A Recovery Algorithm based on Minimum Distance Redundant Nodes in Fault Management in WSNs

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Abstract

Fault recovery is vital to WSNs since node death is a typical fault. Aiming to recover the "coverage hole", a Recovery Algorithm based on Minimum Distance Redundant Nodes (MDRN) is proposed in this paper. By employing redundant nodes carefully, the recovery algorithm is deployed on the sink node with unconstrained energy consumption which knows the locations of all active nodes and redundant nodes in the WSNs. Simulation results demonstrate that, by choosing appropriate number of redundant nodes, this algorithm will have great recovery accuracy and coverage quality, also achieve the purpose of prolonging the lifecycle of WSNs.

Keywords: *Coverage hole; Fault recovery; Fault management; WSNs*

1. Introduction

Although the concept of a sensor network is proposed in 1980 (DARPA initiated the Distributed Sensor Networks program), there is an explosive increase of interest in wireless sensor networks (WSNs) in the last 10 years.

Failures are inevitable in WSNs due to the inhospitable environment and unattended deployment. Furthermore, the constrained energy, storage capacity and computational ability make the situation worse. In practical application, faulty sensor nodes are one of the most important sources of faults. A node is fragile and has limited resources, which makes it easy to become faulty. In any cases, it uses multi-hop communication between nodes, which means when a node senses parameters, it also transmits others nodes' data at the same time. Thus some nodes need to support more communication load, which cause the nodes dead prematurely due to the lack of energy consumption [1-5] . So there appears some "coverage hole", which will end the life of WSNs and leave much more energy resources wasted in the networks.

Our institute, cooperated with Northern Arctic-alpine Horticultural Genetic Modification and Installation Cultivation Lab of Northeast Agriculture University, develops the WSN-based greenhouse environment monitoring system (GEMS), aiming for monitoring the growing environment of a certain kind of improved tomato and providing support to the agriculture experts for analyzing the relationship between the growth/development of the tomato and its growing environment. Node Self Detection by History data and Neighbors (NDHN) algorithm [6] and Fault Detection Technique based on Clustering (FDTC) [7] are proposed to detect the faulty nodes. In this paper, we target the problem of recovering the "coverage hole" in WSNs.

2. Related work

2.1. Restructure the network

There are many redundant nodes deployed randomly in WSNs, so it is possible to isolate failed nodes directly and choose some redundant nodes to restructure a new route to transmit the information. Many existing approaches use this technique to handle simple fault situation. Marti, *et al*., [8] proposed a technique to detect faulty neighbor and choose another new neighbor instead. Kuo-Feng, *et al*., [9] proposed a method that the sink node triggers re-routing procedure when the faulty path occurs. In the paper [10-11], Xu, *et al*., presented Best Fit Node Policy (BFNP) and Directed Furthest Node First Policy (DFNFP) to repair "coverage hole".

2.2. Using mobile node

The approach of using mobile node to repair "coverage hole" is one of the most effective techniques in fault recovery, which can solve hard fault. In the paper [12], Guiling Wang designed a mobile agent-based technique with the help of her lab, which pays more attention on the mobile sensor deployment. A subset of mobile sensors are deployed in the networks, and treated as servers to heal coverage holes, where mobile sensors move from densely deployed areas to sparse areas to increase the coverage. Static sensors will detect the "coverage holes" locally, estimate their sizes as bids, and bid the mobile sensors with a base price lower than their bids. Mobile sensors choose the highest bids and move to heal the largest coverage holes. This process iterates until no static sensor can give a bid higher than the base price of any mobile sensor and the process terminates naturally. In the paper [13], Wang, *et al.*, suggested another technique for sensor relocation, which consists of two phases. The first phase is to find the redundant sensors in the sensor networks, and the other phase is to relocate them to the target location. For the first phase, a grid based solution is proposed to quickly locate the redundant sensors with low message overhead. For the second phase, efficient heuristics are proposed to achieve good balance between energy efficiency and relocation time when determining the sensor relocation path. But it vastly wasted the energy and it was very difficult to control a mobile node to reach the right place, which was the obvious shortcoming of this method.

3. Localized Faulty Recovery Algorithms

In this section, we describe our algorithm for recovering the "coverage hole". Firstly, we illustrate MDRN by using a session scenario example, and then we present the recovery procedure and the algorithm.

3.1. Assumptions

The algorithms in this paper are developed under the following assumptions:

1) WSNs are deployed with clustering model, showed in Figure1;

2) Active nodes are structured and deployed in advance; redundant nodes are deployed randomly;

3) All sensor nodes are stationary after deployment;

4) All sensor nodes have the same structure and function, and their status is equal in anyway;

5) There is only one sink node, and it is deployed outside the network, which has unrestricted energy;

6) Sink node can wake every node up or control it to sleep periodically;

7) Every node has its location information;

8) Sensor nodes are Omni-directional with symmetric sensing range R_s and communication range R_c, where $R_c > R_s \geq R_c/3$.

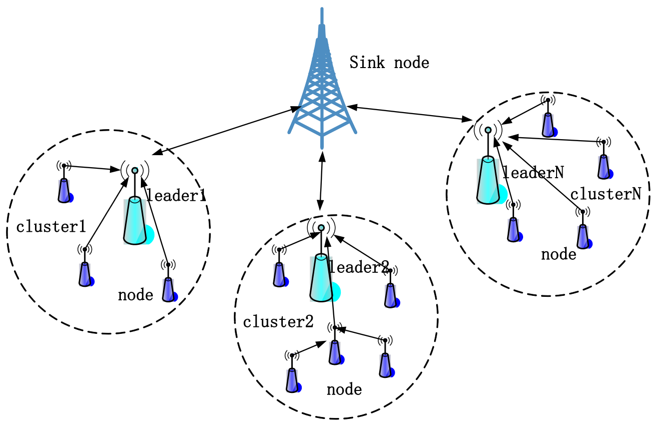


Figure 1. The model schemes of WSNs

3.2. Session Scenario

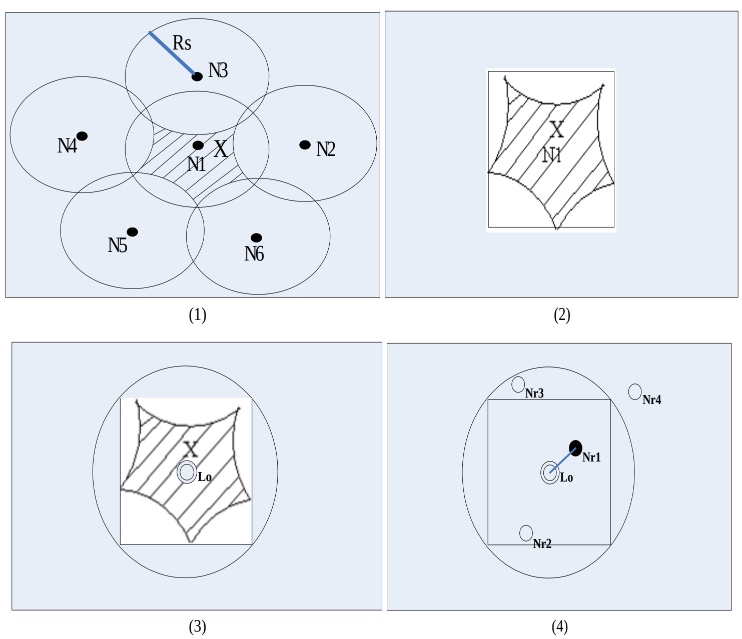


Figure 2. Session scenario

Figure 2 illustrates the main role of the sensor node during a recovery session, which starts when the sink node detects a death node N1 through NDHN technique [3]. The "coverage hole" caused by N1 is showed by the shadow X (1). According to the location information of N1's neighbors, such as N2 N3 N4 N5 and N6, we can obtain the irregular shape of X. Then seek a foursquare to cover the whole area of X, which the square area should be minimum (2). After that, it is important to seek a minimum circle to cover the foursquare, and the centre of the circle will be the optimum location of a substitute node, marked Lo (3). Furthermore, the adjacent redundant nodes calculate the distances to Lo, and transform the distances to the sink node. Finally, according to the principle of minimum distance, sink node chooses redundant nodes Nr1 as the substitute node, and wake it up to join the network and end the procedure of recovery (4).

3.3. Derivation of recovery procedure

The procedure of recovering a "coverage hole" can be explained as follows. Denote $R(N_i)$ as a bounded closed set of $n \times m$ that contains active nodes $N_1, N_2, ...N_n$, and redundant nodes $N_{r1,} N_{r2,} ...N_{rm}$. Denote their coordinates as $N_i(x_i, y_i)(i = 1,2 \cdots n)$ and $N_{ri}(x_{ri}, y_{ri})(i = 1,2 \cdots m)$. Denote an arbitrary spot $L(x_l, y_l)$ in $R(N_i)$, and denote r_i as the distance from L to N_i , which are computed by equation (1).

$$r_i = \sqrt{(x_l - x_i)^2 + (y_l - y_i)^2} \quad (1)$$

We also denote $L_o(x_{lo}, y_{lo})$ as the optimal location of recovery node. And denote d_i as the distance from N_{ri} to L_o , which are computed by equation (2).

$$d_i = \sqrt{(x_{lo} - x_{ri})^2 + (y_{lo} - y_{ri})^2} \quad (2)$$

3.4. Algorithm

1) NDHN algorithm will be operated in the cluster, and then the sink node makes a decision whether there has a faulty node N_d ;

2) Sink node knows all nodes' locations, so it can immediately know every neighbor node N_j of node N_d ;

3) Calculating the distance from an arbitrary spot L to neighbor node N_j by equation (1). When every r_i is satisfied with $r_i \geq R_s$, it indicates that the arbitrary spot L is in the "coverage hole";

4) Searching for the extreme x-coordinates of all arbitrary spots in the "coverage hole", marked $x_{\max}$ and $x_{\min}$, and the extreme y-coordinates, marked $y_{\max}$ and $y_{\min}$;

5) Choosing the greater value of x_t and y_t as the length of the side of one square S_h , which are calculated by equation (3) and equation (4), and determining four endpoints of S_h at the

same time, marked $P_1(x'_{\min}, y'_{\min})$, $P_2(x'_{\min}, y'_{\max})$, $P_3(x'_{\max}, y'_{\max})$ and $P_4(x'_{\max}, y'_{\min})$;

$$x_t = |x_{\max} - x_{\min}| \tag{3}$$

$$y_t = |y_{\max} - y_{\min}| \tag{4}$$

6) Choosing a circle to cover S_h completely, and the centre of the minimum circle $C_{\min}$ will be the optimal location of replacement node, marked L_o. The radius of $C_{\min}$ and the coordinate of L_o will be calculated by equation (5) (6) and (7);

$$r_C = \frac{1}{2}\sqrt{(x'_{\max} - x'_{\min})^2 + (y'_{\max} - y'_{\min})^2} \tag{5}$$

$$x_{Lo} = x'_{\min} + \frac{1}{2}(x'_{\max} - x'_{\min}) \tag{6}$$

$$y_{Lo} = y'_{\min} + \frac{1}{2}(y'_{\max} - y'_{\min}) \tag{7}$$

7) Calculating the value of d_i by equation (2). Sink node actives node N_{ri} to join the network and sense parameters, which has the minimum value of d_i, and orders the rest of the redundant nodes to sleep.

8) MDRN algorithm will be rescheduled periodically, and the “coverage hole” will be eliminated.

4. Simulation and discussions

4.1. Design of simulation experiment

Based on the voltage data of nodes collected during Aug.10, 2010 to August 14, 2010 from the experiments of GEMS, we simulate the algorithm. We did the experiments in the intelligent greenhouse of Northern Arctic-alpine Horticultural Genetic Modification and Installation Cultivation Lab, which is the key provincial laboratory in Northeast Agriculture University. The experiment field is showed in Figure 3.

Figure 3. The sensor nodes deployed in the greenhouse

MATLAB is used to perform the simulations. The GEMS contains 24 nodes in a square region of size 140×100m^2, in which active nodes are structured and deployed in advance and 10 redundant nodes are deployed randomly, as showed in Figure 3. We use the NDHN technique to detect the voltages of the nodes. Once the voltages are lower than 2.2V, nodes in the system will stop transmitting data and be regarded as faulty practically. Then MDRN technique is triggered to recover the "coverage hole", and the simulation result of one faulty node is showed in Figure 4.

Because the number of redundant nodes will affect the recovery result seriously, we choose 10, 20, 30 and 50 redundant nodes respectively to recover 1 faulty node, as showed in Figure 5 a. b. c. and d., and then to recover 2 faulty nodes. In every situation, we operate MDRN algorithm 30 times and calculate the average value.

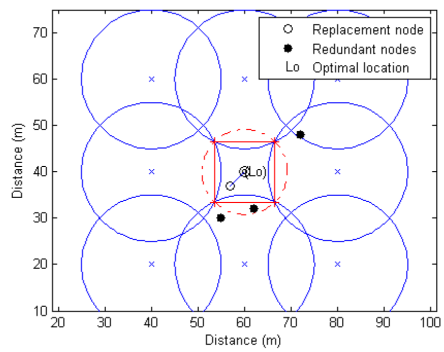


Figure 4. Recovery result of MDRN

4.2. Discussions

Table 1 illustrates the details of the simulations.

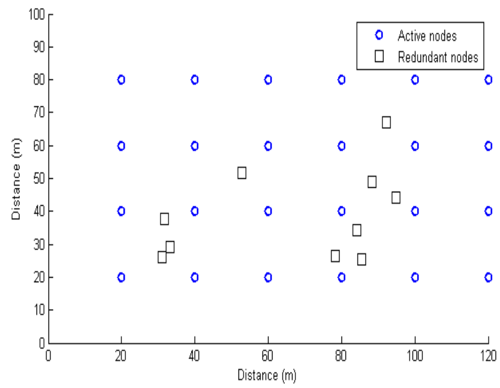
Table 1. Details of the simulations

Number of redundant nodes	Number of faulty nodes	Times of recovery correctly	Recovery accuracy
10	1	25	83.3%
	2	19	63.3%
20	1	27	90.0%
	2	24	80.0%
30	1	29	96.7%
	2	28	93.3%
50	1	30	100.0%
	2	29	96.7%

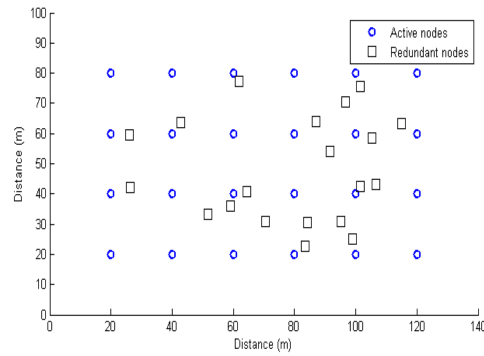
It should be specially explained that when the value of d_i is greater than the difference between R_s and r_c, the "coverage hole" will not be covered completely, and considered as recovery failure. Thus when there are more numbers of faulty nodes and less numbers of redundant nodes, the recovery failure rate will increase.

The recovery accuracy is affected by the number of redundant nodes primarily, which will distinctly increase the cost, and that is the shortcoming of MDRN. The recovery accuracy of MDRN is showed in Figure 6.

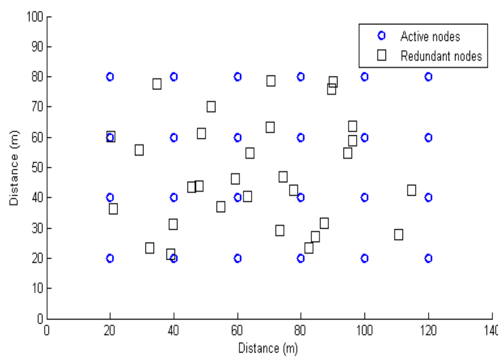
The quality of coverage is one of the most important performance metrics. In the paper [14], Parikh et al. presented that the WSNs' coverage of 100% is not possible, but when the ratio is greater than 70%, the networks could work smoothly. In MDRN, it always has a distance between the replacement node and the optimal location, so the quality of recovery is hard to get 100%. The quality of recovery is showed in Figure 7.



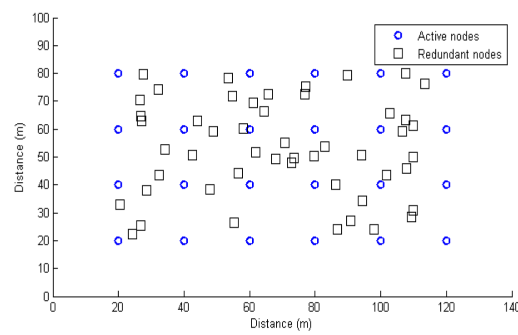
(a) 10 redundant nodes



(b) 20 redundant nodes



(c) 30 redundant nodes



(d) 50 redundant nods

Figure 5. Deployment of redundant nodes

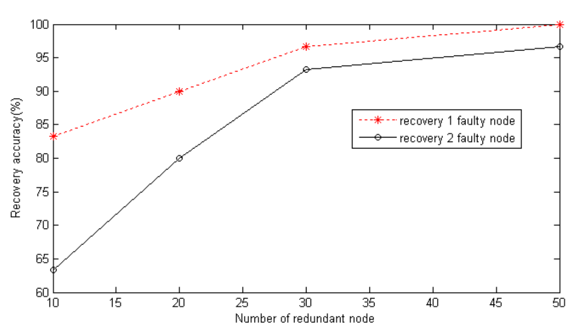


Figure 6. Recovery accuracy of MDRN

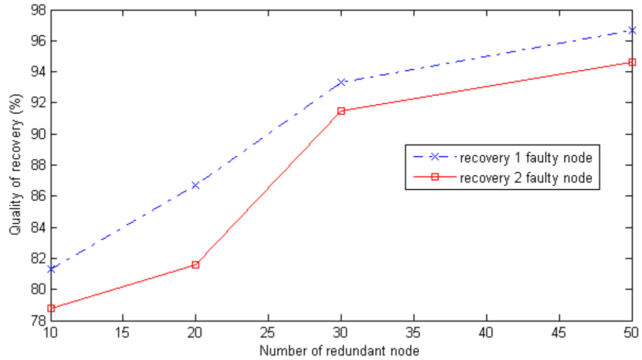


Figure 7. Quality of recovery

5. Conclusion

This paper presents a technique MDRN for node fault recovery in fault management of WSNs. According to the simulation result, the technique proposed in this paper is feasible and effective for treating "coverage hole" caused by faulty node. Furthermore, the method could be served as a support for sensor networks energy balancing and optimization. In the future, we will explore the technique of reducing the number of redundant nodes in MDRN, and improving the recovery accuracy when treating the situation of multiple fault nodes.

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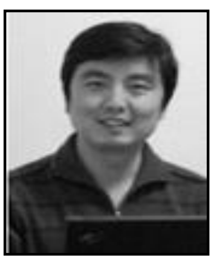

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