Robots for Energy-Efficient Data Collection from High-Fidelity Sensor Networks

Sandra P. Tinta*, Yu Zhou†, Jennifer L. Wong‡
*‡Computer Science Department, †Mechanical Engineering Department
State University of New York at Stony Brook
Stony Brook, NY 11794
*stinta@cs.sunysb.edu, †yuzhou@notes.cc.sunysb.edu

‡Corresponding Author: jwong@cs.sunysb.edu
Phone: (631)632-1728
Fax: (631)632-8334

Abstract

In emerging real-world applications of Wireless Sensor Networks (WSNs) where high-fidelity data collection and large area coverage are requirements, robots acting as mobile data collectors traversing the sensor-deployed field can aid in elongating the lifetime of the network. Robots for these kinds of applications need to be able to traverse the sensor field efficiently and effectively while performing high data-rate wireless data transfer with the deployed high-data rate wireless sensing devices.

WSNs have emerged as an essential technology for monitoring and exploring remote, hazardous, and hostile environments. WSNs for environmental, ecological, or hostile environment monitoring such as the Great Duck Island [4], Redwood forest [7], and Norway glaciers [5] have been reported. A two-tiered WSN architecture where sensors collect information from the monitored site and transmit data through energy-expensive multi-hop wireless communications to a single base station is most widely used. A base station makes the collected data available for off-line data analysis, or for query serving in a query-retrieval system. Besides the unavoidable energy-constrained nature of sensing devices, current real-world WSNs deployments work under the limitations of area coverage and storage constraints. The area coverage limitation is due to the multi-hop nature of the WSNs that is introduced mainly as a simplifying consideration of WSN design; while the storage constraints limitation can be usually attributed to the inherent limitation of the sensing device at the time of deployment. Being able to monitor a large area with sensors capable of storing and performing high-fidelity sampling, or capturing acoustic or visual data is the trend driving the state-of-the-art of WSNs research. The use of WSNs into different domains such as structural[1], bridge [3], volcanic activity [8], and surveillance [2] monitoring, call for addressing new requirements and challenges.

However, in order to realize a real-life deployment of this kind of WSNs the aforementioned limitations need to be overcome, and the high-fidelity sensed data should be transfered to the base station in a more energy-efficient manner than through multi-hop communications. Therefore, a new tiered WSN architecture needs to be employed. Current technologies have allowed overcoming the storage limitation by enabling sensing devices to expand its memory by additional flash memory. Solving the issue of expanding the covered area and enabling high-fidelity data collection calls for architecting a new class of WSNs. We propose a two-tiered multi-hop hybrid WSN architecture, where static wireless sensors collect high-fidelity data and the robots act as data collectors from the sensor to bring data to the base stations for a single-hop transmission of data. Using hybrid topology the sensor network lifetime can be greatly extended.

Given that the design of WSNs is typically driven by application specific requirements, our architecture is motivated by an event-triggered data sensing WSN. Spatio-temporal events are captured by the static sensors located around the area of the event occurrence. At event occurrence time, a small event-notification detailing time and location of the event is generated and sent in a multi-hop manner to the base station. Note that sending the high-fidelity sensed data in a multi-hop manner would prohibitively consume energy of the static sensors in the relaying path which would in turn, over time, cause disconnected areas in the WSN and potentially deeming the network useless. Robotic assitance minimizes energy consumption on the data collection paths by greatly reducing the amount of multi-hop communications with high-fidelity data. The main goal of our architecture is to extend the lifetime of the WSN deployment as long as possible, providing greater sensing information service to the user.

The base station serves as an entry point of the WSN that enables a user of the network to interact with the data. The base station houses the data for off-line study of sensing events or for query serving of the most up to date information. In addition, the base station keeps the logs of event-occurrence and informs the robot of necessary high-fidelity data collection points. The robot performs these collection requests in rounds. Each round consist of the robot coming in contact with the base station, through a single-hop exchange of messages, in order to learn about event-occurrence locations, the robot planning a trajectory to carry out the data collection from the event-occurrence sites, and the robot bringing and transferring the collected data to the base station in a single-hop manner. The robot is assumed to be able to navigate through the sensor-deployed field, to hold the data gathered during a round, and to recharge its battery when needed.

The gains and trade offs of our proposed system are evaluated by simulations in NS-2, a popular networking simulation tool[6]. In the future, we would like to understand the technical limitations and easiness of deployment of this kind of WSNs. Prototyping our WSNs architecture will be pursued using hardware at hand, TelosB motes and the Activmedia Pioneer 3-DX robot.

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