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A distributed routing for wireless sensor networks with mobile sink based on the greedy embedding

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ABSTRACT

Mobile sinks can be a solution to solve the problem that energy consumption of sensor nodes is not balanced in Wireless Sensor Networks (WSN). Caused by the sink mobility, the paths between the sensor nodes and the sink change with time. It is necessary to find a protocol that can find efficient routings between the mobile sink and sensor nodes but do not consume too many network resources. In this paper, we propose an algorithm called virtual-node greedy embedding (VGE) to embed the topology of a WSN into hyperbolic plane without the physical geographic information. This algorithm gives each node a virtual coordinate that guarantees the greedy forwarding of the packets from sensor nodes to the sink when there is no failed node in WSN, even if some obstacles exist in the network. VGE keeps the greedy property when new nodes join the network after the initial embedding and does not change the node coordinates assigned previously. Based on the characteristic of embedding process, modified gravity-pressures (MGP) algorithm is proposed to find a routing path quickly when there are some failed nodes in WSN. Furthermore, particular solutions of the parameters in VGE are presented with concise style, and the simulations show that our algorithm has an efficient performance.

1. Introduction

A Wireless Sensor Network (WSN) is composed by many sensor nodes and one or multiple sinks. It gathers data from the sensing environment. However, if the sink involved in collecting data is static, the sensor nodes that are close to the device would become hotspots (also called energy holes) and die earlier than others, because they have to transmit huge amounts of data for other sensor nodes [1]. One method to avoid the formation of energy holes is to use sink mobility. The sensor nodes can take turns to become the neighbors of the sink due to the sink mobility, so the energy is consumed evenly among the sensor nodes, and the lifetime of the entire network can be prolonged [2].

There is a lot of research on the moving strategy of mobile sinks [1–8]. Almost all of them use the routing based on the physical locations of nodes for data transmission (e.g., [1–3,5–8]). It is important to choose a routing protocol for WSN with a mobile sink, because the efficient routing paths between the sensor node and the sink change with time. The greedy forwarding is a candidate because it is simple and efficient about data transmission in WSN. In greedy forwarding, each node just needs to know three pieces of information: its location, the location of neighbors, and the location of the sink. In the WSN with mobile sink, the first two pieces are fixed and the location of the sink could be broadcasted to the nodes with a virtual

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backbone [9]. However, greedy forwarding may lead into a dead end when there is no neighbor closer to the destination, and recovery strategy such as GPSR [10] is necessary to guaranty data packets can be delivered to the destination.

But, what if we cannot get the physical location of the node? In some scenarios, the limitations of environment, devices or the funds for devices bring challenges to deploy positioning equipment. Thus, a routing protocol that does not depend on geographical position information is needed. The tree-based routing protocol is an appropriate choice because it just depends on the links between nodes. However, the fixed tree-based routing protocol is not efficient when we consider the mobile sink, as shown in Fig. 1. In this figure, triangle represents mobile sink, solid line represents link that is contained in the tree and dotted line represents link that is not contained in the tree. In this paper, the dotted line is called crosslink because it connects different subtrees. A subtree of node w, which is denoted by subtree(w), is a tree consisting of w and all of its descendants in T.

In Fig. 1(a), each sensor node has a shortest routing to sink in the network when sink situates the areas near node a. But, as Fig. 1(b) shows, most of the sensor nodes have a stretched routing to the sink when the sink moves to the areas near node d. The tree should be reconstructed if we need to keep the shortest routing. However, the reconstruction cost is very high in terms of energy consumption and communication load [11].

In this paper, a greedy embedding algorithm called virtual-node-based greedy embedding (VGE) is purposed to give nodes virtual coordinates. And a routing algorithm called modified gravity-pressure (MGP) is proposed to transmit data packet. Combing VGE and MGP, we get a routing algorithm (called VGE–MGP) to gather date efficiently in a WSN with mobile sink and do not need the physical locations of sensor nodes. Based on a spanning tree of WSN, VGE embeds the WSN into a hyperbolic plane. After the embedding process, there is always a greedy path between any two nodes of the network if there is no failed node in the network. Furthermore, VGE supports the additions of new nodes after the initial embedding, and the node coordinates assigned previously do not need changes to retain the property of greed. In MGP, a heuristic method is proposed to solve the outer failure mode which is caused by the failure of nodes.

In sum the contribution of this paper can be listed as follows. First, a novel greedy embedding algorithm, VGE, which use virtual nodes to support the online additions of new nodes, is proposed. Second, particular solutions of the parameters in VGE are presented with a concise style. Finally, a routing protocol, MGP, is proposed according to the characteristic of embedding process to efficiently deliver the date packet.

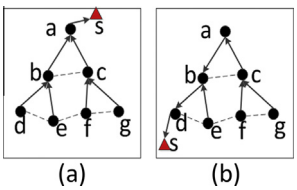

Fig. 1. Examples of tree-based routing.

This paper is organized as follows. Section 2 reviews the related work. Section 3 presents the VGE algorithm in detail and gives particular solutions to the embedding parameters. Section 4 describes the routing when there is a failure of greedy forwarding. Section 5 evaluates the performance of the VGE–MGP by comparing it with other routing protocols. Finally, the conclusion is presented in Section 6.

2. Related work

Various routing protocols have been proposed for the WSNs with mobile sinks. In [12], Nazir proposes the Mobile Sink based Routing Protocol (MSRP) in which the sink movement strategy depend on the residual energy information from the cluster-heads and takes the movement based on the residual energy of the cluster-heads [12]. In the Local Update-based Routing Protocol (LURP) [13], a broadcast protocol is proposed to resolve the problem that frequent location updates from the sink can lead to both rapid energy consumption of the sensor nodes and increased collisions in wireless transmissions [13]. Another similar algorithm called virtual circle combined straight routing (VCCSR) is presented in [14]. With the help of a virtual backbone, VCCSR establish regular update paths for updating the location of mobile sink. But, there are some limitations about the density of networks and trajectory of mobile sink. Yang et al. [15] presents a protocol which is based on a swarm agent that integrates the remaining energy of nodes into the route selection mechanism and maximizes the network's lifetime by evenly balancing the remaining energy across nodes. In [16], Gu et al. build a unified framework for analyzing joint sink mobility, routing, delay, and discuss the induced sub problems and present efficient solutions for them.

However, the above protocols need the physical geographic information of nodes to find a routing. But, in some scenarios, various limitations bring challenges to the deployment of positioning device. Routing protocol that based on virtual coordinate is proposed for avoiding using physical locations of nodes. Combining those virtual coordinates based routing with mobile sink in WSNs is available because most of those protocols rely mainly on greedy forwarding, followed by a backtracking scheme to overcome local minima. And, the information that used in the routing is localized and distributed, thus, those routing protocols adjust the location changes of mobile sink.

Rao et al. [17] proposes an algorithm to assign a virtual coordinate for geographic-like greedy forwarding. It exploits a heuristic algorithm to determine the perimeter nodes and use relaxation algorithm to determine each node's virtual coordinate that used for performing geographic routing. Nevertheless, it does not guarantee the delivery of data packets and requires heavy construction overhead [18].

In [18], a location-free point to point routing scheme, called virtual domain and coordinate routing (VDCR), in wireless sensor networks is proposed. VDCR applies the concepts of the virtual domain and the virtual coordinate