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Self-maintenance model for Wireless Sensor Networks☆

Walaa Elsayed[a], Mohamed Elhoseny[a,*], Sahar Sabbeh[b,c], Alaa Riad[a]

[a] Faculty of Computers and Information, Mansoura University, Egypt
[b] Department of Computer Science, Université Claude Bernard Lyon, France
[c] Faculty of Computers and Information, Banha University, Egypt

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ABSTRACT

Wireless Sensor Networks have wide variety of applications and their nodes are prone to failure due to a hardware failure or malicious attacks. The self-healing mechanism is used for fault detection, diagnosis and healing. However, implementing the self-healing procedures at the cluster head affects the network performance. In this paper, we present a distributed self-healing approach for both node and cluster head levels. At node level, battery, sensor and receiver faults can be diagnosed while, at cluster head level, transmitter and mal-functional nodes can be detected and recovered. Compared to the state-of-the art methods, our model tolerates up to 67.3% of different hardware faults at node level. Moreover, it realized a detection accuracy of sensor circuit fault tolerate up to 76.9%, 52% of battery fault and 71.96% of receiver faults. At head class level, 75.7% of transmitter fault and 60% of microcontroller circuit fault are realized.

1. Introduction

Wireless Sensor Network (WSN) is a self-organized network that consists of thousands of inexpensive and low powered devices, called sensor nodes. WSNs are usually deployed in an environment for different purposes: sensing or collecting/processing data, as well as communicating the data with other nodes. These require the WSNs to be tolerant to hardware and software failures as well as nodes dis-connectivity. This require the sensors to be able to guarantee the fault tolerance. Faults in WSN nodes always occur due to failure of any of its hardware components. Generally, there are two types of faults affect the performance of sensor network. They are hard fault (permanent or function fault) and soft fault (transient, byzantine or intermittent fault) [1].

The bulk of fault detection techniques in WSNs are broadly performed, using either a centralized or a distributed approach. Failures that often occur in WSNs may be attributed to many causes such as: node failures, link failures, and design or implementation errors. Locating the causes of such failures is a crucial issue to insure the reliability of the network. Also, it is a challenging task due to several reasons such as the distributed nature of most protocols and applications, the energy constraints imposed on any technique and the wide variety of faults in such networks. Therefore, self-healing must be used to recover such systems to deliver a desired level of functionality in the presence of faults [2].

The contribution of this paper is solved hardware fault in sensor nodes within WSN via two-fold: First, a distributed self-healing approach (DSHA) is proposed to allow the individual nodes to detect, diagnose hardware components failures

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* Corresponding author.
E-mail address: mohamed_elhoseny@mans.edu.eg (M. Elhoseny).

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and make decision as a response to malfunction nodes. DSHA present self-maintenance to sensor node through these mentioned phases, by (a) monitoring the system for any improper conduct (fault-detection), (b) analyzing collecting data and diagnosis its (fault-diagnosis), (c) suggesting recovery operation. This was carried out by providing automated responses using a proposed recovery algorithm, which works at two levels, i.e., sensor node level, and cluster head level. Second, DSHA is utilized clustering model to overcome the challenge of energy loss and sudden failures of hardware components to extend WSN lifetime is suggested.

This paper is organized as follows: related works of fault detection techniques in WSNs application is presented in Section 2, while Section 3 describes the self-healing mechanism to prevent WSNs failures. Section 4 describes the problem formulation and reports the DSHA for WSNs. The experimental results are discussed in Section 5.

2. Related works

In [3] the author tried to provide reactive procedures against hardware malfunctioning, bugs in software and environmental hazards. In addition, a method to detect the sensor node failure or malfunctioning using the round trip delay (RTD) time is presented in [4] to estimate the confidence factor of RTD path. Based on the confidence factor, the failed sensor node was detected. In [5], a comparative study of fault detection techniques using different approaches in terms of their energy and computational constraints is provided. Generally, there are various faults can cause WSNs to misbehave and affect the functional performance of the network. A secure clustering method is proposed in [6] to avoid the common types of attack, such as the cluster head compromises attack, and provides a fault tolerant algorithm using genetic algorithm. Recently, most researches practically studied self-healing mechanism and built it upon two categories, centralized and distributed.

Centralized approach is the most common approach to detect and diagnose node failures that is caused by anomalous data reading, which occurs through monitoring process, misbehavior of sensor node components or environmental events. The authors used centralized method for detecting malfunction nodes and the proposed fault model in [1] to confirm accurate performance of the designated WSNs. Centralized Naïve Bayes Detector (CNBD) was presented for enhancing the network's life in [7]. CNBD analyzed the collected data at the sink via the end-to-end transmission time, in order to conserve higher power of the battery of each sensor node. In [8] the authors proposed a Faulty Node Detection (FIND) for WSNs. FIND was utilized to detect nodes faulty nodes centrally, without assume a particular sensing model. FIND measured the signal attenuates with distance. Moreover, a centralized fault detection method was based on the clustering approach by Saihi et al. [9]. The proposed technique in [9] used exchanging heartbeat messages mode between neighbors in active manner, for building scalable and energy balanced applications for WSNs. FNR [10] was proposed as a fault node recovery algorithm to enhance the lifetime of a WSN. It aimed to replace a faulty node, which no long have battery energy or they have reached their operational threshold, by its high-energy one. For that, we can classify it as a node replacement algorithm. FNR needs additional resources to keep the network serving. This makes it insufficient in harsh environments at which replacing sensor nodes is impossible. In 2014, Karim et al. presented fault tolerant mechanism as an extension to their previous work. It provided the continuous operation of the network by detecting the failure of sensor nodes and assigning the operation of failed nodes to other nodes based on Fault Tolerant & Energy Efficient Clustering (FTEEC) protocol. FTEEC protocol worked in two phases, are setup phase and steady phase [11]. In February 2015, Dhumale et al. proposed a fault diagnostics framework composed of a pattern recognition system, having machine learning technology as its integral part is utilized for failure detection of different switches and tracing multiple types of faults in an inverter. This work is carried for detecting faults and classifying the switches that cause the fault in an inverter and diagnosing breakdown, to make possible to run an emergency operation in case of a fault. The authors have utilized Discrete Wavelet Transform (DWT) and Fuzzy Inference Logic (FIL) to process the generated signal [12]. In April 2016, Tahir et al. evaluated the energy consumption in WSNs by proposing a scheme whereby a small number of high-energy nodes gather both location information and residual energy status of the sensing nodes, and then they transmit to the Base Station (BS). The authors proposed an algorithm in which a small percentage of high-energy nodes are used to convey each node's information to BS [13].

Distributed approach trades off the resources of centralized detection for quicker and more localized detection and healing. Distributed fault detection uses spatial data for detecting its faulty data and possibly diagnoses this failure [14]. In 2011, the authors in [15] studied a distributed hardware fault detection and node management in WSN through cellular automata method. Also, a distributed solution was used for identifying hardware faults in WSNs is presented in [16]. Based on the proposed schema in [16], an online-distributed fault diagnosis and healing algorithm for WSNs is provided in [17]. This work explicitly took into account the possibility of faults in different sections of sensor networks and communication channel. The diagnostic local view was obtained by exploiting the spatially correlated sensor measurements. These local views were then disseminated using a spanning tree of cluster heads. In [18] a study that independently analyzed the behaviors of sensor components by a distributed model based on Petri nets while the links of the sensor's components were investigated is provided by means of the correlation graph. In addition, an Effective Fault Detection and Routing (EFDR) [19] scheme for WSNs is proposed. EFDR is a distributed data routing schema capable of detecting the hardware failures, by neighbor node's temporal and spatial correlation of sensing information. Data routing scheme used L-system rules to determine optimal routing path between cluster head and base station (sink). Moreover, EEFCA [20] is proposed as a distributed algorithm to design an energy efficient cluster base WSN. In addition, EEFCA provided a local recovery mechanism for the orphan sensor nodes, which are generated due to the failure of any cluster head.

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