Sensor Network Tomography: Monitoring Wireless Sensor Networks

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I. Introduction

Wireless sensor networks have been attracting increasing research interest given the recent advances in miniaturization and low-cost, low-power design. Consisting of a large collection of small wireless, low-power, unattended sensors and/or actuators, wireless sensor network technology poses its unique design challenges. Given their unattended nature and their complexity, it is critical that the users be given continuously updated indications of the sensor network *health*, i.e., explicit knowledge of the overall state of the sensor network after deployment. We call such indications of network health *scans*. Such macroscopic view of resources or activities in large sensor networks can provide users early warning of system failure, aid in incremental deployment of sensors, or tuning sensor collaboration algorithms.

Monitoring wireless sensor networks leads to different challenges compared to existing diagnosis protocols for the Internet, or monitoring systems in other domains such as telecommunication networks, or power generation systems. The monitoring system should introduce minimal impact on network lifetime, scale with network size, yet preserve the *fidelity* of the overall picture. We propose *Sensor Network Tomography* to construct abstracted scans of sensor network health by applying localized algorithms in sensor networks for energy-efficient *in-network aggregation* of local representations of scans. Rather than collect detailed state information from each individual sensor node and then process centrally, this technique builds a composite scan by combining local scans piecewise on their way towards a collecting point. When local scans are aggregated, detailed information at an individual node may be lost. However, the compactness of such an abstracted representation can reduce the communication and processing cost significantly.

II. Residual Energy Scan and Others

Specifically, we design a *residual energy scan* (or *eScan* for short) that approximately depicts the remaining energy distribution within a sensor network. Without loss of generality, we assume each node is static and knows its location by localization systems such as GPS. Each node measures the residual energy level periodically and constructs its local scan consisting of the node's residual energy level and its location. A user may express a special INTEREST message for a network-wide eScan. This INTEREST message propagates throughout the network by flooding. Upon receiving an INTEREST message, each node sets the sender as its parent node leading toward the user gateway. Thus an aggregation tree is constructed whose root is at the user gateway. Each node then sends the local eScans back towards the user.

Along the path to user gateway, nodes that receive two or more eScans may aggregate those eScans according to several rules. If the eScans are topologically adjacent and have the same or similar energy level, they can be *aggregated* into a tuple which contains a polygon that describes the coverage of nodes, and the range of residual energy levels at those nodes. The goal of aggregation is to reduce the messaging cost on collecting eScans while losing little critical information content in the scans.

We evaluate the performance of our design using simulation. To calibrate the performance of distributed scan collection, we compare our scheme to centralized collection of node residual energy. Distributed scan collection and aggregation can introduce error in observed node residual energy. Can distributed scan collection provide significant energy savings while introducing little error? We show that there exist reasonable models of node energy dissipation for which eScanning can result in an order of magnitude energy savings while introducing less than 10% error in observed residual energy.

Residual energy scan is only one type of scan. We have designed another tool "link scan" to discover topology of our PC-104 based wireless sensor network testbed. Given the unpredictable nature of radio propagation when conducting indoor experiment, our link scan tool continuously provides connectivity information between nodes to validate the experiment results.

III. Future Work

We will continue to explore the design space for monitoring sensor networks. Different network resource or performance metrics may require different techniques to achieve good energy-efficiency, scalability and robustness characteristics. We are planning to implement eScan for our testbed and in return we believe it will give us first-hand experience of design challenges.

To our knowledge, there is no other ongoing or previous work on continuous monitoring large-scale distributed sensor networks. To some extent, monitoring wireless sensor networks itself is a quite unique application for sensor networks. Our research on this topic is also intended to enrich understanding of wireless sensor network design in general.

This student poster and related publications can be found at `http://www.isi.edu/scadds` and `http://lecs.cs.ucla.edu`. A longer version of this summary is filed as USC Computer Science Department technical report TR-01-745.

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