] K. Yang, Q. Liu, S.K. Zhang, J. Li, D.L. Weng, “Hole Recovery Algorithm Based on Mobile Inner Nodes in Wireless Sensor Networks,” Journal on Communications, vol. 32, no. 4, pp.116-124, 2012.

[4] J.X. Yao, G.Y. Zhang, J. Kanno, R. Selmic, “Decentralized Detection and Patching of Coverage Holes in Wireless Sensor Networks,” // Intelligent Sensing, Situation Management, Impact Assessment, and Cyber-Sensing. Florida: SPIE, vol. 7352, 2009. [2013-02-01]. http://dx.doi.org/10.1117/12.819294.

[5] H. Li, S.L. Song, “Recovery Algorithm of Coverage Hole Based on Distribution in Wireless Sensor Network,” Computer Engineering, vol. 38, no. 16, pp.85-88, 92, 2012.

[6] M. Liu, J.N. Cao, Y. Zheng, et al. “Analysis for Multi-coverage Problem in Wireless Sensor networks,” Journal of Software, vol. 18, no. 1, pp. 127-136, 2007.

[7] J.A. Jiang, C.P. Chen, et al, “CoCMA:Energy-Efficient Coverage Control in Cluster-Based Wireless Sensor Networks Using a Memetic Algorithm,” Sensors, vol. 9, pp. 4148-4940, June 2009.

[8] X. Bao, Y.F. Ju, “Coverage-Hole Repair Algorithm towards Nodes Failure in Wireless Sensor Networks,” Computer Measurement & Control, vol. 19, no. 6, pp.1516-1518, 1522, 2011.

[9] C.G. Xu, X.H. Deng, H.J. Zou, “Repair Policies of Coverage Holes in Wireless Sensor Networks,” CHINESE JOURNAL OF SENSORS AND ACTUATORS, vol. 23, no. 2, pp. 256-259, 2010.

[10] C.G. Xu, X.H. Deng, “Method to Repair Coverage Holes Based on Wake-up Mechanism in Wireless Sensor Networks,” Journal of Computer Applications, vol. 32, no. 6, pp.1516-1518, 2012.

[11] S. Babaie, S.S. Pirahesh, “Hole Detection for Increasing Coverage in Wireless Sensor Network using Triangular Structure,” IJCSI International Journal of Computer Science Issues, vol. 9, no. 1, pp. 213-218, 2012.

[12] H. Su, Y. Wang, “A Self-Healing Algorithm without Location Information in Sensor Networks,” CHINEST JOURNAL OF COMPUTERS, vol. 32, no. 10, pp.1957-1970, 2009.