Distributed Algorithms in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are an emerging field of research which combines many challenges in distributed computing and network optimization. One important goal is to improve the functional lifetime of the sensor network using energy-efficient distributed algorithms, networking and routing techniques, and dynamic power management techniques. The energy consumption represents the major cost metric in almost all algorithms that are to be run in and on top of the WSN. Resulting from these constraints, various optimization criteria emerge. In our talk, we present some of the differences between energy-efficient wireless networking and network optimization usually considered by explaining key design features needed in the envisioned setting of wireless sensor networks.

1 Introduction

Wireless sensor networks are one of the prime examples of Ambient Intelligence, also known as Ubiquitous Computing. The phrase "Ubiquitous Computing" was coined by the late Mark Weiser (1952-1999) in 1988 as "the calm technology that recedes into the background of our lives". There has been major progress recently in off-the-desktop computing, moving more and more towards a notion of a pervasive, wearable, unobstrusive, dissapearing, or invisible computer.

The improvements in digital circuitry technology allow for the integration of sensing, processing, and wireless communication capabilities on a single chip in the near future. Small, battery-operated sensor nodes can cheaply be deployed

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virtually everywhere, and the resulting distributed sensor network allows for a great variety of possible application areas. Some of these scenarios are:

- environmental applications, e.g. disaster detection and biological mapping,
- health sector, such as telemonitoring of patients,
- in-home and in-office scenarios, including home automation and smart environments, but also security issues, or
- vehicle and inventory tracking.

In essence, WSNs provide the end user with a better knowledge and intelligence of the environment in which the network operates. Among the different kinds of WSN applications in which the sensor nodes perform a wide range of activities, most require that sensor nodes collectively form an ad-hoc distributed processing network. Each sensor node is autonomous, and operates without a central control.

Due to the high volume of sensors in such networks, the envisioned settings consist of hundreds, maybe thousands of individual nodes, and their use in possibly harsh environments, replacement of batteries in sensor nodes is not practical in these systems. Their lifetime, however, is required to extend over years.

The challenges to face in this developing new technology for sensor networks are the need for the nodes to be smart, self-configurable, capable of networking together, and energy awareness resulting from the inherent poverty of resources of the nodes.

2 Wireless Networking

Compared to classic networks, sensor networks present a few differences, which are to be taken into account, and which lead to different design criteria, some of which are still to be developed. Unlike traditional wireline network nodes, sensors are cheap, low-energy, rugged, and able to process and communicate among themselves. Another major difference is the type of traffic that is produced, and the requirements about its delivery. Quality-of-Service cannot be defined in classic terms such as network throughput or packet delay, most importantly the energy needed has to be taken into consideration.

Usually, the most energy-consuming operation in a WSN is the wireless communication. The cost, in terms of energy, for computations within a sensor node is considered to be virtually neglectible compared to the cost of transmitting data. For example, comparing the power consumption of the CPU of the EYES sensor node (see cf. [2]) to the power consumption of the transceiver, we obtain that for the cost of transmitting one byte of raw data, the CPU is able to perform about 2800 instructions.

Since single nodes have a limited transmission range, and are able to adjust their transmission power to save more energy, messages have to be relayed by adjacent nodes to reach destinations further away in the network, thus yielding a multi-hop routing topology. This topology is often modeled as disk graphs, and usually undirected models are considered by assuming bidirectional communication. However, there is a large discrepancy between these assumptions and the actual settings of wireless transmissions in realistic scenarios.

In the setting of wireless networking, the communication topology is subject to a vast number of changes due to, e.g., mobility and node failures. This represents another challenge usually not considered in classical network optimization.

3 Local, Distributed Algorithms

By nature of the spatial distribution of the sensors, and usually the lack of a centrally controling unit or sink, the algorithms for a WSN need to be of distributed fashion. Moreover, the amount of information to be exchanged between nodes and the process of obtaining information, e.g. about neighboring nodes, has to be regarded for the analysis of such algorithms as well.

In the talk, we present some of the key challenges for distributed algorithms that rely on wireless communication networks with respect to sensor network applications. We focus on the differences for this emerging field of research with respect to classical network optimization problems.

As an example, the sensor network to be developed within the EYES project is used to give some real-life examples of current research in the field. The EYES project is a three year European research project (IST-2001-34734, [2]) on self-organizing and collaborative energy-efficient sensor networks. It addresses the convergence of distributed information processing, wireless communications, and mobile computing.

References

[1] I.F. Akyldiz, W. Su, Y. Sankarasubramaniam, and E. Cairici, *Wireless Sensor Networks: A Survey*, Computer Networks 38 (2002), 393–422.

[2] Energy Efficient Sensor Networks (EYES), website http://eyes.eu.org.