

An Intelligent and Energy-Efficient Fault Detection Algorithm for Wireless Sensor Networks[†]

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Abstract. Fault detection is vital to wireless sensor networks since node death is a typical fault. One of the central challenges is to design a detection algorithm which has good performance in energy efficiency. In this paper, we propose an intelligent fault detection algorithm based on numerical taxonomy. Firstly, all nodes are divided into clusters according to their geographical distribution. Besides, the sink node uses numerical taxonomy to process the measurements and detect faulty node. Simulation results validate that this algorithm outperforms NDHN and will consume less energy.

Keywords: fault detection; fault management; WSNs

1 Introduction

Wireless sensor networks (WSNs) are always deployed in unattended operation and remote sensing situation, where the harsh environment and the character of organizing networks randomly make fault happen frequently. WSNs' node has constrained energy, storage capacity and computational ability, which makes it easy to become faulty. Therefore, fault management, including fault prevention, fault detection and fault recovery, is as important as other performance metrics such as energy efficiency, latency and accuracy no matter in theoretical or practical conditions^[1].

Node Self Detection by History data and Neighbors (NDHN) algorithm^[2] and Fault Detection Technique based on Clustering in WSNs (FDTC)^[3] are proposed to detect the faulty nodes. In this paper, we propose a Fault Detection Technique based on Numerical Taxonomy (FDNT) to improve the NDHN and FDTC algorithms.

2 Related Work

Fault detection techniques are used to detect potential faults and search for the source of faults, which are convenient for fault recovery work. In the paper [4], it is proposed to use nodes' residual energy value to indicate the faults. In the paper [5], nodes' self-

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detection method is proposed, which arranges within every node to detect the status periodically and transmit to its neighbors. If the update packet does not achieve in a proper time, the node would be regarded as faulty node. This technique can reduce the energy consumption of leaders obviously.

The main idea of NDHN is using neighbors' cooperation and node's history records to diagnose the node's fault. Node A invites its neighbors to cooperate by sending them a cooperation request in order to gather their measurements. The collected data is concatenated and analyzed in node A to judge the fault [2]. It is necessary to detect the node's hardware parameters or collect the neighbors' measurements, which will consume much more energy. Furthermore, better fault detection accuracy needs higher operation frequency, as a result, there will be more energy consumption, and it will also decrease the lifecycle of the network desperately.

3 Fault Detection Technique based on Numerical Taxonomy

The algorithms in this paper are developed under the following assumptions: 1) All sensor nodes are stationary after deployment;

3) All sensor nodes have the same structure and function, and their status is equal in any way;

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

5) Every node has its location information.

6) We denote e as the initial energy of every node, and the energy consumption model [6] is showed by equation (1) (2).

$$\begin{aligned} E_{Tx}(l, d) &= l \epsilon_{elec}^E + l \epsilon_{fs}^E, \text{ if } d \leq d_0 \\ E_{Tx}(l, d) &= l \epsilon_{elec}^E + l \epsilon_{amp}^E, \text{ if } d > d_0 \end{aligned} \quad (1)$$

$$E_{Rx}(l) = l \epsilon_{elec}^E$$

Where, we denote $E_{Tx}(l, d)$ as the energy consumption by transforming l bit data crossing d distance, and denote $E_{Rx}(l)$ as the energy consumption by receiving l bit data. ϵ_{elec}^E is denoted as the emission circuit's loss of energy. The power amplification loss is calculated by free space model if the transmit distance d is less than threshold d_0 , while calculated by multipath fading model if d is greater than d_0 . We also denote ϵ_{fs}^E and ϵ_{amp}^E as the power amplifier's energy consumption of the two models mentioned above.

The procedure of FDNT is showed as follows.

1) Sink node collects several samples of measurements, marked $Z_i = \{Z_1, Z_2, \dots, Z_N\}$;

2) Set a threshold of similarity scale as τ ;

- 3) Choose a sample data Z_1 randomly and consider it as the core, C_1 , of the first taxonomy;
- 4) Calculate the deviation between Z_1 and all measurements $Z_i = \{Z_1, Z_2, \dots, Z_N\}$, marked D_{1i} ;
- 5) If $D_{1i} \leq r$, it is judged that Z_i belongs to C_1 , otherwise it belongs to C_2 , a new taxonomy;
- 6) Calculate the difference value between C_2 and the rest data of Z_i to get D_{2i} ;
- 7) If $D_{2i} \leq r$, it is judged that Z_i belongs to C_2 , otherwise it belongs to C_3 , another new taxonomy;
- 8) Repeat step 4) to 7) until all measurements are processed;
- 9) When WSNs is activated, calculating the 2-norm between every new measurement Z_i' and the average value of C_i ;
- 10) If the 2-norm is greater than threshold σ , it triggers an alarm and the sink node broadcasts commands to reset NDHN algorithm.

4 Simulation and Discussions

Basing on the voltage data of nodes collected during Aug.10, 2010 to Aug.14, 2010 in the experiments of GEMS^[4], we simulate the algorithm.

MATLAB is used to perform the simulations. The GEMS contains 24 nodes in a square region of size $140 \times 100m^2$, in which active nodes are structured and deployed in advance. We use the FDNT technique to detect the voltages of the nodes. When the voltages are lower than 2.2V, nodes in the system will stop transmitting data and be regarded as faulty practically.

In practical, clustering method in WSNs is always based on their geography position. In this paper, we cluster the network into 2 clusters, just like FDTC^[5]. We illustrate the proof in detail for the integrity of this paper, as showed in Fig.1.

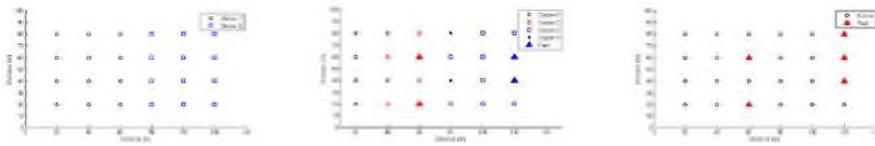


Fig. 1. Simulation of clusters **Fig 2.** Detection result of FDNT **Fig 3.** Detection result of NDHN

We use nodes' air humidity measurements as the samples to cluster the network. Then we set 4 faulty nodes, and choose $r=10$, $\sigma=10$. The simulation result of FDNT is showed in Fig.2. NDHN is also simulated to compare with FDNT, and we choose $\alpha=0.8$, $\beta=0.2$, $r=0.20$. The simulation is showed in Fig.3.

Table 1. Details of comparison

Algorithm	Number of nodes	Number of faulty nodes	Number of nodes detected	of Detection faulty accuracy
NDHN	24	4	5	75%
FDNT	24	4	4	100%

The comparison is showed in Table.1. It should be specially explained that there are 4 faulty nodes actually, FDNT detects the faulty nodes correctly, but there appears false alarm in NDHN, where a healthy node is treated as fault. The detection accuracy and false alarm mostly depend on r and α , which are chosen in experience, and this is the shortcoming of FDNT.

We stabilize $r = 10$ and change the value of α , then run FDNT to deal with the GEMS, and the detection accuracy and false alarm are showed in Fig.4 and Fig.5 respectively.

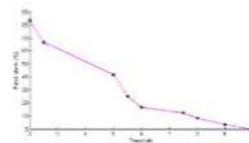
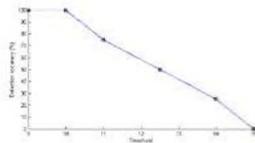


Fig 4. Detection accuracy vs. α of 24 nodes **Fig 5.** False alarm vs. α of 24 nodes **5**

Conclusion

This paper presents a technique FDNT to modify NDHN and FDTC for node fault detection in WSNs. According to the simulation result, the technique proposed in this paper is feasible and effective to reduce energy consumption and false alarm greatly, while still maintains high detection accuracy. In the future, we will do some research of mathematical method in modeling and the threshold choosing. And we will research the time and space correlation of measurements to perfect FDNT.

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