Reliability of Ad Hoc Networks with Imperfect Nodes

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Abstract. In this paper we present a new network reliability measure that is useful to evaluate performance of ad hoc networks with imperfect nodes and perfectly reliable links. An ad hoc network is modeled as undirected probabilistic graph. It is assumed that a network contains initially excessive amount of nodes to provide properly functioning of the network. That is, we consider the networks which carry on work acceptably even if some amount of nodes fails. Nodes unavailability can be caused by scuffing or intrusions. We define the reliability of such network as the probability that sink nodes are connected and can collect data from other nodes which amount exceeds a specified threshold limit. The method for new reliability measure calculating is obtained. It is shown that this method can be used for optimal sink nodes placement in networks in order to obtain the most reliable version of network topology. The provided approach can be used for performance analysis of attacks against wireless sensor networks.

Keywords: ad hoc networks, wireless sensor networks, network reliability, random graph connectivity.

1 Introduction

The area of wireless ad hoc networks has received a lot of attention in the research community over the past several years. Research on generic wireless ad hoc networking also ramified to special types of networking like wireless mesh networks, wireless sensor networks, vehicular networks, radio frequency identification networks etc. In this paper we study a problem of reliability in these networks.

Probabilistic graph models have been used extensively in the literature for studying network reliability problems, especially in the case of unreliable edges [1–12].

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A case of unreliable nodes was a subject for studying too [13, 14]. However these studies do not usually take into account the specificity of wireless ad hoc network. The reliability of wireless sensor network with unreliable nodes was subject of study in [15]. In this research the reliability criterion is defined as all nodes connectivity. A method of sensors lifetime maximizing under required level of network reliability is offered. The reliability and survivability models for wireless sensor has been considered in [16]. Given these models, once can calculate the probability that a node is imperfect.

Some works [17, 18] have been proposed, in which area coverage reliability of wireless sensor networks is studied. In [19] the task of reliability of wireless distributed sensor networks is considered. Reliability is defined as the probability that there exists an operating communication path between the sink node (command node), and at least one operational sensor in a target cluster. A three-state node reliability model for sensor networks has been proposed in [20]. This model allows node to be in a state where only the wireless module is operating and a sensing module is failed. Thus, in this state a node can only relay traffic among its neighbours without generating its own data. The problem of events detecting with given level of reliability using the minimal number of network nodes is considered in [21].

In this paper we offer a novel concept of ad hoc network reliability, which has not been discussed in the previous works. We consider ad hoc networks with imperfect nodes and perfectly reliable links. Nodes unavailability can be caused by scuffing or intrusions. An operational probability is associated with every node. It is assumed that the node failures are statistically independent. At the same time, if any two operable nodes are within a communication range then the nodes communicate with each other without any losses.

A special feature of our model is that network contains initially excessive amount of nodes to provide proper functioning of the network. The failure of one or more nodes can cause the operational data sources to be disconnected from the data sink nodes (command nodes). However, operational nodes in the faulty nodes neighborhood may still be able to communicate with end-users, although, through a larger number of hops resulting in a larger delay of the information. For example, wireless sensor network may work acceptably even if some amount of nodes fails. In other words, it works until there is a sufficient number of workable nodes which are connected to any sink node. Another requirement for the network operation is the connectivity of sink nodes through workable nodes. We define the reliability of such network as probability of the proper functioning in the above meaning.

The rest of the paper is organized as follows. In section 2 the basic notations and definitions are presented. Sections 3, 4 describe the method of reliability calculation, section 5 describes numerical experiments which demonstrate optimal sink nodes placement in network. Section 6 is the brief conclusion.