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Restoring Virtual Backbone of Wireless Sensor Network using Position Restricted Relay Nodes

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Abstract

In Wireless Sensor Network (WSN), sensor nodes send sensed data through multi-hops involving intermediate relay nodes. Construction of virtual backbone (VB) of sensor network is preferred to reduce the energy depletion of the WSN. The VB brings substantial benefits by simplifying routing and topology control. In WSN, sensors are prone to failure, due to power depletion or some other reasons. Therefore, the existing VB may be partitioned into segments after failure. Hence, re-construction of VB is an important issue in sensor network. This can be achieved either by discovering alternate backbone or by redeployment additional new relay nodes to restore the VB. This paper proposes an efficient strategy for restoring VB by connecting disconnected VBs using minimum relay nodes. Finding the optimal number of relay nodes and their positions is NP-hard, heuristic algorithms are proposed to minimize the repairing cost.

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Keywords: Virtual Backbone Repairing, Network Repair, Connected Dominating Set, Wireless Sensor Network

1. Introduction

Wireless Sensor Networks (WSN) have been used intensively in industry, agriculture, transportation, civil infrastructure, and security. Each sensor node includes different types of sensors to sense environmental data and passes them to a base station through multi-hop communication. Depending on the communication range of the sensors a communication network topology is formed. Two nodes are connected by an edge if they are within their communication range. Hierarchical or cluster based routing methods are proposed in wireless networks, in which a subset of nodes is selected to form the backbone of communication layer. It simplifies the topology of the network and

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saves energy for data gathering and forwarding. In order to improve the lifetime of a WSN algorithms are proposed to construct optimal virtual backbone.

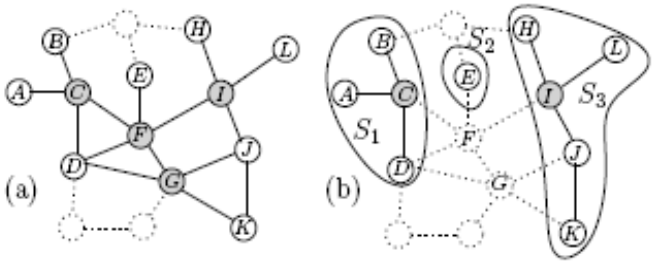

Fig. 1. Broken VB and disconnected network after failure of F,G

There are different schemes for constructing Virtual Backbone (VB) of a sensor network. In this paper, we consider connected dominating set based VB [13], [12]. A VB corresponding to a WSN is formed by a subset of sensors D such that communication sub-graph induced by D is connected and any sensor node either a member of D or communication neighbour to a node in D. Sensed data by the sensors can be routed to their corresponding destinations through the nodes in D only. This is known as backbone based routing, or dominating set based routing. Restricting routing to the nodes in D significantly reduces message overhead and eliminates transmission of redundant information.

Sensors are prone to failure due to drainage of battery power or external environmental hazards. To ensure robustness of the backbone existing literature constructs k-connected dominating set [3], [4]. Due to harsh environments, WSNs may suffer from a large-scale damage that causes many nodes to fail simultaneously and the network is partitioned into multiple disjoint segments. For example, in battlefield surveillance application, enemy explosives may destroy many nodes, or sensors are covered under sand/snow after a storm. In such cases, proactive strategies (deployment of redundant sensors) during network set up time are not suitable.

In this paper, we propose virtual backbone repairing algorithm after sensor nodes failure. An example of a sensor network and its corresponding segmented network after node failure is shown in Fig 1(a) and (b). Dotted circles denote vacant position of sensors for future deployments. Initially the network is connected and the sensor nodes C, F, G, I form the VB for the network. After the failure of two dominators nodes F, G the network is partitioned into three disjoint segments S1, S2 and S3 as marked by solid lines in Fig 1(b). Dotted communication links denote broken links. Uses of relay nodes are popular to interconnect partitioned network. In this work, our objective is to deploy minimum relay nodes to reform our broken VB.

Contribution: The main contributions of the paper on backbone restoring are as follows:

- It introduces VB repairing problem after sensor failure.
- It interconnects disconnected backbones using minimum relay nodes.

The rest of the paper is organized as follows. Section 2 briefly describes related work of the paper. Section 3 describes network model and problem statement. Our localized algorithm to restore backbone for individual connected component in the network and centralized relay node placement algorithm to reconnect disconnected backbones is discussed in Section 4. Section 5 concludes the paper and describes some of its future works.

2. Related Work

In [14] a backbone formation algorithm is proposed for prolonging network lifetime in wireless sensor networks. A node is selected as a member of backbone based on two parameters (i) degree of the node and (ii) remaining energy of the node. If the degree of a node is more than degree constraint and energy of a node is less than energy constraint, the node will not be selected for backbone formation.

Deployments of relay nodes (RN) are considered as a solution to meet various desired quality of network topology in sensor network [7], [11]. Mei et. al. [5], have proposed sensor replacement algorithm using mobile robots. Neighbouring sensors of the failed sensor detect failures and report to robots. Robots move and replace failed nodes with new sensor. In [6], Lloyd et. al. deploy the minimum number of RNs such that sensors can reach at least one RN, and the inter-RN network is strongly connected. The authors proposed polynomial time approximation algorithms