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Adaptively fault-tolerant topology control algorithm for wireless sensor networks

YIN Rong-rong (✉), LIU Bin, LI Ya-qian, HAO Xiao-chen

School of Electrical Engineering, Yanshan University, Qinhuangdao 066004, China

Abstract

Fault tolerance is one of the critical characteristic of wireless sensor networks (WSNs). The most of researches on fault-tolerant topologies are concentrated on graphics structure properties. However, some attributes of sensor nodes neglected have the same decisive role in topology tolerance. In this paper, by analyzing effects of node attributes on topology tolerance, we presented a new fault-tolerant measurement index, fault-tolerant degree. Then an adaptively fault-tolerant topology control algorithm was proposed to allocate networks resources reasonably. In the algorithm, nodes with higher fault-tolerant degree are selected as backbone nodes, and each backbone node has the backup nodes for promoting performances of networks, including energy efficiency and fault-tolerant capability. Theoretical analysis and simulation results show that the algorithm is efficient and reliable to construct and maintain the fault-tolerant topology for networks.

Keywords wireless sensor networks, topology control, fault-tolerant, node attributes, backup nodes

1 Introduction

WSNs are composed of a large number of tiny sensor nodes that can self-organized network whenever and wherever [1]. In practical applications, WSNs are usually deployed in unattended remote and hostile surroundings. When some nodes fail, it could produce networks partition, reduce the availability of networks and even lead to networks failure. Therefore, WSNs must have better tolerance performances to avoid networks partition [2].

The fault-tolerant topology control is to construct the topology with reasonable coverage and connectivity, which can simultaneously content to energy-saving and tolerating fault requirements [3]. Recent works on fault-tolerant topology control are focus on the problems of looking for multiply connected graph [4]. They avoid networks partition based on the topology structure properties (multiple connected). But the real fault-tolerant capability of networks is greatly diminished as the result of ignoring the attributes of sensor nodes (e.g. energy consumption and reliability condition).

In this paper, we introduced the conception of fault-tolerant degree for quantization of node tolerance on which an adaptive fault-tolerant topology control (AFTC) algorithm was presented. AFTC algorithm considers differ in nodes tolerance, and it also reserves backup nodes for the backbone nodes in networks to solve the defects of serious interference and limited fault tolerance of multiply connected topologies. Compare with previous approaches, the contributions of this paper are as follows:

1) Node tolerance is distinguished in networks, and the fault-tolerant degree is used to quantize it.

2) AFTC algorithm is proposed, which considers the node tolerance and topology structure factors together.

3) Topology derived from AFTC can survive in consecutive failures by using the backup nodes instead of fault backbone.

The rest of this paper is organized as follows. In Sect. 2, we review some existing fault-tolerant topology control algorithms. In Sect. 3, we give the description of the problem definition. In Sect. 4, we present the fault-tolerant

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Corresponding author: YIN Rong-rong, E-mail: yrr@ysu.edu.cn
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degree to evaluate the node tolerance. In Sect. 5, we show the AFTC algorithm to construct a fault-tolerant topology. And provide theoretical analysis and simulations of AFTC in Sect. 6. Finally, we conclude the paper in Sect. 7.

2 Related work

In *k*-connected graph, the residual graph is still connected after deleting $k-1$ nodes arbitrarily, i.e., *k*-connected graph can tolerate $k-1$ fault nodes. Considering the fault tolerance of *k*-connected graph, some references about fault-tolerant topology are beginning to emerge.

Li et al. studied the relation between transmission radius of nodes and the probability that the resulted network is (k+1)-connected [5]. Hajiaghayi et al. considered the problem of constructing the *k*-connected topology while minimizing power consumption [6]. Li et al. proposed a distributed topology control algorithm FLSS_k to construct *k*-connected topology by minimizing the maximum power of nodes [7]. However, only on condition that the topology is a *k*-faults tolerant deployment, the topologies formed by above algorithms are *k*-faults tolerance.

For general planar graph, Shi et al. introduced the concepts of preserving maximum *k*-connectivity between two nodes [8]. Saha et al. and Wan et al. further constructed the *k*-connected topologies for mobile and heterogeneous networks [9–10]. They produced *k*-connected topology with optimal energy to tolerate k-1 fault nodes by power control. But the topology gotten based on these methods are so dense that radio interference is increased rapidly.

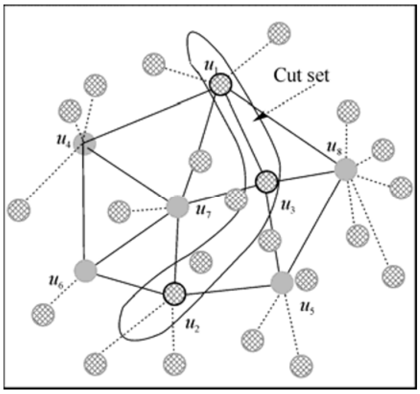
A connected dominating set (CDS) working as a virtual backbone is an efficient routing, broadcasting and collision avoidance way. So, most of researches on the fault-tolerant CDS topology problem have been developed. In Ref. [11], Dai et al. proposed three localized algorithms to construct *k*-connected *k*-dominating topology. Considering the nodes with different status (dominating and dominated), Wang et al. introduced the problem of constructing 2-connected 1-dominating set topology [12], Li et al. proposed a distributed algorithm for constructing *k*-*m*-CDS topology [13].

In summary, they take connectivity $k(k,m)$ as the standard to evaluate the topology tolerance. The topology tolerance increases with the adding of connectivity $k(k,m)$. So the deficiency of higher energy consumption is existent. To improve energy efficiency of topology, Chen et al. presented the fault-tolerant topology algorithm P-CDS with efficient power. The topology derived by P-CDS can be recovered by using the backup nodes to substitute for fault backbone nodes. For failure-free operation, the backup nodes remained in the dormancy state [14]. But P-CDS algorithm chooses $k-1$ backup backbone node sets for the backbone of networks, that is to say, the P-CDS keeps the same tolerance requirement for each node, which brings overabundant energy consumption into fault-tolerant topology.

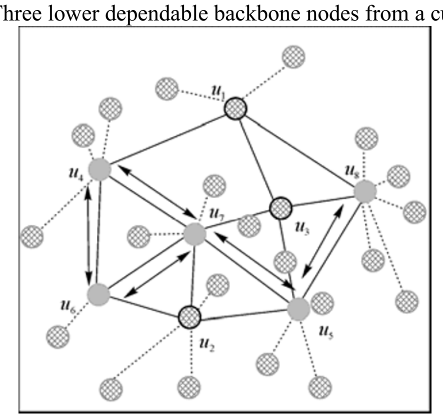
3 Problem statements

The problem of the fault-tolerant topology control in WSNs has been interpreted as $k(k, m)$-connected graph. But there is certain limit in topology tolerance only considering structure characteristics.

Generally, WSNs are abstracted into a two-dimensional graph $G(V,E)$, in which V is the set of nodes and E is the set of wireless links. Considering the nodes possess different attributes because of malfunction probability, energy deplete ratios and communicating ability etc., we denote graph (Fig. 1) with three lower dependable backbone



(a) Three lower dependable backbone nodes from a cut-set



(b) Three lower dependable backbone nodes do not constitute cut-set

Fig. 1 Effect of node attributes on topology tolerance