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A geographic cross-layer routing adapted for disaster relief operations in wireless sensor networks☆

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ABSTRACT

Wireless Sensor Networks (WSNs) have been studied for various applications, especially for facilitating relief operations in disasters such as earthquake and fire. In this paper, we propose a new geographic cross-layer routing method in WSNs called geographic cross-layer routing adapted for disaster (GCRAD) relief operations. GCRAD integrates MAC and routing using a handshake mechanism for relay selection and considers node's queue status, distance to the sink, and the number of potential relay nodes as the relay selection criteria. GCRAD eliminates the ineffective transmissions and shortens the handshake mechanism by affecting these criteria in a single step (all of them concurrently) and also, decreases the collision probability as much as possible. Through ns2-based simulations, we show that GCRAD significantly achieves lower end-to-end delay, lower energy consumption, and acceptable delivery ratio in comparison with the state-of-the-art geographic cross-layer routing methods, especially in high traffics, which is the main characteristic of disasters.

1. Introduction

Recent advances in micro-electro-mechanical systems and wireless communications have provided the ability of designing and manufacturing sensor nodes [1]. Sensor nodes can receive information from the environment or other sensor nodes and send the gathered information to the sink. Wireless sensor networks (WSNs) consist of many sensor nodes which monitor the environment by interacting and cooperating with each other. These networks have the advantages such as scalability, reliability, flexibility as well as low cost and easy placement compared with the conventional networks [2]. These advantages led to the wide use of WSNs in various applications ranging from environmental and military monitoring to commercial and health applications. Nevertheless, sensor nodes forming the WSNs have some constraints such as limited power and memory, short-range communications, low bandwidth, and weak processing functionality. In addition to the mentioned applications, WSNs are used for relief operations in disasters such as earthquake and fire [3–8]. The frequent occurrence of such disasters proves that an effective system can help to manage the disaster relief operations and save hundreds of lives. As far as we aware traditional techniques such as using dogs in disaster relief operations are ineffective and time-consuming [5]. Therefore, in such applications, WSNs can facilitate the relief operations by localizing trapped persons and identifying risky areas [9].

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In order to use WSNs in disaster relief operations, sensors should be placed in the environment and then send the sensed data to the sink. Therefore, routing problem of the sensed data from the source nodes to the sink is one of the most important issues for realizing WSNs applications. Investigating existing routing methods, which are used in the disaster relief operations projects [4,5,8], show that central routing methods are exploited in them. In these methods, a large number of control packets should be exchanged to establish a path from the source nodes to the sink. Therefore, these methods suffer from the overhead of the high control packets, which cause high energy consumption and delay. Consequently, such routing methods are not suitable for satisfying the disaster management requirements, including minimum delay and energy efficiency in high traffics, and new ones are needed to be provided.

Among the existing routing methods, geographic routing methods have received special attention as a routing solution in WSNs. In the geographic routing method, it is assumed that each node is aware of its location using some special mechanisms such as the global positioning system (GPS) or localization solutions [10,11]. Moreover, it uses a distributed method to select the next hop and it is based on the location information of the source node, one-hop neighbors, and the sink. Geographic routing methods deliver data by exploiting local information, therefore, these kinds of methods have low overhead of control packets and low energy consumption [9,12]. In the following, two geographic routing approaches, namely traditional and cross-layer are discussed.

Traditional approaches [13–18], consider node's energy and distance to the sink for selecting the relay node. In these methods, other features like node's queue status are not considered. Thus, congestion and packet dropping can occur in traditional approaches. On the other hand, in cross-layer approaches [19–24], in addition to the routing layer, features of some other layers, such as physical, MAC or transport layers are considered in the relay node selection. Since cross-layer approaches reduce the overhead and the consumed energy by sharing the data among different layers [25,26], they are much more useful, energy efficient, and scalable compared with traditional ones. In literature, many examples can be found, in which the MAC and the routing layers operate jointly to enable the relay selection. Some cross-layer routing methods [18,21–23,27] use a handshake mechanism to select the relay node according to the criteria such as node's energy, distance to the sink, and delay. In [20,24,28], node's queue status is another criterion that is considered beside the mentioned criteria. Considering node's queue status in relay selection process helps for congestion control. However, in the existing cross-layer routing methods, there are two main problems; first, relay selection criteria are affected sequentially. This sequential affection imposes some undesirable priority to the relay selection process and the criterion, which is used in the first step of the relay node selection process, gets higher priority than others. The second problem is high collision probability, due to the ignorance number of potential relay nodes which are located in the forwarding area of the source node. Both of the mentioned problems are discussed in details in Section 3.1.

With the goal of resolving the mentioned problems, in this paper, we propose a new cross-layer routing method named geographic cross-layer routing adapted for disaster (GCRAD) relief operations. Firstly, GCRAD removes the undesirable imposed priority by jointly affecting the relay node selection criteria such as node's distance to the sink and its queue status in a single step. Moreover, GCRAD suggests a criterion named potential relay number (PRN) for decreasing the probability of collision occurrence. Our simulation results in ns2 show that GCRAD decreases delay and energy consumption significantly in comparison with the state-of-the art methods. Although we face with a little reduction in the delivery ratio in GCRAD, it is negligible compared with a remarkable improvement in end-to-end delay and energy consumption. Thus, the achieved results prove the efficiency of GCRAD in satisfying disaster relief operations requirements, where real-time communication and minimum energy consumption are required in high traffics.

The rest of this paper is organized as follows: Section 2 reviews the state-of-the-art on the existing WSN-based disaster relief projects and geographic routing approaches. GCRAD is described in Section 3. Section 4 shows the analyses and simulation results of GCRAD in comparison with state-of-the-art methods. Finally, Section 5 concludes the paper.

2. Related works

In this section, at first, we briefly review some routing methods used in disaster relief operations. Then, we review two related approaches of the geographic routing protocols, namely traditional and cross-layer.

2.1. Routing methods used in disaster relief operations

SENDROM [5] is one of the well-known projects which has used WSN for the management of disaster relief operations. In this project, there are some collector nodes which are responsible for sending the sensed data to the sink. The routing method of SENDROM consists of two major steps, namely task dissemination and data dissemination. In the task dissemination step, the collector node broadcasts the tasks and makes nodes switch from an idle mode to an active mode. By receiving the tasks, each node starts to sense and report the sensed data to the collector node. In the data dissemination step, the sensed data is routed to the collector node which has disseminated the task. Moreover, the power efficient paths are selected by the collector node through a controlled flooding process. Saha and Matsumoto [8], proposed a framework for disaster relief operations which is based on SENDROM. According to this method, the next hop is selected based on the minimum angular deviation on the way to the collector node. As discussed, routing methods provided in the existing disaster relief operations projects are a kind of central methods in which a disruption occurrence in one collector node leads to connection disruption in that region. Also, exchanging of an excessive number of routing packets causes overhead to the