ARTICLE IN PRESS

Journal of King Saud University – Computer and Information Sciences (2016) xxx, xxx–xxx

King Saud University

Journal of King Saud University – Computer and Information Sciences

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An ANFIS estimator based data aggregation scheme for fault tolerant Wireless Sensor Networks

Sasmita Acharya [a,*], **C.R. Tripathy** [b]

[a] *Department of Computer Application, Veer Surendra Sai University of Technology, Burla, India*
[b] *Department of Computer Science and Engineering, Veer Surendra Sai University of Technology, Burla, India*

Received 28 July 2016; revised 9 September 2016; accepted 3 October 2016

KEYWORDS

Wireless Sensor Networks;
Fault tolerance;
Data aggregation;
ANFIS;
Estimator

Abstract Wireless Sensor Networks (WSNs) are used widely in many mission critical applications like battlefield surveillance, environmental monitoring, forest fire monitoring etc. A lot of research is being done to reduce the energy consumption, enhance the network lifetime and fault tolerance capability of WSNs. This paper proposes an ANFIS estimator based data aggregation scheme called Neuro-Fuzzy Optimization Model (NFOM) for the design of fault-tolerant WSNs. The proposed scheme employs an Adaptive Neuro-Fuzzy Inference System (ANFIS) estimator for intra-cluster and inter-cluster fault detection in WSNs. The Cluster Head (CH) acts as the intra-cluster fault detection and data aggregation manager. It identifies the faulty Non-Cluster Head (NCH) nodes in a cluster by the application of the proposed ANFIS estimator. The CH then aggregates data from only the normal NCHs in that cluster and forwards it to the high-energy gateway nodes. The gateway nodes act as the inter-cluster fault detection and data aggregation manager. They proactively identify the faulty CHs by the application of the proposed ANFIS estimator and perform inter-cluster fault tolerant data aggregation. The simulation results confirm that the proposed NFOM data aggregation scheme can significantly improve the network performance as compared to other existing schemes with respect to different performance metrics.

1. Introduction

The Wireless Sensor Networks (WSNs) consist of a large number of small, low cost, limited energy and autonomous sensor nodes which are randomly deployed in different areas of interest. The sensor nodes are usually organized into different clusters in order to conserve energy in data transmission and to prolong the network lifetime. The Non-Cluster Head sensor nodes (NCHs) sense the environment for some phenomenon of interest, collect data and forward them to their Cluster Heads (CHs). The CH node performs in-network data aggregation and then forwards the aggregated data to the base

* Corresponding author.
E-mail addresses: talktosas@gmail.com (S. Acharya), crt.vssut@yahoo.com (C.R. Tripathy).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksuci.2016.10.001
1319-1578

station through single or multiple hops depending upon the network topology. The WSN is used widely in many applications which include search and rescue operations, battlefield surveillance, environmental monitoring, forest fire monitoring, and home automation and weather monitoring.

Generally, the WSNs are designed to operate in harsh environments with the minimum human intervention. A sensor node has to rely on its limited battery power due to the limited resources in WSNs. There are many factors that may cause the failure of a WSN. A WSN may fail due to the malfunctioning of some of its components that may be hardware or software faults, faults in the network communication layer or the application layer or may be due to battery depletion etc. The fault tolerance refers to the ability of a system to perform at a desired level even in the presence of faults. A number of research papers have been published in the area of fault detection and recovery in WSNs (Javanmardi et al., 2012; Jiang, 2009; Chang et al., 2013; Xu et al., 2014). But most of these mechanisms consume lots of extra energy for fault detection and recovery and even some require additional hardware and software resources for the same. The problem arises when a cluster has a large number of faulty NCH nodes that transmit their faulty data to the CH and finally to the base station. This makes the entire network unreliable for future data transmission and in severe cases, the network may collapse.

This paper proposes an ANFIS estimator based data aggregation scheme called Neuro-Fuzzy Optimization Model (NFOM) for fault tolerant data aggregation in WSNs. The proposed scheme employs an Adaptive Neuro-Fuzzy Inference System (ANFIS) estimator for intra-cluster and inter-cluster fault detection for different fault cases. The ANFIS estimator takes some fuzzy inputs from the sensor node parameters and generates a fuzzy output by the application of fuzzy rules. The generated fuzzy output is then fed to a defuzzifier which returns a crisp output about the sensor node status. The CH acts as the intra-cluster fault detection and data aggregation manager. It identifies the faulty NCH nodes in a cluster by the application of the proposed ANFIS estimator. The CH then aggregates data from only the normal NCHs in that cluster and forwards it to the high-energy gateway nodes. The gateway nodes act as the inter-cluster fault detection and data aggregation manager. They identify the faulty CHs by the application of the proposed ANFIS estimator. The faulty cluster is then isolated and not allowed to participate in the data aggregation process. This pro-active approach prevents the network from partitioning into disjoint segments due to faulty clusters. The faulty CH is then replaced by its nearest one-hop neighbor with maximum residual energy.

The paper also compares the relative performance of the proposed NFOM scheme with Distributed Fault Detection (DFD) Jiang, 2009, Low Energy Distributed Fault Detection (LEDFD) Xu et al., 2014, Majority Voting (MV) Javanmardi et al., 2012 and Fuzzy Knowledge based Fault Tolerance (FTFK) Chang et al., 2013 through simulation with respect to different performance metrics and the simulation results are discussed. The related work is presented in Section 2. The grid cluster WSN model and the proposed fault model are presented in Section 3 as the system model. An overview of the ANFIS estimator and the proposed ANFIS estimator based data aggregation scheme NFOM, NFOM mechanism and the algorithm are presented in Section 4. The simulation results are presented and discussed in Section 5. The Section 6 presents the concluding remarks and the future scope for further research.

2. Related work

This section outlines the different distributed fault detection and recovery techniques used in WSNs and their relative advantages and disadvantages.

A routing protocol known as the Threshold sensitive Energy Efficient sensor Network protocol (TEEN) for reactive networks is discussed in Manjeshwar and Agrawal (2009). This protocol lacks mechanism to handle node failures and is not suitable for real-time applications. An intelligent sleeping mechanism (ISM) for WSNs is discussed in Hady et al. (2013) where the base station decides on which clusters to be set to sleep mode in a specific round depending on the significance of the data sent by that cluster to the base station.

The Dual Homed Routing (DHR) mechanism discussed in Jain et al. (2008) is efficient in case of Primary Cluster Head (PCH) failures but consumes a lot of energy in transmitting data twice to the PCH and the Backup Cluster Head (BCH) nodes simultaneously. The Informer Homed Routing (IHR) mechanism proposed in Qiu and et al. (2013) is an improvement over DHR in which the Non-Cluster Heads (NCHs) send data only to the Primary Cluster Heads (PCHs). A reinforcement-based Q-Learning technique for routing in WSNs is discussed in Sharma et al. (2012).

The Low Energy Adaptive Clustering Hierarchy (LEACH) presented in Kaur and Saini (2013) gives a mechanism to avoid out-of-power node failures in micro-sensor networks. This mechanism only extends the lifetime of the network but fails to reduce the data loss due to node failures. The Hybrid Energy Efficient Distributed Clustering (HEED) clustering algorithm proposed in Younis and Fahmy (2004) is an improvement over LEACH where a hybrid function is used to periodically select cluster heads based on the residual energy of a node and its proximity to its neighbors or nodal degree. Different energy efficient fault tolerance mechanisms are discussed in Jeevanandam et al. (2014), Heinzelman et al. (2002), Attia et al. (2007). A scheme to provide continuous sensor services against random node failures called R-Sentry is discussed in Yu and Zhang (2007). This scheme has the disadvantage that it incurs extra communication overhead between the sentry and the active nodes periodically. Further, the sentry nodes do not collect any data.

An analytical model for WSNs with sleeping nodes is discussed in Chiasserini and Garetto (2006). The sensor nodes of this WSN may enter into sleep mode corresponding to low power consumption or reduced operational capabilities like low battery life. A novel approach for faulty node detection in WSNs using fuzzy logic and majority voting technique is discussed in Javanmardi et al. (2012). An improved Distributed Fault Detection (DFD) scheme to check out the failed nodes in the network is discussed in Jiang (2009). The DFD scheme works by exchanging data and mutually testing among neighbor nodes in the network. But when the number of neighbor nodes is small and the node's failure ratio is high, the fault detection accuracy of a DFD scheme decreases rapidly. A Fault Tolerance Fuzzy Knowledge based control algorithm (FTFK) is discussed in Chang et al. (2013) which detects faulty communication between sensor nodes and provides Fault