Mobile Relay as Doze Nodes in Data-Intensive Wireless Sensor Networks

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Abstract:

Wireless Sensor Networks (WSNs) are increasingly used in data-intensive applications such as microclimate monitoring, precision agriculture, and audio/video surveillance. A key challenge faced by data-intensive WSNs is to transmit all the data generated within an application's lifetime to the base station despite the fact that sensor nodes have limited power supplies. We propose using low cost disposable mobile relays as doze nodes to reduce the energy consumption of data-intensive WSNs. Our approach differs from previous work in one main aspect. Mobile relay does not actively forward data from source node to base station but continues to listen to the source nodes and monitors the signal level around it. It gets active and forward the data from source node to base station, when there is a noticeable change in the signal level. In the sleeping time of the mobile relay, it does not consume more energy. Finally this technique produces an efficient energy optimization that can be integrated in the system that can be used in the data-intensive applications. We further conduct extensive simulations to examine the efficiency of our technique with varied network settings.

Keywords: Wireless sensor networks, energy optimization, mobile nodes, wireless routing.

1 INTRODUCTION

WSNS have been deployed in a variety of data-intensive applications including microclimate and habitat monitoring [1], precision agriculture, and audio/video surveillance [2]. A moderate-size WSN can gather up to 1 Gb/year from a biological habitat [3]. Due to the limited storage capacity of sensor nodes, most data must be transmitted to the base station for archiving and analysis. However, sensor nodes must operate on limited power supplies such as batteries or small solar panels. Therefore, a key challenge faced by data-intensive WSNs is to minimize the energy consumption of sensor nodes so that all the data generated within the lifetime of the application can be transmitted to the base station.

Several different approaches have been proposed to significantly reduce the energy cost of WSNs by using the mobility of nodes. A robotic unit may move around the network and collect data from static nodes through one-hop or multihop transmissions [4], [5], [6], [7], [8]. The mobile node may serve as the base station or a "data mule" that transports data between static nodes and the base station [9], [10], [11]. Mobile nodes may also be used as relays [12] that forward data from source nodes to the base station. Several movement strategies for mobile relays have been studied in [12], [13].

Although the effectiveness of mobility in energy conservation is demonstrated by previous studies, the following key issues have not been collectively addressed. First, the movement cost of mobile nodes is not accounted for in the total network energy consumption. Instead, mobile nodes are often assumed to have replenishable energy supplies [7] which is not always feasible due to the constraints of the physical environment. Second, complex motion planning of mobile nodes is often assumed in [35] which introduces significant design complexity and manufacturing costs. Third, continuous working of mobile relay is often assumed in existing solution which introduces more power consumption. In [7], [8], [14], [15], mobile nodes need to repeatedly compute optimal motion paths and change their location, their orientation and/or speed of movement. Such capabilities are usually not supported by existing low-cost mobile sensor platforms. For instance, Robomote [16] nodes are designed using 8-bit CPUs and small batteries that only last for about 25 minutes in full motion.

In this paper, we use doze mobile relay nodes to reduce the total energy consumption of data-intensive wireless sensor networks. Different from mobile base station or data mules or mobile relays, doze mobile relays do not always active; instead, they go to sleeping mode, while there is no noticeable change in the signal level.

2 RELATED WORK

We review three different approaches, mobile base stations, data mules, and mobile relays, that use mobility to reduce energy consumption in wireless sensor networks. A mobile base station moves around the network and collects data from the nodes. In some work, all nodes are always performing multiple hop transmissions to the base station, and the goal is to rotate which nodes are close to the base station in order to balance the transmission load [4], [5], [6]. In other work, nodes only transmit to the base station when it is close to them (or a neighbor). The goal is to compute a mobility path to collect data from visited nodes before those nodes suffer buffer overflows [7], [8], [14], [15]. In [8], [19], [20], several rendezvous-based data collection algorithms are proposed, where the mobile base station only visits a selected set of nodes referred to as rendezvous points within a deadline and the rendezvous points buffer the data from sources. These approaches incur high latencies due to the low to moderate speed, e.g., 0.1-1 m/s [14], [16], of mobile base stations.

Data mules are similar to the second form of mobile base stations [9], [10], [11]. They pick up data from the sensors and transport it to the sink. In [21], the data mule visits all the sources to collect data, transports data over some distance, and then transmit it to the static base station through the network. The goal is to find a movement path that minimizes both communication and mobility energy consumption. Similar to mobile base stations, data mules introduce large delays since sensors have to wait for a mule to pass by before starting their transmission.

In the third approach, the network consists of mobile relay nodes along with static base station and data sources. Relay nodes do not transport data; instead, they move to different locations to decrease the transmission costs. We use the mobile relay approach in this work. Goldenberg et al. [13] showed that an iterative mobility algorithm where each relay node moves to the midpoint of its neighbors converges on the optimal solution for a single routing path. However, they do not account for the cost of moving the relay nodes. In [22], mobile nodes decide to move only when moving is beneficial, but the only position considered is the midpoint of neighbors.

Unlike mobile base station and low-cost disposable mobile relay, our doze mobile relay technique considers the energy consumption of both active and sleeping mode. Our approach also forwards the data from source node to base station by mobile relay, while the relaying is beneficial. Unlike a previous mobile relay schemes [13],[22] and [35], it forward data from source node to the base station, when the reasonable variation in the data.

Mobility has been extensively studied in sensor network and robotics applications which consider only mobility costs but not communication costs. For example, in [23], the authors propose approximation algorithms to minimize maximum and total movement of the mobile nodes such that the network becomes connected. In [24], the authors propose an optimal algorithm to bridge the gap between two static nodes by moving nearby mobile nodes along the line connecting the static points while also minimizing the total/maximum distance moved. In [25], [26], the authors propose algorithms to find motion paths for robots to explore the area and perform a certain task while taking into consideration the energy available at each robot. These problems ignore communication costs which add an increased complexity to OMRC, and consequently their results are not applicable.

3 EXISTING SYSTEM

In the previous work, they use low- cost disposable mobile relay to reduce the total energy consumption of data-intensive WSNs. Different from mobile base stations and data mules, mobile relays do not transport data; instead, they move to different locations and then remains stationary to forward data along the path from source to the base stations. Thus, the communication delay significantly reduced compared with using mobile sinks or data mules. Moreover, each mobile performs single relocation unlike other approaches which requires repeated relocations. But it always being active and forwards the data from source node to the base station, even when the function of mobile relay is unnecessary. It consumes more power, when the mobile relay is always being active and forwards the data.

4 PROPOSED SYSTEM

In this paper, we use doze mobile relay nodes to reduce the total energy consumption of data-intensive WSNs. Different from existing technology, doze mobile relays do not always being active; Instead, they goes to sleeping mode, until the noticeable variation in the data rate from the source nodes. Thus, the power consumption significantly reduced compared with using low-cost disposable mobile relay. Moreover, it consumes the energy only, when the mobile relay is in the active mode.

The doze mobile relay node does not always actively forward the data from source node to base station. It simply listen the value of the data collected from the source node. If the data rate varies, it become active and forward the data from source node to base station, otherwise it remains sleeping state.

4.1 Energy Consumption Models

Nodes consume energy during communication, computation, and movement, but communication and mobility energy consumption are the major cause of battery drainage. Radios consume considerable energy even in an idle listening state, but the idle listening time of radios can be significantly reduced by a number of sleep scheduling protocols [32]. In this work, we focus on reducing the total energy consumption due to transmissions and mobility. Such a holistic objective of energy conservation is motivated by the fact that mobile relays act the same as static forwarding nodes after movement. For mobility, we consider wheeled sensor nodes with differential drives such as Khepera [17], Robomote [16], and FIRA [18]. This type of node usually has two wheels, each controlled by independent engines. We adopt the distance proportional energy consumption model which is appropriate for this kind of node [33]. The energy EM(d) consumed by moving a distance d is modeled as:

$$EM(d) = kd.$$

The value of the parameter k depends on the speed of the node. In general, there is an optimal speed at which k is lowest. In [33], the authors discuss in detail the variation of the energy consumption with respect to the speed of the mote. When the node is running at optimal speed, k = 2 [33].

4.2 Problem Formulation

In our definitions, we assume that all movements are completed before any transmissions begin. We also assume there are no obstacles that affect mobility or transmissions. In this case, as we show that the distance moved by a mobile relay is no more than the distance between its starting position and its corresponding position in the evenly spaced configuration which often leads to a short delay in mobile relay relocation. Furthermore, we assume that all mobile nodes know their locations either by GPS units mounted on them or a localization service in the network. We focus on the case where all nodes are in a 2D plane <2, but the results apply to <3 and other metric spaces.

4.3 Static Tree Construction

Different applications may apply different constraints on

the routing tree. When only optimizing energy consumption, a shortest path strategy (as discussed below) yields an optimal routing tree given no mobility of nodes. However, in some applications, we do not have the freedom of selecting the routes. Instead, they are predetermined according to some other factors (such as delay, capacity, etc.). In other less stringent cases, we may be able to update the given routes provided we keep the main structure of the tree. Depending on the route constraints dictated by the application, we start our solution at different phases of the algorithm. In the unrestricted case, we start at the first step of constructing the tree. When the given tree must be loosely preserved, we start with the relay insertion step. Finally, with fixed routes, we apply directly our tree optimization algorithm. Our simulations show that our approach outperforms existing approaches for all these cases.

We construct the tree for our starting configuration using a shortest path strategy. We first define a weight function w specific to our communication energy model. For each pair of nodes si and sj in the network, we define the weight of edge sisj as: w(si; sj)= a + b||oi _ oj||2 where oi and oj are the original positions of nodes si and sj and a and b are the energy parameters discussed in Section 4.1. We observe that using this weight function, the optimal tree in a static environment coincides with the shortest path tree rooted at the sink. So we apply Dijkstra s shortest path algorithm starting at the sink to all the source nodes to obtain our initial topology.

4.4 Node Insertion

We improve the routing tree by greedily adding nodes to
the routing tree exploiting the mobility of the inserted nodes. For each node sout that is not in the tree and each tree edge sisj, we compute the reduction (or increase) in the total cost along with the optimal position of sout if sout joins the tree such that data is routed from si to sout to sj instead of directly from si to sj using the LocalPos algorithm described. We repeatedly insert the outside node with the highest reduction value modifying the topology to include the selected node at its optimal position, though the node will not actually move until the completion of the tree optimization phase. After each node insertion occurs, we compute the reduction in total cost and optimal position for each remaining outside node for the two newly added edges (and remove this information for the edge that no longer exists in the tree). At the end of this step, the topology of the routing tree is fixed and its mobile nodes can start the tree optimization phase to relocate to their optimal positions.

5 EFFICIENCY AND OPTIMALITY

We first consider efficiency. Our initial tree construction algorithm is essentially a single source shortest path algorithm. Using Dijkstra s algorithm, the time complexity is O(n2) where n is the number of nodes. Our second algorithm needs to compute the reduction in cost for each pair of node and tree edge, so the time complexity is O(n2). Our tree optimization algorithm runs until the change in position for each node falls below a predefined threshold. The value of this threshold represents a tradeoff between precision and cost. As the threshold decreases, more iteration is needed for convergence. Upon termination, no node can move by itself to improve the overall cost (within the threshold bound). We have not completed a rate of convergence analysis for this algorithm. However, in our simulations, we reach our error threshold within 8 to 10 iterations. Since each iteration involves only half the nodes and each computation of uj i can be performed in constant time, the time complexity of our algorithm is O(_n), where _ is the number of iterations to reach convergence. Given that _ < 10 in our simulations, our observed time complexity is O(n). The resulting time complexity for the full approach is O(n2). With respect to optimality, our resulting configuration is not necessarily optimal because we do not necessarily find the optimal topology. However, two of our algorithms, the initial tree construction algorithm and the tree optimization algorithm, are optimal for their respective sub problems. That is, our initial tree construction algorithm is optimal in a static environment where nodes cannot move so that only the original positions of the nodes are considered. Likewise, for our tree optimization algorithm, we prove that the final configuration where no node can move by itself to improve the overall cost (within the threshold bound) is globally optimal; that is, no simultaneous relocation of multiple nodes can improve the overall cost.

6 SIMULATION

We carried out simulations on 100 randomly generated initial topologies, each of which has 100 nodes placed uniformly at random within a 150 m by 150 m area. We used these initial topologies to generate two subsequent sets of complete topologies with established sources and sink. We used the first set to study the effectiveness of our algorithms as the amount of data transferred to the sink varies and the second set to study the effectiveness of our algorithms for different numbers of sources. In the first set, we selected sources and sinks uniformly at random from these 100 nodes. We varied the number of sources from 4 to 12, by increments of two, and used each number of sources for 20 initial topologies. For each resulting topology, we created many separate input instances by varying the data chunk size from 1 to 150 MB where the data chunk size for an input instance is the common amount of data to be transferred from each source to the sink. In the second set, for each initial topology, we generated 10 different complete topologies by starting with two randomly selected sources, and adding two new sources to the previous set at each step.

We used the following settings to model the transmission and mobility costs of our nodes. For transmission, we use a = 0.6 *10_7 and b = 4 *10_10 as the standard setting which is consistent with the empirical measurements on CC2420 motes [36]. For mobility, we used different settings in each of our two sets. In the first set, we used k = 2 as the standard setting because it models several platforms such as Robomote [16], [17]. In the second set, we set k to be 1, 2, and 4 since we additionally use that set to study the effect of different mobility costs on the energy reduction. Furthermore, we set the maximum communication distance of a node to be 30 m, which was shown to result in a high packet reception ratio for the CC2420 radio [36]. We ran simulations using different values for the convergence threshold. We obtained similar gains for values less than or equal to 0.01. In the following simulations, we set the threshold to 0.01.

Our algorithmic framework starts with an initial routing tree. In the centralized setting, we construct this initial routing tree using the following three widely used routing algorithms: power-based routing, hop-based routing, and greedy geographic routing. Power-based routing computes a shortest path from the sink to each source with each edge weight being the square of the distance between the two corresponding nodes plus some constant value to represent the energy consumed a + bd2 to transmit each byte of data over that edge. Hop-based routing minimizes the number of hops between each source and the sink and is the base of several widely used algorithms in wireless networks (e.g., AODV [39]). Given our maximum communication range of 30 m, we do not have any links with poor quality which is a common concern with hop-based routing. Greedy geographic routing is a greedy strategy in which each node forwards messages to the reachable node (within the communication range of the node) that is closest to the sink. The first two tree construction approaches require global knowledge of the network whereas the last one is fully localized. For the distributed setting, we construct the initial routing tree using greedy geographic routing because it is fully localized. Of the 100 initial topologies, the distributed routing algorithm resulted in a disconnected path between the sources and the sink in only four networks given our maximum communication distance of 30 m.

6 CONCLUSION

In this paper, we proposed a doze mobile relay to minimize the total energy consumed by both mobility of relays and wireless transmissions. Most previous work ignored the energy consumed by forwarding data from source node to base station. In our approach the mobile relay does not actively forward the data from source nodes to base station, but it continues to the source nodes and monitors the signal level around it. It gets active and forward the data to the base station, when there is a noticeable change in the signal level. In the sleeping time of the mobile relay, it does not consume more energy. Finally this technique produces an efficient energy optimization that can be integrated in the system that can be used in the data-intensive applications. Our approach can be implemented in a centralized or distributed fashion. Thus, the simulation show it substantially reduces the energy consumption by up to 40 percent.

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