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Mobile sink based fault diagnosis scheme for wireless sensor networks

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ABSTRACT

Network diagnosis in Wireless Sensor Networks (WSNs) is a difficult task due to their improvisational nature, invisibility of internal running status, and particularly since the network structure can frequently change due to link failure. To solve this problem, we propose a Mobile Sink (MS) based distributed fault diagnosis algorithm for WSNs. An MS, or mobile fault detector is usually a mobile robot or vehicle equipped with a wireless transceiver that performs the task of a mobile base station while also diagnosing the hardware and software status of deployed network sensors. Our MS mobile fault detector moves through the network area polling each static sensor node to diagnose the hardware and software status of nearby sensor nodes using only single hop communication. Therefore, the fault detection accuracy and functionality of the network is significantly increased. In order to maintain an excellent Quality of Service (QoS), we employ an optimal fault diagnosis tour planning algorithm. In addition to saving energy and time, the tour planning algorithm excludes faulty sensor nodes from the next diagnosis tour. We demonstrate the effectiveness of the proposed algorithms through simulation and real life experimental results.

1. Introduction

Recently, Wireless Sensor Networks (WSNs) have risen as a practical solution for a variety of remote applications, such as battlefield surveillance, environmental monitoring, home security and automation, weather forecasting, medical and industrial monitoring, etc. (Banerjee et al., 2014; Wu et al., 2008; Chen et al. 2006; Lee and Choi, 2008a; and Chanak et al. 2014). A WSN comprises of a set of smart sensing devices where each sensor node is equipped with limited memory, typically a low performance microcontroller, a power constrained transceiver and limited power availability.

In a monitoring field, sensor nodes are usually deployed without a preconfigured infrastructure. After deployment, sensor nodes form an ad-hoc network using a nearby node discovery process. In WSNs, the deployed sensor nodes are prone to various faults such as transceiver unit fault, sensor unit fault, processing unit or microcontroller unit fault and the power unit fault (Banerjee et al., 2014; Lee and Choi, 2008b; Chen et al., 2012; Misra et al., 2014; and Bari et al., 2012). Faulty sensors produce erroneous data during the normal operation of the network which can reduce the number of available multihop paths in the network. Hence, faulty sensor nodes can potentially degrade the Quality of Service (QoS) of the WSN, since it is desirable to detect, locate, and ignore faulty sensor nodes during normal operation of the network.

Due to instability and uncertainty, fault diagnosis is very difficult in WSNs. However, network diagnosis is more crucial within a highly dynamic topology as the network structure of the WSN frequently changes due to environmental interference and uncertainty of the wireless medium. Therefore, the design of a Mobile Sink (MS) based distributed fault diagnosis scheme can effectively help network administrators monitor the network operation and maintain a wireless sensor network system.

In existing fault detection approaches, most of the energy available to a sensor node is consumed on two major tasks, *viz.* diagnosis status selection of deployed sensor nodes and localization of faulty nodes within the network. Fault diagnosis strategies depend on the network topology or the location of sensor nodes since fault diagnosis is an important factor that can directly impact the performance and lifetime of the network. In dynamic applications of WSNs, the network structure can frequently change due to rapid fault occurrences within the network. Existing static sink based fault diagnosis approaches lead to large numbers of messages sent over the network (both data and status) in order to adapt to the topological changes. Hence, the available energy of the sensor nodes in the network can be rapidly depleted. In addition, sensors close to the sink suffer from much more traffic being routed through them compared to sensors at the boundary of the network due to the need to route data and status packets

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from sensors that are far away from the sink (Lau et al., 2014 and Koushanfar et al., 2003). After these sensors fail, communication holes, or energy holes, are created near to the sink node and the network can then become unreliable or even disconnected. In some cases, nodes and link failures may potentially portion an entire network into several sub-networks, hence these sub-networks become disconnected from the rest. Then, a Base Station (BS), or network administrator can declare these sub-networks dead due to the lack of available health information and exclude these sub-network nodes from the main network, despite most of the sub-network nodes can still survive for a long period of time. Recently, interesting approaches have been used for MS data gathering that can collect data from deployed sensor nodes in an energy efficient manner (Zahhad et al., 2015 and Mi et al., 2015). These MS based data gathering strategies successfully collected data from different sub-networks in the network portion state. In these approaches, it was argued that MS based WSN management strategies are more effective in improving the performance of the network in dynamic environments. These works motivated us to propose an MS based fault diagnose strategy for WSNs.

To address the above problems, this paper proposes an MS based distributed fault diagnosis approach. In our approach, a mobile fault detector starts the fault diagnosis tour periodically from the BS, traverses the network, performs a diagnosis action on each static sensor node using single-hop communication and at the end of each fault diagnosis tour the mobile fault detector transports the entire network health information to the BS. During the fault detection tour, each deployed sensor node is directly diagnosed by the mobile fault detector and hence the current network structure is not affected by the fault diagnosis process. Moreover, if the fault detection tour is well planned, the mobile fault detector can accurately localize the abnormal nodes within in the network thus reducing the fault detection delay. This will give network administrators an up to date status of the network.

The major contributions of this paper can be summarized as follows:

(1) We propose a Mobile Sink based fault detector to perform fault diagnosis in WSNs. It reduces the message overhead and is resilient to network topology changes during the fault diagnosis process.
(2) We propose a hardware fault detection mechanism where each hardware component of the deployed sensor nodes is diagnosed by the mobile fault detector. Therefore, network administrators find the exact causes of any faults within the network. The proposed detector may also help to maintain the network.
(3) We focus on the problem of minimizing the length of each fault diagnosis tour by excluding faulty sensor nodes from the WSN, improving QoS.
(4) We carry out extensive simulations and real life experiments. The effectiveness of the proposed scheme is verified by comparing our method with other fault detection approaches in the literature. In addition, the real time applicability of the proposed scheme is confirmed by the real life experimental results.

The rest of the paper is organized as follows. Section 2 introduces the related work. Section 3 describes preliminaries and architecture of the proposed algorithm. The proposed fault diagnosis mechanism is presented in Section 4. In Section 5, we discuss the shortest fault diagnosis tour planning mechanism. Section 6 gives the simulation results and discussion. Finally, Section 7 concludes this paper.

2. Related works

Existing fault detection approaches can be classified into two groups: (a) centralized fault detection approaches (Lau et al., 2014), and (b) distributed fault detection approaches (Lee and Choi, 2008a, 2008b; Chen et al., 2012; and Bari et al., 2012).

2.1. Centralized fault detection approaches

In the existing centralized fault detection approaches, a centralized static sink makes diagnostic decisions by periodically injecting health requests or query messages to other nodes. Therefore, a large number of message exchanges are needed over the network for data and status exchange. This process also puts a significant level of traffic onto the network which itself depletes the energy of the deployed sensor nodes. Hence, the functionality of the network can be decreased due to the fault detection process itself.

Lau et al. (2014), proposed a centralized fault detection strategy for a WSN based on the Naïve Bayes framework. This approach explored end-to-end packet transmission delay to analyze the network status. The disadvantage of this approach was that it did not work in a dynamic environment where network topology frequently changes due to faulty nodes. It required a large time frame to diagnose the fault condition of the deployed sensor nodes in large scale WSNs and it also created a high volume of traffic through the central fault diagnosis node. Therefore, this approach is not suitable for large scale WSNs.

A management architecture based fault detection scheme for WSNs was proposed by Ruiz et al. (2014) where faulty sensor nodes were detected by the central manager. In this approach, a central manager with a global vision of the network was primarily responsible for diagnosis of sensor node failures within the network. This approach led to a large number of message exchanges over the network for status and data exchange which potentially reduces the lifetime of the network. This approach also puts a significant traffic load on the central node for large scale WSNs.

The taxonomy for classification of faults in the WSN and an on-line model based fault testing mechanism was introduced by Koushanfar et al. (2003). This fault detection system worked for a heterogeneous sensor network with an arbitrary type of fault model. In this centralized fault detection approach, the BS gathered all the sensor node information and conducted an on-line fault diagnosis process. This centralized fault detection approach suffered from large message overhead which potentially decreases the functionality of the network. Furthermore, this approach is not an efficient fault detection algorithm in terms of detection accuracy since it did not consider the dynamic changes of the network during the fault detection process.

A centralized fault detection approach “Sympathy” was studied by Ramanathan et al. (2005) and in this approach, a centralized sink node gathered data from the deployed sensor nodes and analyzed the gathered data through their “Sympathy” fault detection tool. Using this approach the fault diagnosis time and message overhead was very high because of the time taken to make a decision for each sensor node to send their data to the central sink node. This approach suffered from poor network lifetime and detection accuracy.

2.2. Distributed fault detection approaches

In the distributed approaches in the literature, sensor nodes themselves make node failure decisions on the basis of results from their neighbor nodes and updates individual node status information to the sink or BS. Hence, distributed fault detection approaches can handle fault detection delay and traffic load problems that have been created during the centralized fault diagnosis process.

Lee and Choi (2008a, 2008b) proposed a distributed algorithm, termed FDWSN, for detecting and isolating faulty sensor nodes from a WSN. Faulty sensor nodes in FDWSN were detected based