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An energy efficient approach for data collection in wireless sensor networks using public transportation vehicles

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ABSTRACT

Applications of wireless sensor networks (WSNs) involve a large number of energy constrained nodes to monitor the areas of interest, where the energy efficiency is an important concern of network design. Compared to the conventional approach using multihop communication, mobile sinks (MSs) attached to public transportation vehicles, such as buses, are the ideal infrastructure for collecting sensory data. This paper studies the problem of using such MSs to collect data from sensor nodes that are nonuniformly deployed. The proposed protocol aims at balancing the energy consumption, including energy expenditure to transmit data packet and network overhead across the network, to make the network operate as long as possible with all nodes alive. We design an energy-aware unequal clustering algorithm and an energy-aware routing algorithm. Theoretical analysis and simulation results confirm the effectiveness of the proposed approach against the alternative methods.

1. Introduction

A WSN consists of a number of battery-powered sensor nodes. Energy consumption for radio transmissions corresponds to a considerable portion of the total energy consumption at sensor nodes [1]. In traditional WSNs, the sensory data is transmitted from source nodes to a centralized sink via multihop communication. A side effect of this approach is that the nodes closer to the sink are more overloaded than others. This issue is known as the funneling effect [2], since the neighbour nodes of the sink represent the bottleneck of network lifetime.

Recent studies have shown that using MSs to collect data in WSNs can relieve the funneling effect issue [3,4]. A MS traversing the sensing field can collect data from sensor nodes over a short range communication link [5,6], and then the on-board MS transmits the collected data wirelessly to a remote center, since it has no energy limitation. Long-hop relaying is not used at sensor nodes and the energy consumption is reduced. Traversing the sensing field by MS needs to be timely and efficient because failure to visit some parts of the field leads to data loss, and infrequently visiting some areas results in long delivery delay. Besides, the trajectory planning of MS in these cases become more difficult to cope with. Furthermore, in the urban areas, the planned trajectory sometimes cannot be realized since the MS is constrained to roads. Alternatively, amounting MS on a vehicle, such as a bus, avoids some difficulties and can provide better performance for data collection. First, since the bus is already a component of the environment and its trajectory is predefined, the difficult path planning and complex control of MS's movement are avoided. Second, instead of visiting each sensor node individually, which is a time consuming task due to the low physical speed of MS, combining multihop communication with path constrained MS is able to increase the data delivery delay.

This paper investigates using a MS, which is attached to a bus, to collect data in WSNs with nonuniform node distribution. Such WSNs exist in many applications. For example, in the case of monitoring the air pollution of a city, the industrial areas are usually deployed with more sensors than the residential areas. Also, since the areas of interest may be isolated from each other, using conventional data collection approaches is not appropriate due to the limited budget of energy resource. In this case, exploiting a MS amounted on a bus is able to relieve the bottleneck of energy at sensor nodes. Because the MS can serve the isolated areas at different time. It is like that there is a virtual static sink for each area and such sink only works at specified time duration. The specified time duration is the duration during which the MS is in the area. Instead of the coverage problem studied in our previous work [7–9], the focus here is on routing the sensory data from source

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nodes to MS in an energy efficient way such that the energy expenditure is balanced across the entire network.

The main contributions of this paper are a clustering algorithm and a routing algorithm. The core of the clustering algorithm lies in the selection of cluster heads (CHs). With the aim of balancing energy consumption, we design unequal cover ranges for CHs considering the feature of nonuniform node distribution. The cover range of a CH depends on its distance to MS and the local node density. Unlike other works, the distance here is the hop distance instead of Euclidean distance. Removing the ability of measuring Euclidean distance simplifies the sensor nodes. The unequal cover ranges can make the clusters with similar distances to MS have approximate sizes such that the energy consumption by CHs can be balanced. Since the designed cover range does not exceed the single hop communication range, the cluster members (CMs) consume energy approximately also. The proposed routing algorithm associates each CH to a CH that is closer to MS' trajectory. The CH u will associate to a CH v only if v's hop distance is no larger than u's. Further, the association accounts the residual energy of CH v and the number of attached CMs. We compare our approach with some existing ones through simulations and we conclude that our approach achieves longer network lifetime.[1]

The remainder of this paper is organized as follows: Section 2 briefly reviews related work encompassing the various approaches that deal with data collection in WSNs. Section 3 provides the main assumptions of the network and the considered energy consumption model. Section 4 gives the proposed protocol in detail. Section 5 analyses several properties of the protocol. Section 6 demonstrates simulation results and Section 7 concludes our work.

2. Related work

Relieving traffic burden from a specific set of nodes makes exploiting MSs an effective method of improving system performance in WSNs. Recent surveys on WSNs with MSs can be found in [3,4]. Based on the mobility type, three classes of approaches have been proposed. The first one uses random mobility. For example, data MULEs [10,11] are employed to randomly walk in the sensing field and pick up data from sensor nodes when they are close. Although it is simple to implement, it is difficult to bound the collecting latency and data delivery ratio due to the randomness. The second approach employs controllable mobility where the MSs are able to freely move in the field to visit all or a certain part of sensor nodes [5,6,12–16]. However, since many applications are deployed in environments that constrain motion patterns of MSs to roads, trails, or hallways, not all movements of fully controllable MSs are actually realized. The approach in between focuses on constrained mobility where the MSs are attached to some vehicles and trajectories of the vehicles are predefined [17–23]. In the rest of this section, we provide a brief review on the approaches using path constrained MSs.

In recent years, a number of approaches using trajectory constrained MSs to collect data in WSNs have been proposed. The MSs can collect data either through single hop communication [17,20,21] or multihop communication [23,18]. The authors of [21] consider the scenario where a MS is installed on a bus which moves on its fixed path periodically and collects data from a set of sensor nodes deployed near the path. They propose a queuing formulation to model the process of data collection and show that using predictable mobility can lead to large energy saving over convention static WSNs. Further they propose a communication protocol to assist gathering data by MS. Under the similar context, [17] focuses on the scheduling problem in node-sink transmission and a trade-off between the probability of successful information retrieval and node energy consumption is studied. Different from [17] which considers sparsely deployed network, the authors of [20] focus on dense networks. They consider the maximization of data collection throughput by dividing the traversing time into a set of time slots with equal duration and studying the problem of assigning nodes to the time slots. One defect of these approaches is that they all use single hop communication, which requires that the sensor nodes are deployed within the communication range of MS when it moves on the trajectory.

In [23], the assumption, i.e., all the nodes are located within in the communication range of MS, is removed while multi-hop communication is used. During the movement, MS broadcasts a packet continuously within its communication range. The nodes that can hear this packet are called subsinks. Subsinks then forward the packet within their communication ranges. When MS finishes its trip, every node knows its shortest hop distance to a subsink as well as the shortest path towards the subsink. From MS's next trip, nodes transmit their sensory data to the corresponding subsinks and when MS comes, the subsinks upload the data. Compared to the single hop case, using multi-hop communication improves the applicability and scalability of system. The authors of [18] consider the same problem as [23]. They first point out that the shortest path based routing leads to an unbalanced assignment of nodes to subsinks, which further results in that some subsinks having long contacting time with MS is associated with a small number of nodes. Thus, the subsinks may not manage to upload all its buffered data. Considering this, they formulate a constrained assignment problem such that each subsink is associated with an appropriate number of nodes, which enables more data can be collected. By doing this, the throughput is improved. However, some nodes may be associated to a far away subsink, thus relaying their data consumes more energy than the shortest path routing.

The above approaches using either single hop or multihop communication are based on the flat network structure. While the large-scale deployment of WSNs and the need for data aggregation necessitate efficient organization of the network topology for the purpose of balancing the load and prolonging the network lifetime. Clustering, as opposed to direct single hop communication schemes, has proven to be an effective approach for organizing the network, which improves energy efficiency, reduces channel contention and packet collisions, and results in increased network throughput under high load [24]. Researchers have proposed many well known clustering approaches, such as LEACH [25], EEHC [26], HEED [27], and their extensions. However, they all focus on static networks. The authors of [19] consider the same context as [23,18], but clustering is introduced. The data collection protocol presented in [19], MobiCluster, is based on a clustering algorithm, called Unequal Routing Clustering (URC) [28]. The authors of [28] point out that given a network with a static sink, the sizes of the clusters near the sink should be smaller than those far away. The reason is as follows. The CHs near the sink have heavier burden of relaying data compared to the CHs far away. CHs also need to collect data from their CMs within cluster and aggregate the collected data. Thus, if the cluster size is identical across the network, the CHs near the sink may run out of energy much more quickly than those far away (funnelling effect). To avoid this, an effective approach is to construct unequal clusters, i.e., the clusters near the sink have smaller sizes while the clusters far away have larger sizes. Thus, the energy consumption on intra-cluster communication of CHs near the sink is reduced, and these CHs can spend more energy on inter-cluster communication, i.e., relaying data. The authors of [19] adopt a simplified version of URC where only two sizes are considered, and apply it to the scenario of using MS.

[1] There are several definitions of network lifetime in the literature. Here we adopt the definition of network lifetime as the number of rounds until the first node exhausts its energy reserve, which has been widely used.