A Data Gathering Algorithm Based on Energy-Aware Connected Dominating Sets to Minimize Energy Consumption and Maximize Node Lifetime in Wireless Sensor Networks

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ABSTRACT

This paper develops an energy-aware connected dominating set based data gathering (ECDS-DG) algorithm for wireless sensor networks. The algorithm includes only nodes that have a relatively higher energy level in ECDS. For every round, a data gathering tree (ECDS-DG tree) rooted at the ECDS Leader, that is, the node with the largest available energy, which transmits the data packet to the sink, is formed by considering only the nodes in the ECDS as the intermediate nodes of the tree. The non-ECDS nodes are leaf nodes of the tree, and the upstream node of an intermediate ECDS node in the ECDS-DG tree is the closest ECDS node that is also relatively closer to the ECDS Leader. Performance comparison studies involving well-known LEACH and PEGASIS algorithms indicate that ECDS-DG incurs the lowest energy consumption per round and sustains the largest number of rounds before first node failure.

Keywords: Connected Dominating Set, Data Aggregation, Data Gathering Algorithms, Energy-Awareness, Sensor Networks, Simulations

INTRODUCTION

A wireless sensor network is a distributed system of smart sensor nodes that collect data about the ambient environment and propagate it to one or more control centers called the sinks or base stations, where the end-user can access the data.

A typical sensor node has limited computing capability and memory capacity, and operates with very limited battery power. The transmission range of a sensor node is the distance until which the signals emanating from the node can propagate and be received with appreciable signal strength. The wireless sensor network has limited bandwidth and is shared among the nodes that are within a common transmission range.

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range. The sink is normally fixed and located far away from the sensor nodes. Direct communication between the sensor nodes and the sink is expensive in terms of energy consumption and bandwidth usage. This motivates the need for data gathering algorithms that can be run at the sensor nodes to combine data into a small set of meaningful information, which is a representative of the network condition and can be transmitted to the sink, leading to significant energy and bandwidth savings. Throughout this paper, the terms ‘data gathering’, ‘data fusion’ and ‘data aggregation’ are used interchangeably. They mean the same.

In this paper, we consider a wireless sensor network where data is periodically reported from the sensor nodes to the sink. Data collection and transmission proceeds in rounds, where each node has a packet of information in each round of communication. The data packet from the sensor nodes are gathered and aggregated with the packets of peer sensor nodes and only one data packet is sent per round from the sensor network to the sink. If each sensor node directly transmits the data to the sink that is typically located far away from the network field, the total energy consumed per round will be very high. Data aggregation helps to reduce the uncorrelated noise in several signals and produce a more accurate signal that is representative of the network condition and that can be transmitted to the sink.

Various data aggregation algorithms have been proposed in the literature. Well-known among these are the Low-Energy Adaptive Clustering Hierarchy, LEACH, (Heinelman et al., 2000) and the Power-Efficient Gathering in Sensor Information Systems, PEGASIS, (Lindsey et al., 2002) algorithms. Both algorithms operate through discrete rounds of data collection. In LEACH, each round has the following two phases: a set-up phase, when clusters of sensor nodes are formed with the assignment of a cluster head for each cluster and a steady-state phase, when the data collected from the sensor nodes in each cluster is transmitted to the sink through direct transmission from the cluster heads. In PEGASIS, each round involves the formation of a chain of the sensor nodes in the field, starting from the sensor node that is farthest from the sink. The chain of sensor nodes is formed using a greedy heuristic based on the distance between the sensor nodes. The original PEGASIS algorithm resulted in huge delay as data moves across the complete chain of sensor nodes before getting transmitted to the sink. For Code Division Multiple Access, CDMA, (Viterbi, 1995) systems, PEGASIS has been later improved using a chain-based binary scheme to minimize the delay incurred and to reduce the energy*delay metric (Lindsey et al., 2001). In the chain-based binary approach, a round comprises of \( \log N \) levels, where \( N \) is the number of nodes in the network. For data gathering in each round, each node transmits to a close neighbor in a given level of the hierarchy. Nodes that receive data at a given level are the only nodes that rise to the next level. At the top level, there will be only one node that will remain as the leader and it will transmit the aggregated message to the sink.

The distance-based chain formation heuristic of PEGASIS is prone to an increase in the physical distance between successive nodes as the chain progresses away from the starting node. This can lead to higher energy consumption per round. The chain-based binary version of PEGASIS consumes more energy per round compared to its original version (Lindsey et al., 2001). The energy consumed per round of LEACH is significantly more than that consumed in PEGASIS and its chain-based binary scheme (Lindsey et al., 2001). If multiple cluster-heads are selected, even though the delay per round would be low because of reduced size of a cluster, several cluster-heads would be transferring data over long-distances to the sink. On the other hand, if few cluster-heads are selected, the sensor nodes may have to transmit over long-distances to reach the nearest cluster-head. Due to competition in each cluster, the delay might also increase. The above qualitative analysis of the energy consumption per round for the LEACH and PEGASIS
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