Distributed Construction of Connected Cover Graph in Wireless Sensor Networks

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Abstract

In this paper, we consider the problem of scheduling sensor activity to prolong the network lifetime while guaranteeing both discrete target coverage and connectivity among all the active sensors and the sink, called *connected target coverage* (CTC) problem. We proposed a distributed scheme called Distributed Lifetime-Maximizing Scheme (DLMS) to solve the CTC problem. Our proposed scheme significantly reduces the cost of the construction of the connected cover graphs in comparison with the some conventional schemes. In addition, the energy consumption is more balanced so that the network lifetime will be increased. Our simulation results show that DLMS scheme performs much better than the conventional schemes in terms of the network lifetime.

1. Introduction

In CTC problem, a number of targets with fixed locations are required to be continuously monitored (covered) in the field by a (large) number of randomly scattered sensors. A sensor, which is selected to be active for performing the monitoring task, is called a *source* sensor. The source sensors generate sensed data messages and send these messages to a sink node. In many assumptions used by the prior work, the transmission range of sensor does not enable all nodes to communicate with the sink directly. So, the sensed data could reach the sink via single-hop or multi-hop communication. A sensor node which does not perform monitoring task but needs to be activated to relay data is called a *relay* node. A sensor is called an *active* node if it is selected either as a source or as a relay or both. A sensor that is not active goes into an energy saving sleep state.

In this paper, we proposed a light way scheme, which selects some source nodes to ensure the coverage first, and then finds energy efficient paths to transmit the sensing data from these selected source nodes to the sink. Moreover, our proposed scheme tries to balance the energy consumption of the sensors in the network to maximize the network lifetime.

The remainder of this paper is organized as follows. In the next section, we briefly describe the related works. The system model and our assumptions are provided in section 3. Our proposed schemes are presented in section 4. Finally, we conclude our work and give some future research directions in the last section.

2. Related Work

Scheduling sensor activity while guaranteeing a certain coverage requirement to prolong the network lifetime has been studied in the literature (see e.g., [2] for a survey and references therein). Here, we briefly review two recent advances on scheduling sensor activity to cover discrete targets [1], and [3].

In [3], M. Lu et al. schedule sensor activity by self-configuring sensing range, in the environment where both discrete target coverage and connectivity are satisfied. However, only sensing power is taken into account in their energy consumption model. Further, the heuristic proposed in [3] maintains network-wide connectivity which may not be necessary for target coverage. In fact, only those sensors along the routes carrying the sensed data are required to be active.

In [1], Q. Zhao et al. proposed an algorithm for solving the connected target coverage (CTC) problem by scheduling sensors into multiple sets, each of which can maintain both target coverage and connectivity among all the active sensors and the sink. However, in their proposed schemes, a spanning tree covering the entire network must be rebuilt whenever they want to use another subset to ensure certain targets coverage and connectivity. This approach is not efficient, especially for the networks with a large number of nodes, because the cost for construction the whole network spanning tree is very high. Moreover, due to the utilization of static cover tree, the scheme could not achieve a good energy balancing between nodes in some cases. In these cases, some nodes may be selected as both relay and source node, or some nodes can be bottleneck nodes if they have many child nodes selected as source nodes.

We are motivated by these above remaining problems. Our proposed scheme tries to reduce the protocol overhead and balances the energy between the sensors

3. System Model and Assumptions

The sensor field consists of a set of discrete targets with fixed locations, a number of randomly deployed sensors and a sink node. We assume that sensors are equipped with power controlled transceivers and non-rechargeable batteries with limited energy. Each sensor covers a disk centered at itself with a fixed sensing range as the disk radius. All sensors are assumed to have the same sensing range and the same maximum communication range. Each node knows its location, its residual energy, location of targets within its sensing range, and the minimum weight of path originated from itself to the sink. Source nodes generate data messages at a certain rate.

In this paper, scheduling sensor activity refers to determining the state of the deployed sensors to be either active (as source or relay or both) or sleep as well as their state durations.

The network lifetime is defined as the time period from the time when the network was set up until 1) one or more targets cannot be covered, or 2) a route cannot be found to send the sensory data to the sink. The network lifetime can be increased by scheduling only a subset of sensors necessary to be active for meeting the application requirements.

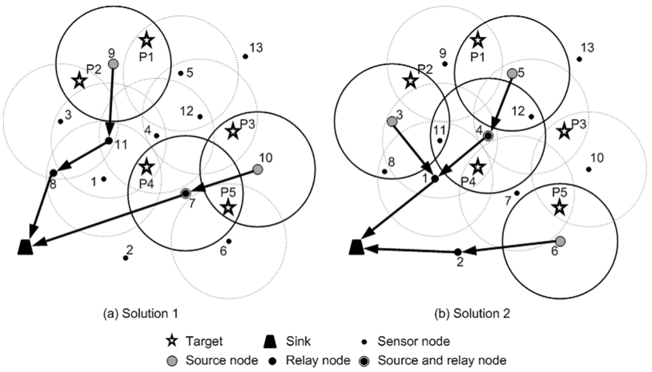

Fig. 1: Connected Target Coverage problem

We illustrate the CTC problem in Fig. 1. There are thirteen sensors, five targets and one sink in the sensor field. The sensors that can cover one or more targets are indicated by their circles—solid circles for active source sensors and others for sleep or relay sensors. Arrowed lines are used to denote the routes used to relay data from sources to the sink. Two possible solutions are illustrated in Fig. 1(a) and Fig. 1(b). This figure illustrates that only a subset of the deployed sensors is sufficient to carry out the functionalities of sensing targets and forwarding sensory data to the sink in the WSN. Different subsets can be used in different time intervals, call operational time interval (OTI).

4. Proposed Scheme

In our proposed scheme, first the source nodes are selected to ensure the target coverage. After that, energy-efficient paths to transmit the sensory data from source nodes to the sink will be built. The cost of the construction of the connected cover tree is significantly reduced in comparison with the original scheme in the target paper since the number of targets (i.e., the necessary number of source nodes) is much smaller than the number of sensor nodes. In addition, the energy consumption is more balanced so that the network lifetime will be increased.

The proposed scheme composes of two stages. The initialization stage is executed once and the operation stage is executed after each operation time duration. In the initialization stage, each node broadcasts its information to other neighboring nodes. In the operation stage, a cover graph is built. The proposed scheme iteratively executes the process of building cover graphs and this process stops only when no new cover graph can be built (i.e., the network lifetime is reached). Each sensor can estimate its residual energy using the energy consumption model (given in [1]) to adjust the building process balancing the energy consumptions. There are three phases in each iteration of building a new cover graph.

In phase 1, the node, which covers most number of uncovered targets and is closest to the sink, will be selected as a source node. The source node estimates its residual energy and updates its minimum weight of path originated from itself to the sink. It then broadcasts an advertising message to their neighbors which have higher level. A node receives the advertising messages from its neighbors, will update its minimum path weight.

In phase 2, after the source nodes are selected, source nodes recursively notify the nodes in their shortest paths towards the sink to become the relay nodes. Each relay node then updates its minimum path weight by updating the residual energy of its neighbors and broadcasts its status, including estimated residual energy, to its neighbors. The cover graph is dynamically built because a node can update its minimum path weight by updating the residual energy of its neighbors.

Finally, in the last phase, the operation time duration for this cover graph will be estimated. Each cover graph operates during this fixed time duration if no sensor in the cover graph die (i.e. out of battery) before the time duration expires. Otherwise, the operation time duration of the cover graph is determined based on the sensor which has the least residual energy.

A sensor which runs out of battery is called a dead sensor. An alive sensor which cannot find any route towards the sink without traversing a dead sensor is considered as an isolated sensor. The network will be updated by removing the dead and isolated sensor nodes.

5. Conclusion

In this paper, we have proposed a scheme to schedule the active time of sensors such that the active sensors can cover all the targets and formulate the efficient routes from each monitor node to the sink. As part of our future work, we will study the CTC problem in the duty-cycled wireless sensor networks. In another research direction, we will extend our ideas to the other types of coverage, e.g., area coverage or barrier coverage.

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