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Energy consumption bounds analysis and its applications for grid based wireless sensor networks

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ABSTRACT

Grid based wireless sensor networks have the advantages of dynamic topology configuration and flexible selection of forwarding paths. However, like other schemes, the energy management of electronic device is a very important issue when the lifespan of the network is critical. The energy consumption of a grid based network depends on the topology of the grid as well as the actual forwarding path. In this paper, we analyze the upper and lower bounds of the transmission energy costs for grid based wireless sensor networks. The results are applicable for evaluation of the effectiveness of grid construction scheme and the routing efficiency of grid based networks. In order to illustrate the applications of the derived results, we proposed an example of topology combination approach to evaluate efficiency with respect to the derived lower bound. Experiments were conducted to verify the validity of the derived bounds and evaluate the energy consumption of the multiple sources forwarding through topology combination.

1. Introduction

Wireless sensor networks are recognized as a convincible technology for the provisioning of environment sensing over wide geographic areas by means of small electronic devices (sensor nodes) (Biswas and Phoha, 2006; Chintalapudi et al., 2006; Boukerche et al., 2009; Ma et al., 2011). Typical applications of sensor networks include detection systems for security, military surveillance, target tracking, and others. In the deployment of a sensor network, a number of sensor nodes are distributed over an area and communicate with each other wirelessly. The query message is broadcast by the base station (or the sink node) to all sensor nodes regarding a specific interest. Information sensed by sensor nodes is forwarded to the sink node for further processing. Basically, the sensor consumes energy for event sensing, data processing, and data transmission. Among them, energy consumed for data transmission heavily depends on the routing efficiency. Therefore, it is the purpose of this paper to analyze the energy required for data transmission in wireless sensor networks. Because sensor nodes have limited access to power, energy consumption is one of the most important issues for the deployment of wireless sensor networks. If each sensor node transmitted its information to the sink node directly, it could very quickly exhaust its energy and drop out of service, at which point the sensor network would become disconnected and fragmented. It has been determined that direct transmission schemes are beneficial only when the sensor network is confined to a limited area (Ma et al., 2011; Liu and Lin, 2003; Heinzelman et al., 2000). For this reason, the low energy adaptive clustering hierarchy (LEACH) method was proposed (Heinzelman et al., 2000; Handy et al., 2002). In the LEACH approach, packets are transmitted in a multi-hop manner to evenly distribute the consumption of energy among nodes, thereby lengthening the life span of the sensor network. In this manner, each node can control its coverage by adjusting its transmission energy to self organize a network topology. The topology of sensor networks can be dynamically changed in accordance with the locations of sensor nodes and sink nodes. The selection of the intermediate nodes for the path of information forwarding from a sensor node to its sink node is determined not only to find the shortest distance but also in consideration of the residual energy of the intermediate nodes. If a routing path is improperly selected, a number of nodes may completely exhaust their energy supplies.

Several topologies (Lindsey and Raghavendra, 2002; Kulik et al., 2002; Intanagonwiwat et al., 2003), including cluster, link, grid, and diffusion, have been adopted as the bases for routing data packets within sensor networks. Among these topologies, the grid based approach is the most suitable for querying across a specific area by mobile sink nodes. This is because the topology of grids can be dynamically configured with respect to the location of source and sink nodes. In addition, the existence of multiple paths between source nodes and sink node increases the

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flexibility of selecting a forwarding path to account for the residual energy of individual nodes. During the construction of a grid, the selection of grid nodes is critical because grid nodes are responsible for the forwarding of packets. A complete overview about the modeling, tools, and their applications of wireless networks was provided in Haenggi et al. (2009). And a number of schemes (Akan et al., 2009; Bulut and Korpeoglu, 2011; Xiao et al., 2008; Quwaider et al., 2010) have been proposed to minimize energy consumption in wireless sensor networks. The feasibility of passive sensor networks was studied in Akan et al. (2009) to provide an environment free of energy constraints; however, such a network would require an external RF resource. Expected coverage and sleep scheduling schemes were proposed in Akan et al. (2009) to minimize energy consumption. In Xiao et al. (2008), Quwaider et al. (2010), nodes could dynamically adapt their transmission energy to forward data according to distance. It is clear that, energy management is critical issue in the deployment of wireless sensor networks.

In grid topology, a grid node is assumed to have a relatively higher power than its neighboring nodes to extend the life span of the sensor network. Although the topology of a grid is considered a regular shape, a grid node may not be exactly located at the designated point because there might be no sensor node at that location or the designated node would be an inappropriate selection (as grid node) owing to a deficiency of energy. In this paper, we studied the selection of grid nodes and routing issues for the sensor networks. Upon receiving of a query message from the sink node, the sensor node (which is responsible for the collection of environmental data of the specific interest) establishes a grid to forward the collected information to the sink node. The major consideration in selecting appropriate grid nodes and establishing the routing path for information forwarding is to maintain the connectivity of the sensor network, thereby prolonging its lifespan. Additionally, we also derive the bounds of energy consumption for the forwarding of information in a grid topology. The derived lower and upper bound are helpful for evaluation of the grid topology based schemes. In a number of applications, such as surveillance, more than one node may detect a particular condition that the sink node has queried through the broadcasting. In such situations, each node that senses the specific condition forms a grid to the sink node. In this paper, we propose a combination grid topology scheme to forward the aggregate data in order to reduce overall energy consumption and compare the results with the derived lower bound.

The remainder of this paper is organized as follows. In Section 2, we provide analysis of the appropriate grid distance, according to a given source node and sink node with consideration of energy consumption. In Section 3, we derive the lower and upper bound of energy consumption in transmission of data from the source node to the sink node by referring to the derived grid distance. In Section 4, we describe the construction of grid topology and data forwarding schemes. In Section 5, we provide the results of our experiments to illustrate the validity of the derived bounds and the performance of the proposed topology combination scheme. Finally, the conclusions are presented in Section 6.

2. Related works

Grid node selection and energy conservation are the critical issues for the research of routing in grid-based wireless sensor networks. The sensor deployment is an efficient practice for provisioning sensing services, however, the accuracy of sensor node placement may be subject to various errors in reality. These placement errors always introduce ineffective energy consumption and result in shorter network lifetime. The authors overviewed the placement techniques of sensor nodes in Younis and Akkaya (2008). In Zhou et al. (2010), the energy dissipation forecast and cluster management (EDFCM) method for the selection of the cluster head in heterogeneous wireless sensor network was studied. Their results show the improvement of energy saving when compared with distributed energy efficient clustering (DECT) and the original LEACH schemes. Several traditional routing techniques of wireless sensor networks were surveyed in Al-Karaki and Kamal (2004). Those techniques have the common objective of trying to extend the lifetime of the sensor network. The non-uniform grid-based coordinated routing design for wireless sensor network was proposed in Akl et al. (2009) to save energy consumption and prolong the network lifetime. The proposed scheme extended the traditional uniform grid-based routing scheme by dynamically partition the network to achieve better energy utilization. The authors proposed multi-candidate selection (MCS) and latency-adaptive distance-based multi-candidate (LDMS) schemes together with greedy routing to achieve lower delivery latency under the constraint of sleep and wake-up scheduling of sensor nodes (Nguyen et al., 2011).

Although the above studies proposed numerous routing algorithms to effectively transmit information and to minimize the energy consumption, it lacks of theoretical reference to judge the effectiveness of the routing algorithms. It is the objective of this paper to analyze the upper and lower energy bounds of data transmission in grid based wireless sensor networks for the evaluation of energy utilization.

3. Grid distance analysis

As sensor nodes tend to be haphazardly strewn across a wide area, the sink node broadcasts the query of specific interest to all sensor nodes. The node with the desired information receives a request to relay the information to the sink node via a forwarding path chosen from a dynamically constructed topology. The node with the desired information is called the source node. In a grid-based approach, a grid topology is constructed of grid nodes from the source node to the sink node for information forwarding as shown in Fig. 1.

Generally, the amount of transmission energy required to forward a packet is proportional to the volume of data (number of bits) and the square of the distance between the sender and receiver. To determine the distance between two neighboring grid nodes for the construction of grid, a tradeoff between distance and energy consumption is required. If the distance selected is too great, more energy will be required for a grid node to forward information to its neighbor. On the other hand, if the distance is too short, the number of forwarding hops increases with a corresponding increase in energy consumption. We define r to

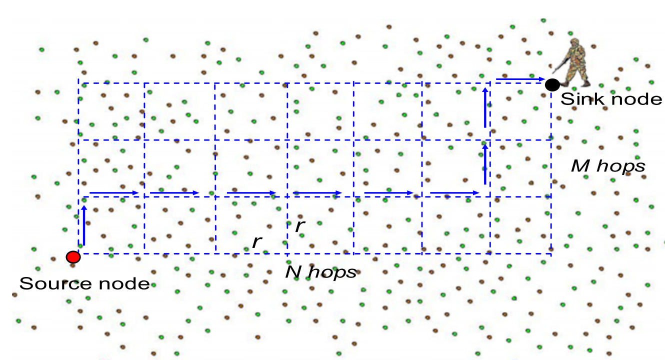

Fig. 1. Grid-based topology in wireless sensor network.