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Reducing delay and energy consumption in wireless sensor networks by making virtual grid infrastructure and using mobile sink

Ramin Yarinezhad[a,*], Amir Sarabi[b]

[a] Department of Computer Science, Amirkabir University of Technology, Iran
[b] Department of Electrical Engineering, Islamic Azad University of Ilam, Iran

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ABSTRACT

In wireless sensor networks, sensor nodes close to sink have more traffic loads, they will quickly deplete their energy and it will finally lead to network partition and isolate the sink. To solve this problem it is possible to use mobile sink in the network. The proper use of mobile sink creates a balance in energy consumption of network. On the other hand, the sensor nodes need to know the latest position of the mobile sink to transfer their data to it. Informing the nodes about the last sink position leads to high energy consumption and increases delay in the network. In this paper, a routing algorithm based on virtual grid infrastructure and mobile sink is proposed. In the proposed algorithm, some of the nodes that are selected by virtual infrastructure keep the last position of the sink. The simulation results show that the proposed algorithm has better performance in terms of energy consumption and delay compared to similar algorithms.

1. Introduction

In recent years, wireless sensor networks (WSNs) have been used in some areas such as pollution prevention, precision agriculture, structures and buildings health, intrusions, fire/flood emergencies and surveillance. WSNs usually contain a large number of sensor nodes that each sensor node is a small device and its power supplied by a battery. Sensor nodes can collect data from their surrounding environment and transmit them to a data collection point which is called sink node or base station [1,2].

One of the most significant restrictive factors for WSNs is the limited battery power of sensor nodes. WSNs due to their applications are not accessible by humans and outside agents after deployment and the network operation should continue as autonomous. For example, in military applications a sensor network is deployed in the region to monitor enemy's actions where the enemy exists. Thus, access to the network is not possible. Therefore, the sensor nodes' batteries are not rechargeable or replaceable. This causes the algorithms for the sensor networks be different from other networks. In fact, the concept of energy consumption is one of the most important challenges in these networks [3].

Another important challenge in WSNs is energy hole problem [4,5]. Sensor nodes close to the sink have more traffic loads, because they have to participate in forwarding data to the sink for other sensors, they will deplete their energy more quickly, and it will lead to network partition and isolate the sink. This problem is called energy hole problem.

To prolong the lifetime of WSNs, the algorithms used in these networks should have energy efficiency. So far, many studies are conducted on the issue of routing in these networks. One of the main ideas exist in most routing algorithms is the use of mobile sink. Mobile sink means the position of the sink changes in the network. There are several advantages in using of mobile sink. For example, the proper use of mobile sink creates a balance in energy consumption of network, mobility of sink causes changing of its neighbors thus the energy hole problem is solved, it also creates security in the network and the use of an optimal routing algorithm could reduce delay in network [6–9].

Despite all sink's mobility advantages, it creates new challenges in WSNs. If these challenges are not addressed properly, they reduce the efficiency of wireless sensor networks. When the sink is mobile in the network, unlike the case that it is static, the network topology is dynamic because when the sink changes its position, it changes the network topology [2,13]. To overcome the dynamic topology of the network, which means the sensor nodes can deliver data to the mobile sink efficiently, they should know the last position of the mobile sink. A number of data diffusion protocols such as direct diffusion [10,14] inform sink position as flooding periodically to all sensor nodes, which leads to more conflict and huge message transmission on the network. Considering the sensor nodes' power supply limitation, the sink position should not be informed to all sensors nodes to preventing more energy

* Corresponding author.
E-mail address: yarinezhad@aut.ac.ir (R. Yarinezhad).

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consumption. Accordingly, in order that the sensor node could have a route to the mobile sink at any moment, it is possible to use virtual infrastructure as an efficient method [11,13]. For data dissemination in the network, in which virtual infrastructures is used, just a given set of nodes are responsible for keeping the position of the mobile sink.

In this paper, a novel routing algorithm is proposed for WSNs based on a virtual infrastructure and mobile sink. The proposed algorithm uses geographic routing as the underlying routing solution. Geographic routing is scalable and energy-efficient; therefore, it is an attractive routing solution for WSNs with position-aware sensors [13,14]. In geographic routing, each node needs to be aware of the sink position to send the sensed data from the environment to the sink. Accordingly, the proposed algorithm by building a virtual infrastructure, which contains several nodes, saves and updates the last sink position in this nodes and the rest of the nodes could find the last sink position by sending a message to nearest virtual infrastructure node. Some key features and the contributions of the proposed algorithm are highlighted as follows:

- In the proposed algorithm network is divided into several equal-sized cells and closest nodes to intersection of four cells save the last sink position. The main purpose of cell structure is optimal selection of nodes that save the sink position. The advantage of choice the nodes in this way is that all of them are spread in the network with proper distribution and normal sensor nodes can get the last sink position with minimum hop. On the other hand, selecting nearest nodes to the intersection of four cells instead of nodes at the center of each cell (as holder of the sink position) reduces number of these nodes. Reducing the number of nodes in this way makes the cost of updating the sink position in these nodes be less and sink could update its position at shorter intervals in these nodes, and therefore the saved position of the sink in the virtual infrastructure is always up to date. Proper distribution of these nodes and updated sink position saved in these nodes reduces energy consumption and delay in the network.
- The mechanism of updating of sink position in virtual infrastructure with minimal number of control messages can update sink position, because in virtual infrastructure in the proposed algorithm nodes selection and their communication with each other is properly.
- Virtual infrastructure can be easily repaired if it needed (high-energy reduction in an infrastructure node). Intersection Node Replacement procedure replaces the current node with an appropriate node by minimum number of control messages.
- The proposed algorithm in this paper is usable for small and large-scale WSNs with static sensors and mobile sink and also this protocol supports multiple sinks in the network.
- No information about the motion of the sink is required for proposed algorithm to operate. It does not rely on predicting the sink's trajectory, and is suitable for the random sink mobility scenarios.
- Simulation of the proposed algorithm is done to demonstrate superiority over some existing algorithms.

The rest of this paper is organized as follows: Next section describes the related work. Network model is expressed in Section 3. Section 4 presents our proposed algorithm in detail. To evaluate the performance of the proposed algorithm, simulation setup and results are presented in Section 5. Finally, Section 6 concludes the paper.

2. Related works

Several mobile sinks based data dissemination protocols have been proposed for WSNs. The proposed protocols fall in two major categories: (1) *Flooding-based* and (2) *Virtual infrastructure-based*. In general, virtual infrastructure-based protocols can be divided into (1) *rendezvous-based* approaches, and (2) *backbone-based* approaches depending on how the virtual infrastructure is formed by the set of storage nodes. All protocols discussed in this section are virtual infrastructure-based.

2.1. Rendezvous-based approaches

In most of these methods, the main focus is on the path of the sink. Mobile sink visits the proximity of sensor nodes to collect data from them.

Salarian et al. [16] proposed a heuristic algorithm for routing mobile sink in WSNs. In the proposed procedure, a series of nodes are considered as rendezvous points and other nodes should transfer their data to these nodes. Then the mobile sink finds an optimal tour includes rendezvous points. Finding an optimal tour is an NP-hard problem. So, to address this problem, a heuristic called weighted rendezvous planning (WRP) is proposed. Then the mobile sink moves on this tour and receives data from the rendezvous points. The results show that this method improves and balances energy consumption. Here the WRP algorithm is provided to solve an NP-hard problem that does not guaranty to produce an optimized tour and this makes the proposed protocol have a large delay in some implementations.

Mishra et al. [22] proposed an efficient path design algorithm for mobile sink in WSNs. This method is based on rendezvous point (RP). The target area is partitioned into hexagonal cells whose centers are considered as the potential positions of RPs. These potential positions are minimized based on several network parameters to select minimum number of RPs to form the delay bound path. Sensor nodes should transfer their data to RPs, and then mobile sink visits the proximity of RPs to collect data from them.

Kaswan et al. [23] proposed an algorithm to design efficient trajectory for mobile sink in WSNs which is applicable for delay bound applications. The algorithm is based on rendezvous points where a mobile sink visits the rendezvous points of a predetermined delay bound trajectory. The proposed algorithm determines these rendezvous points based on the routing load.

Kinalis et al. [17] proposed a routing algorithm in WSNs that uses the mobile sink. The WSN in this paper consists of a mobile sink. The mobile sink path is determined dynamically. The method to determine sink path is probabilistic. Less visited location is more likely to be the next sink position. This method has been analyzed by different simulation and test methods, authors have shown that it has a better performance than other methods but the delay in this method is relatively high.

Zhao et al. [18] have provided a protocol for gathering information on WSNs. In this protocol, there is a mobile sink in the network that moves on a predetermined path and using a heuristic algorithm, the sensor nodes send their data to the sink. The proposed heuristic algorithm in this paper finds a minimum spanning tree and using this tree, the nodes transfer their data to the sink through the multi-hop method. The use of mobile sink balances the energy consumption but the use of multi-hop data transmission in this paper increases energy consumption.

Santos et al. [25] use multiple sinks in the wireless sensor network. In this work, they consider a sensor network as a graph. Then the graph is divided into independent sets and there is one mobile sink in each set. Nodes in each set can transfer their data to the sink with less hops and this improves energy consumption in the network.

Yun et al. [26] propose a framework to maximize the network lifetime by using a mobile sink in wireless sensor network. In this framework, each sensor node that generates its data does not immediately send to the sink. To increase the network life, the sensor node waits until the sink appears in the right position and then sends its data to it. In this work, maximum lifetime problem is modeled as a linear programming problem. The constraints of this linear program are a bound on delay, node energy, and data flow.

2.2. Backbone-based

These approaches aim to decrease the load of advertising the sink's position to the network by establishing a virtual infrastructure of nodes.