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Abstract. The efficient and robust realization of wireless sensor networks is a challenging technological and algorithmic task, because of the unique characteristics and severe limitations of these devices. This talk presents representative algorithms for important problems in wireless sensor networks, such as data propagation and energy balance. The protocol design uses key algorithmic techniques like randomization and local optimization. Crucial performance properties of the protocols (correctness, fault-tolerance, scalability) and their trade-offs are investigated through both analytic means and large scale simulation. The experimental evaluation of algorithms for such networks is very beneficial, not only towards validating and fine-tuning algorithmic design and analysis, but also because of the ability to study the accurate impact of several important network parameters and technological details.

1 Introduction

Recent dramatic developments in micro-electro-mechanical (MEMS) systems, wireless communications and digital electronics have already led to the development of small in size, low-power, low-cost sensor devices. Such extremely small devices integrate sensing, data processing and wireless communication capabilities. Current devices have a size at the cubic centimeter scale, a CPU running at 4 MHz, some memory and a wireless communication capability at a 4Kbps rate. Also, they are equipped with a small but effective operating system and are able to switch between “sleeping” and “awake” modes to save energy.

Their wide range of applications is based on the possible use of various sensor types (i.e. thermal, visual, seismic, acoustic, radar, magnetic, etc.) to monitor a wide variety of conditions (e.g. temperature, object presence and movement, humidity, pressure, noise levels etc.). Thus, sensor networks can be used for continuous sensing, event detection, location sensing as well as micro-sensing. Hence, sensor networks have important applications, including (a) environmental (such as fire detection, flood detection, precision agriculture), (b) health applications

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(like telemonitoring of human physiological data), (c) home applications (e.g. smart environments and home automation) and (d) military/security applications. For a survey of wireless sensor networks see [1].

Because of their rather unique characteristics, efficient and robust distributed protocols and algorithms should exhibit the following critical properties: a) **Scalability.** Distributed protocols for sensor networks should be highly scalable, in the sense that they should operate efficiently in extremely large networks composed of huge numbers of nodes. b) **Efficiency.** Because of the severe energy limitations of sensor networks and also because of their time-critical application scenarios, protocols for sensor networks should be efficient, with respect to both energy and time. c) **Fault-tolerance.** Sensor particles are prone to several types of faults and unavailabilities, and may become inoperative (permanently or temporarily). The sensor network should be able to continue its proper operation for as long as possible despite the fact that certain nodes in it may fail.

Since one of the most severe limitations of sensor devices is their limited energy supply, one of the most crucial goals in designing efficient protocols for wireless sensor networks is minimizing the energy consumption in the network. This goal has various aspects, including: (a) minimizing the total energy spent in the network (b) minimizing the number (or the range) of data transmissions (c) combining energy efficiency and fault-tolerance, by allowing redundant data transmissions which however should be optimized to not spend too much energy (d) maximizing the number of “alive” particles over time, thus prolonging the system’s lifetime and (e) balancing the energy dissipation among the sensors in the network, in order to avoid the early depletion of certain sensors and thus the breakdown of the network.

We note that it is very difficult to achieve all the above goals at the same time. There even exist trade-offs between some of the goals above. Furthermore, the importance and priority of each of these goals may depend on the particular application. Thus, it is important to have a variety of protocols (and hybrid combinations of protocols), each of which may possibly focus at some of the energy efficiency goals above (while still performing well with respect to the rest goals). Furthermore, there exist fundamental, inherent trade-offs between important performance measures, most notably between energy dissipation and latency (i.e. time for information to get to the control center).

In the light of the above, we present and evaluate several data propagation protocols: a) **The Directed Diffusion (DD) Protocol,** that creates and maintains some global structure (e.g. a set of paths) to collect data. b) **The Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol,** that uses clustering to handle data collectively and reduce energy. c) **The Local Target Protocol (LTP),** that performs a local optimization trying to minimize the number of data transmissions. d) **The Probabilistic Forwarding Protocol (PFR),** that creates redundant data transmissions that are probabilistically optimized, to trade-off energy efficiency with fault-tolerance. e) **The Energy Balanced Protocol (EBP),** that focuses on guaranteeing the same per sensor energy dissipation, in order to prolong the lifetime of the network.