Computer Networks 77 (2015) 128–143

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

ODT: Optimal deadline-based trajectory for mobile sinks in WSN: A decision tree and dynamic programming approach

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ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 18 October 2014
Accepted 1 December 2014
Available online 6 December 2014

Keywords:
Wireless sensor network
Mobile sink
Optimal deadline-based trajectory
Dynamic programming
Decision tree

ABSTRACT

Recent studies have shown that utilizing a mobile sink (MS) to harvest and carry data from a wireless sensor network (WSN) can enhance network operations and increase the network lifetime. Since a significant portion of sensor nodes' energy is consumed for data transmission to MS, the specific trajectory has a profound influence on the lifetime of WSN. In this paper, we study the problem of controlling sink mobility in deadline-based and event-driven applications to achieve maximum network lifetime. In these applications, when a sensor node captures an event, it should determine a visiting time and a deadline with respect to the amount of captured data and the type of event. MS then has to determine its trajectory to harvest data from active sensor nodes in single hop transmission so that the network lifetime is increased. We show that this problem is NP-hard when there are no predefined structures like a virtual grid or rendezvous points in the network. We propose an algorithm based on a decision tree and dynamic programming to approximately determine an optimal deadline-based trajectory (ODT). ODT is obtained by considering the geographical positions of active sensor nodes and the properties of captured events. The effectiveness of our approach is validated via the extensive number of simulation runs and comparison with other algorithms.

1. Introduction

In recent years, a number of techniques have been proposed to prolong the lifetime of wireless sensor networks (WSN) by utilizing a *mobile sink* (MS) in networks [1–7]. In many applications of WSN, the sink that is mounted on a mobile robot regularly moves across the monitored area to collect data from all sensor nodes. A significant gain in the network lifetime could be achieved by the optimum control of the trajectory of MS, see [8–16,18–21].

The sink mobility in WSN can be categorized into two main groups: random mobility based [8,9] and controlled mobility based [1,2,11,16,18,31]. For the first group, MS can move freely and randomly over the network and harvests the buffered data [8]. Although the random mobility schemes are simple and easy to implement, they suffer from shortcomings like uncontrolled behaviors and poor performance [14]. The majority of existing works is allocated to the controlled mobility. The main challenge in this category is the determination of the optimal trajectory of MS depending on the status of sensor nodes and the WSN's application. It has been shown that by designing the proper trajectory, the harvesting data via MS

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http://dx.doi.org/10.1016/j.comnet.2014.12.003

would significantly improve the network lifetime [1,11,14].

There are two main problems in the majority of the existing work in this category. The first and foremost is that the trajectory of MS has been assumed to be determined through some predefined special locations [11,16] or special nodes in hardware or resource [1,20,29,30], called *rendezvous points* (RPs). In most of the studies, RPs are predefined and independent of other sensor nodes locations. It is clear that the locations and the number of RPs have a great influence on the performance and the quality of the solution. Considering the fast mobility of MS during its movement on a trajectory, especially among RPs, is the second problem. Some previous proposals showed that the optimal trajectory of MS can be designed through mathematical optimization models based on RPs, but the majority of them avoid addressing the traveling time of MS on the selected trajectory [10,11].

In this study, we are interested in determining the optimal trajectory referred to as *optimal deadline-based trajectory* (ODT) for MS in deadline-based and event-driven applications by assuming single-hop data delivery. We do not assume pre-existing RPs or any other predefined structure. The process of designing ODT considers three main parameters: (1) the group of sensors that capture events (*active nodes* (AN) group), (2) the velocity of MS for traveling on ODT, and (3) the properties of captured data by AN: a visiting time and a deadline that are determined regarding the amount of captured data and type of event, respectively. Since the problem of determining ODT is NP-hard, as it will be proved, we divide the trajectory of MS into a limited number of steps, and then a convex programming model to obtain an optimal line segment for each step is proposed. We introduce a decision tree structure to cover the feasible solution space of ODT, and then through a dynamic programming approach, an optimal deadline-based trajectory can be achieved. Through comprehensive simulation, we show that our proposed model yields a substantial gain in the lifetime of event-driven applications with single hop data delivery.

The remainder of this paper is organized as follows. Summary of related works are reviewed in Section 2. In Section 3, we describe the system model. The problem formulation is discussed in Section 4. In the next section, we propose an approximate algorithm to determine ODT. The performance of the proposed algorithm is examined via simulation in Section 6, and finally, Section 7 concludes the paper.

2. Related works

Prolonging the network lifetime of WSN has been targeted through the mobility management of the *mobile sink* (MS) recently [1–7,23]. We can classify sink mobility into two categories: random mobility [8,9] and controlled mobility [1,2,11,16,18]. In [8], the authors proposed an approach based on the random mobility of mobile agents, called data MULEs (*mobile ubiquitous LAN extensions*), to collect buffered data of sensor nodes in sparsely deployed networks. In a similar study [9], the data of sensor nodes are harvested by a mobile agent that is flying above the sensor field. The main advantage of the proposed algorithm in this category is simplicity in implementation. However, the random mobility algorithm introduces some problems such as the buffer overflow in sensor nodes and the delay of data delivery.

The majority of existing works in sink mobility is proposed for controlled mobility. Shi and Hou in [18] addressed the sink mobility through the determination of the optimal location for MS in the network. Since this problem is NP-hard, they proposed an approximate model and extended their algorithm to support multiple MS. Basagni et al. in [16] offered a mixed integer linear programming (MILP) problem formulation to obtain an optimal trajectory of MS and the sojourn time at RPs for maximizing the lifetime of the network. However, they assumed that the routes were predetermined, and they also ignored the traveling time of MS on its trajectory.

Yun and Xia in [11] proposed a new model for increasing the network lifetime in delay tolerant applications known as the *delay tolerant mobile sink model* (DT-MSM). They determined the trajectory of MS according to the predefined RPs as the special location for data harvesting. Moreover, they assumed that the travelling time of MS between any two RPs is negligible. They extended their work in [31] by proposing an approach to distribute the proposed model in [11]. Akkaya. K et al. in [2] investigated the performance advantage of relocating MS in response to changes in the network state and traffic pattern. They determined the optimal location and time for moving MS regarding the constrained and unconstrained network traffic through an heuristic algorithm. Wang et al. in [13] proposed an approach to control multiple mobile sensors to travel among event locations and harvest data. They assumed that each mobile sensor had limited residual energy. Hence, the main problem was how to dispatch the mobile sensors among the event locations to maximize the number of rounds until some event locations could not be reached.

Konstantopouloset. C et al. in [21] addressed the sink mobility by considering the constrained path. Their proposed algorithm focused on a clustering network and routing of the captured data. The targeted application in [21] is environmental monitoring, i.e., urban park. Xing. G et al. in [12] offered an efficient rendezvous algorithm to determine the trajectory for MS. They considered a subset of sensor nodes to serve as rendezvous points that buffer and aggregate data that originated from sources and they transferred them to the MS when it arrived. They determined the trajectory of MS by considering a routing tree that rooted at RPs. The objective function was to minimize the total edge length of the tree. Although this criterion has shown significant performance on network energy consumption, it cannot guarantee the maximization of the network lifetime. In the majority of the proposed algorithms in sink mobility, the predetermined structure (like a virtual grid or RPs) was considered [14]. In [11], the authors showed that the number of RPs had a significant influence on the performance of the algorithm and the quality of the solution. However, considering the infinite number of RPs to determine at least one optimal location of a sink is an NP-hard problem [10].