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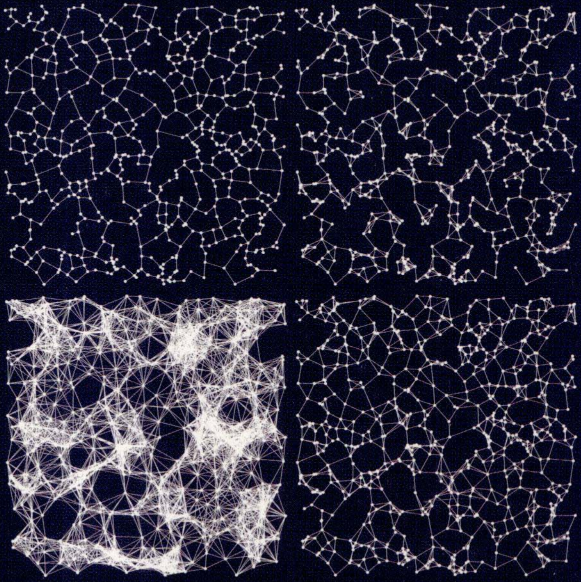
Tutorial

Dorothea Wagner
Roger Wattenhofer (Eds.)

Algorithms for Sensor and Ad Hoc Networks

Advanced Lectures



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Preface

Thousands of mini computers (comparable to a stick of chewing gum in size), equipped with sensors, are deployed in some terrain or other. After activation the sensors form a self-organized network and provide data, for example about a forthcoming earthquake.

The trend towards wireless communication increasingly affects electronic devices in almost every sphere of life. Conventional wireless networks rely on infrastructure such as base stations; mobile devices interact with these base stations in a client/server fashion. In contrast, current research is focusing on networks that are completely unstructured, but are nevertheless able to communicate (via several hops) with each other, despite the low coverage of their antennas. Such systems are called *sensor* or *ad hoc networks*, depending on the point of view and the application.

Wireless ad hoc and sensor networks have gained an incredible research momentum. Computer scientists and engineers of all flavors are embracing the area. Sensor networks have been adopted by researchers in many fields: from hardware technology to operating systems, from antenna design to databases, from information theory to networking, from graph theory to computational geometry.

Both the tremendous growth of the subject and the broad interdisciplinary community make research progress in wireless ad hoc and sensor networking incredibly difficult to follow and apprehend. What are the key concepts of wireless multi-hop networks? Which of the fundamentals that will still be valid in 10 or 20 years' time? What are the main techniques, and why do they work?

This book is a naïve snapshot of the current research on wireless ad hoc and sensor networks. Whenever possible, we focus on algorithmic results, that is, algorithms and protocols that allow for an analysis of their efficiency and efficacy. Often these algorithmic results are complemented by lower bounds, showing that some problems cannot be solved in a better way. Many of our chapters deal with distributed algorithms, in particular local and localized algorithms. Many problems are of an inherently distributed nature, as nodes locally sense data, or locally need to decide on a media access scheme.

Our survey is by no means complete; some topics presented in the book may be identified as wrong paths in a few years' time, and other important aspects might be missing. Most likely, some topics have made it into the book because of their *algorithmic* beauty rather than their *practical* importance. Not surprisingly, one might add. After all, these topics were either proposed or selected (from a much larger list of topics) by the participants of a *GI-Dagstuhl Seminar* held in Dagstuhl on November 23-25, 2005.

The idea of the GI-Dagstuhl Seminars is to provide young researchers with the opportunity to become actively involved in new relevant and interesting areas of computer science. Based on a list of topics and references offered by the organizers, the participants prepared overview lectures that were presented and discussed at the research seminar in Dagstuhl. Each chapter was then elaborated and carefully cross-reviewed by the participants. Although we are aware that further progress has been made since this book was written, we hope to provide at least a first overview of algorithmic results in the field, making the book a suitable basis for an advanced course.

It is our pleasure to thank the young researchers who put a huge amount of work into this book, not only as authors of the chapters but also as reviewers of other chapters. Special thanks go to Steffen Mecke and Frank Schulz who invested a lot of administrative work in the preparation of the seminar. Moreover, Steffen Mecke handled most of the technical parts of the editing process. Finally, we would like to thank the *Gesellschaft für Informatik e. V.* (GI) and *IBFI Schloss Dagstuhl* for supporting this book and the GI-Dagstuhl Seminar.

April 2007

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Contents

1

Applications of Sensor Networks

Hans-Joachim Hof

1.1 Introduction

Networks of small sensor nodes, so-called sensor networks, allow to monitor and analyze complex phenomena over a large region and for a long period of time. Recent advances in sensor network research allow for small and cheap sensor nodes which can obtain a lot of data about physical values, e.g. temperature, humidity, lightning condition, pressure, noise level, carbon dioxide level, oxygen level, soil makeup, soil moisture, magnetic field, current characteristics of objects such as speed, direction, and size, the presence or absence of certain kinds of objects, and all kinds of values about machinery, e.g. mechanical stress level or movement. This huge choice of options allow to use sensor network applications in a number of scenarios, e.g. habitat and environment monitoring, health care, military surveillance, industrial machinery surveillance, home automation, als well as smart and interactive places. The application of a sensor network usually determines the design of the sensor nodes and the design of the network itself. No general architecture for sensor networks exists at the moment. This chapter gives an overview of existing sensor network applications, shows some currently available sensor network hardware platforms and gives an outlook on upcoming applications for sensor networks.

A sensor network can be of great benefit when used in areas where dense monitoring and analysis of complex phenomena over a large region is required for a long period of time. The design criteria and requirements of sensor networks differ from application to application. Some typical requirements are:

- Failure resistance: Sensor networks are prone to node failure. Thus, it is crucial that algorithms for sensor networks can deal with node failures in an efficient way.
- Scalability: As sensor nodes get cheaper and cheaper, it is highly likely that the sensor networks consist of a huge number of nodes. Algorithms

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for sensor networks must therefore scale well with thousands and tens of thousands of sensor nodes.
- Simplicity: Due to the design of sensor nodes, the available resources for algorithms of the application layer are severely restricted. Algorithms for sensor networks must be very efficient considering computation cycles and memory usage.
- Unattended operation: Sensor networks are usually deployed in unattended areas, or administration tasks should be kept at a minimum. It is therefore necessary for an algorithm for sensor networks to work unattended after the deployment of the sensor node. However, it is usually no problem to configure sensor nodes before or during deployment.
- Dynamic: Sensor nodes must adapt to changes of the environment, e.g. changed connectivity or changing environmental stimuli.

This paper is structured as follows: First, some applications of sensor networks are presented. Second, some common sensor network hardware platforms are discussed. The paper ends with an outlook on upcoming applications.

1.2 Applications of Sensor Networks

In this chapter, current sensor network applications are shown. The chapter covers habitat monitoring, environment monitoring, health care, and industrial applications.

1.2.1 Habitat Monitoring

The main objective of habitat monitoring is to track and observe wild life. In the past, habitat monitoring has been done by researchers hiding and observing the wild life, or cameras were used for observations. However, these techniques are intrusive and uncomfortable, and long term observations are difficult and expensive. Usually, live data is not available. Sensor networks offer a better way for habitat monitoring. The sensor network technology is less intrusive than any other technique. Thus, the wild life is less affected, resulting in better research results. Also, long-term observations are possible and sensor networks can be designed in a way that live data is available on the Internet. Human interaction is usually needed only for setup of the sensor network and for removal of the sensors after the end of the observation. Hence, sensor networks help to reduce the costs of habitat monitoring research projects. Two examples of habitat monitoring, the Great Duck Island project and ZebraNet, are presented in the following.

Great Duck Island. The *Great Duck Island project* [273] was one of the first applications of sensor networks in habitat monitoring research. The main objective of the research project was to monitor the micro climates (e.g. temperature and humidity) in and around nesting burrows used by the Leach's

Storm Petrel. The great advantage of this sensor network compared to standard habitat monitoring was that it is non-intrusive and non-disruptive. The project is named after a small island at the coast of Maine, Great Duck Island, where the research took place. At first, a network of 32 sensor nodes was deployed (see Figure 1.1). The sensor network platform consists of processor radio boards commonly referred to as motes. MICA Motes (see Chapter 1.3.1) were used as sensor nodes. They were manually placed in the nesting burrows by researchers. The sensor nodes periodically sent their sensor readings to a base station and got back to sleep mode. The base station used a satellite link to offer access to real-time data over the Internet. To get information about the micro climate in the nesting burrows, the sensor nodes collected data about temperature, humidity, barometric pressure and mid-range infrared. Between spring 2002 and November 2002, over 1 million of sensor readings were logged from the sensor network. In June 2003, a larger sensor network, consisting of 56 nodes, was deployed, and it was extended in July 2003 by 49 additional sensor nodes and again augmented by 60 more sensor nodes and 25 weather station nodes in August 2003. Hence, the network consisted of more than 100 sensor nodes at the end of 2003. The network used multi-hop routing from the nodes to the base station. The software of the sensor nodes was based on the sensor network operating system TinyOS [364]. The sensor network of the Great Duck Island project was preconfigured and did not self configure, e.g. each sensor node got assigned a unique network layer address during compilation of the code prior to deployment.

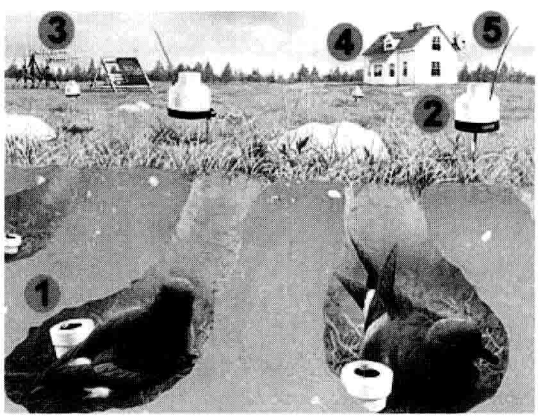

Fig. 1.1. Placement of sensor nodes in the Great Duck Island project: sensor nodes were placed in the nesting burrows of storm petrels (1) and outside of the burrow (2). Sensor readings are relayed to a base station (3), which transmits them to a laptop in the research station (4), that sends it via satellite (5) to a lab in California. Image source: `http://www.wired.com/wired/archive/11.12/network.html`