52. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCCEDINGS

10 - 13 September 2007

FACULTY OF
COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME I

Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

Session 3 - Optimisation and Management of Complex Systems and Networked Systems

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems

TECHNISCHE UNIVERSITÄT
ILMENAU

Bibliografische Information der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in der deutschen Nationalbiografie; detaillierte bibliografische Daten sind im Internet über **http://dnb.ddb.de** abrufbar.

ISBN 978-3-939473-17-6

Impressum

Herausgeber:
Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion:
Referat Marketing und Studentische Angelegenheiten
Kongressorganisation
Andrea Schneider
Tel.: +49 3677 69-2520
Fax: +49 3677 69-1743
e-mail: kongressorganisation@tu-ilmenau.de

Redaktionsschluss: Juli 2007

Verlag:
Technische Universität Ilmenau/Universitätsbibliothek
Universitätsverlag Ilmenau
Postfach 10 05 65
98684 Ilmenau
www.tu-ilmenau.de/universitaetsverlag

Herstellung und Auslieferung:
Verlagshaus Monsenstein und Vannerdat OHG
Am Hawerkamp 31
48155 Münster
www.mv-verlag.de

Layout Cover: www.cey-x.de

Bezugsmöglichkeiten:
Universitätsbibliothek der TU Ilmenau
Tel.: +49 3677 69-4615
Fax: +49 3677 69-4602

Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Ch. Ament

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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52nd Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
10 – 13 September 2007

T. Rossbach / M. Götze / A. Schreiber / M. Eifart / W. Kattanek

Wireless Sensor Networks at their Limits – Design Considerations and Prototype Experiments

ABSTRACT

Wireless sensor networks (WSN) consist of a number of autonomous nodes that are able to communicate within a limited range. In order to send a message to a destination which is not within reach of a given node, the message has to be relayed by intermediate nodes. This article details the design, implementation, and test of such a network for applications whose requirements exceed those of traditional WSNs.

I. INTRODUCTION

There is a plentitude of scientific publications dealing with the design and application of distributed sensor networks [1]. Often this concerns only a particular sub-area or a specific implementation for a given application scenario. This paper details the design of a wireless sensor network (WSN) according to specifications at the limit of what is technically feasible regarding data transfer rates and range of communications (fig. 1), aiming to reduce the impact of transmission errors and provide functionality for analysis.

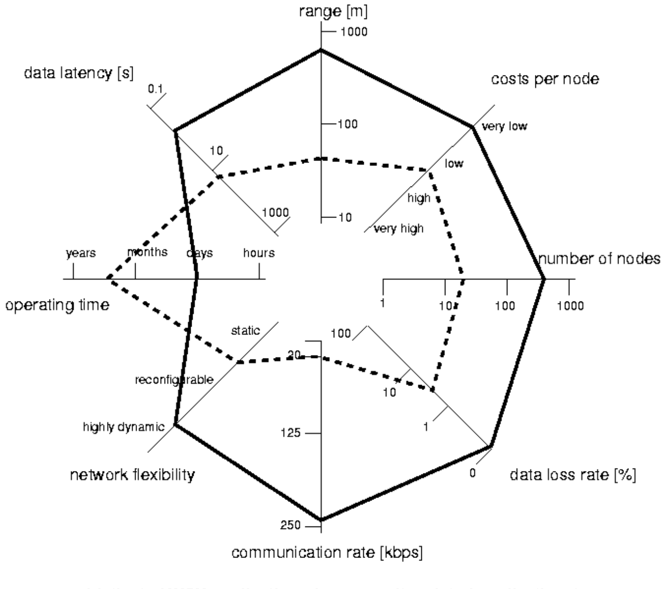

Figure 1: Different Classes of Application Requirements

A. Areas of Application

Besides military applications, there is a great variety of possible civilian applications of wireless sensor networks. These include monitoring a colony of ducks in a natural preserve on an island [10], or the acquisition and transmission of data concerning bodily functions of athletes, such as pulse and blood pressure [11], or tasks in the domain of security and surveillance technology. It is also possible to think of applications in forests, such as the acquisition of environmental data or data concerning the behavior of wildlife.

B. Requirements

A traditional sensor network consists of a number of autonomous participants, so-called motes. Each mote monitors changes in one or more sensor values, logs these and forwards them to a destination via the network. This type of network often exhibits a high density of nodes, i.e., one mote has a large number of neighbors within immediate range of communications. Sensor values accumulate at a slow rate. Packet loss is in most cases uncritical. Missing values within series of measurements can be made up for by, e.g., interpolation. Often placement and environmental conditions are known in advance. This way, the network can be designed with fixed constraints, such as range and data transmission rate, in mind.

The implementation this paper is based on, however, aims at an application of WSN technology at its limits. Motes are spread across a large area, leading to a mote typically having merely two or three neighbors within reach. Looking at the network as a whole, it is designed to be comprised of a large number of participating nodes, in the range of several hundred. Packets are, in contrast to traditional networks, sent rather frequently. To make things even more difficult, data loss is intolerable for critical data. The future conditions of deployment and environmental conditions cannot be completely foreseen or restricted during the design phase. This means that the network might be deployed within a building, in the woods, or in a densely populated area of city. Although the usual destination of data packets will be a dedicated base station, it is still necessary to transmit commands and acknowledgments in the opposite direction, i.e., into the network. A low latency in between the transmission of a packet towards the base node and an acknowledgment or reaction to it was another criterion in the design.

Given these determining factors, the functional realm of traditional sensor networks is left behind. Still, the reason for employing WSN technology consisted in such aspects as physical size, power consumption and simple installation.

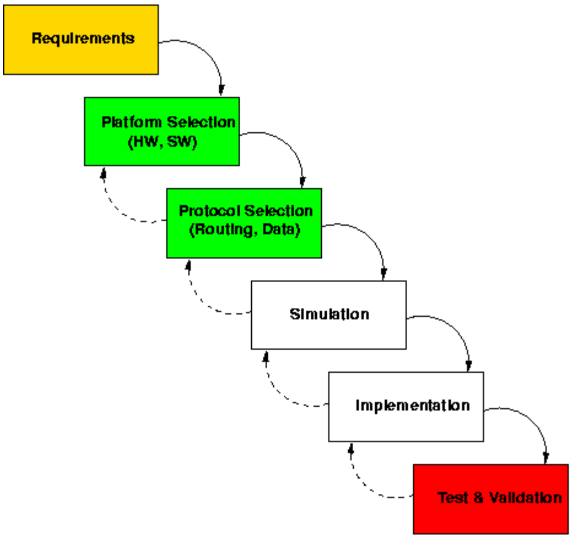

Figure 2: General Design Flow of WSN

II. DESIGN FLOW

The design of a network such as this starts with basic theoretical considerations (fig. 2). At this point, the following aspects are of primary concern:

1. The amount of data generated by each mote as well as its rate of transmission
2. The number of nodes in the network
3. A partition into critical (acknowledged) and non-critical data
4. The type and length of commands sent to a mote

When dealing with critical data, a safeguarding mechanism implemented via acknowledgments at the link and/or transport layer should be employed in order to ensure packets reach their destinations. Non-critical packets are those for which this is not a requirement. A loss of packets from this group is acceptable and is made up for by the receipt of the next packet of the same type.

A. Hardware and Operating System

One important point, particularly inasmuch as data transfer rates and communication range are concerned, is the choice of the hardware platform. Research publications tend to frequently cite the *Mica*, *MicaZ*, and *TelosB* modules by *Crossbow Technology, Inc.* An alternative to this for both research purposes and commercial deployment consists in the use of *TinyNode* [5,6] modules distributed by *Shockfish SA*. These modules employ *TinyOS* [7] — an embedded operating system tailored for WSN applications, major strengths of which consist in its modularity, portability and a reduced time-to-market. TinyOS is open-source, royalty-free software. Programming based on this OS is done in *NesC*, a C dialect extended for modularity, which speeds up development and facilitates reuse among projects. There already are a large number of ports and libraries for such purposes as routing, localization, and processing of measurement data.

B. Range

Under ideal conditions, radio waves spread according to the following formula:

$$P_E = P_S \left(\frac{\lambda}{4\pi \cdot r} \right)^2 \cdot G_S \cdot G_E$$

This formula describes how the power P_S *[W]* emitted by the transmitter decreases with the square of the distance *r [m]*. Furthermore, the received power, P_E *[W]*, depends on the wavelength λ *[m]* as well as the gains of the sending and receiving antennae, G_S and G_E, respectively.

Measurements under realistic conditions, however, are subject to further influences. For example, besides the transmission power and the sensitivity of the receiver, the maximum range also depends on the kind and structure of the environment. The height above ground and reflections of the signal by walls and obstacles also figure into this. The power of a signal received by a mote is represented by the so-called *Received Signal Strength Indicator (RSSI)*. Due to a multitude of factors, this value varies in the course of longer periods of time — even in a static network and under (seemingly) constant environmental conditions (fig. 3).

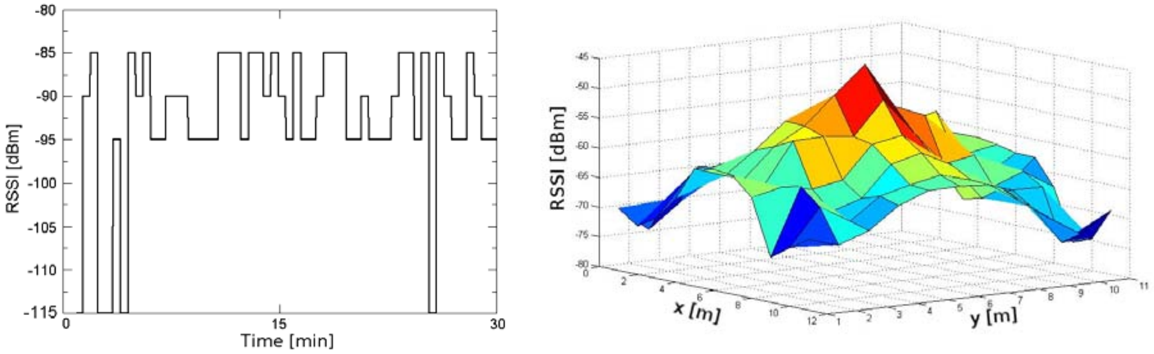

Figure 3: RSSI over the Course of 30 Minutes (left) and Radial Propagation Characteristics [2] (right)

Evaluating the radial propagation characteristics (fig. 3), it becomes obvious that those are not nearly ideal. RF links in between nodes operate accordingly.

The maximum range can be improved further through a careful design of antennae and PCBs and an optimization of transceiver parameters with respect to data transfer rate and filter bandwidth.

C. Routing Protocols

In contrast to traditional networks such as IP-based networks, new approaches and solutions had to be found for routing in mesh networks [4]. Such networks are based on links which are often unreliable and asymmetric (fig. 6) with a potentially high degree of mobility among its participants. Due to the dynamic nature of the network, the information about its topology is subject to continuous change. This also brings about the disadvantage that each node represents an unreliable component because it may fail at any time without advance warning.

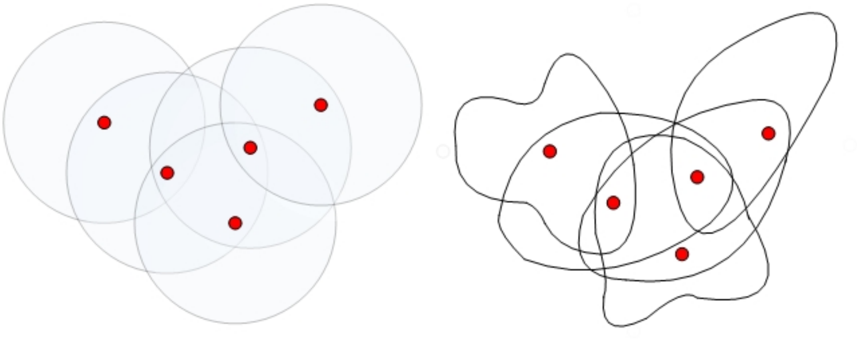

Figure 4: Ideal and Real Network Model

For TinyOS, a plentitude of routing protocols have been developed. There are geographical and topology-based, pro-active and reactive algorithms. They are often based on a link quality judgment. This may be obtained through the amount of packet loss among two nodes or based on the RSSI value. A routing algorithm chooses the optimal route according to a cost function based on the measurements.

D. Transmission Errors and Packet Loss

The link in between two nodes can be protected against packet loss by means of link-layer acknowledgments. If an acknowledgment by the receiver fails to be received, the sender repeats the message and again waits for an acknowledgment. This mechanism by itself, however, represents merely a safeguard against lost packets — they may still have suffered from transmission errors. Checking a Cyclic Redundancy Checksum (CRC) value transmitted along with the message allows for conclusions regarding the occurrence of bit errors. Figure 7 shows the accumulated number of acknowledgment and CRC errors over a period of time. The missing link-layer acknowledgments and resulting packet loss could be avoided thanks to a transport-layer acknowledgment mechanism implemented in the network software. In subsequent tests, no loss of packets acknowledged this way occurred.

Packet loss can still never be completely avoided. If a node fails to receive an acknowledgment for an extended period of time and further messages accumulate in the meantime, messages will have to be dropped sooner or later (at the latest, once the queue's capacity is exceeded). In conjunction with this, the network topology, the degree to which "bottleneck" links are utilized, and interference effects such as the Hidden Node Problem are important to consider. Acknowledgments on a secondary level (transport layer), i.e., end-to-end protection, can help reduce the impact of these effects when dealing with critical data, but they will never be completely avoidable.

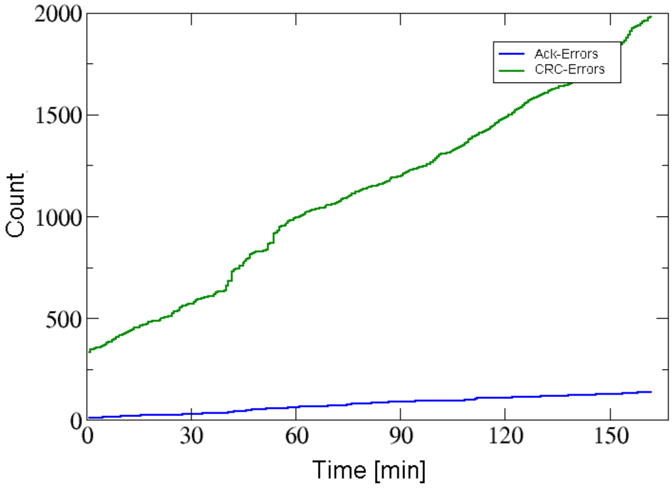

Figure 5: Acknowledgment and CRC Errors (Protocol: Drain) [3]

E. Simulation

Simulation can be used to analyze and optimize the behavior of a network and the selected routing protocol. There is a simulator already integrated with the TinyOS development environment. *TOSSim* [8] allows for simulating both lossless and lossy RF links. Unfortunately, it currently only includes a radio model for the Chipcon CC1000 radio transceiver. This makes a comparison with other platforms difficult. An alternative to TOSSim consists in using one of a variety of stand-alone simulators available, such as *OMNet++* [9]. However, in order to simulate a TinyOS-based environment, its code base first has to be transformed from NesC to regular C++ using a translator.

F. Implementation and Optimization

Profiting from the NesC concepts of software modules and components, a selected routing protocol can be implemented in a modular fashion. For the application whose development this paper is based on, the protocols *Drain* (for any-to-one routing with a fixed base node) and *Drip* (for commands and acknowledgments) have been chosen. The existing TinyOS implementation offers a versatile programming interface which lent itself well to custom extensions, such as acknowledgments of messages on both the link and transport layer, improvements to the cost function employed by the Drain algorithm, and functions for processing measurement data. Added functionality includes:

- Route tracing to the base node
- Roundtrip time measurement as a basic latency indication
- Acknowledgment and CRC error monitoring
- Monitoring of the amount of data transmitted and received by individual nodes
- RSSI and battery voltage monitoring

IV. SUMMARY AND OUTLOOK

This paper has attempted to describe the process from the selection of a hardware platform through the required research into routing protocols and their simulation to a software implementation which is functional and can be deployed in practice. The system designed covers a broad spectrum of applications which go beyond what WSNs are typically used for. Besides the transmission of arbitrary packets of data, performance data concerning the network can be logged and analyzed.

The focus of ongoing work consists in improving upon and optimizing the routing protocol. Goals include a shorter response time to topology changes, error detection and correction, and further optimizations of the link cost calculation.

References:

[1] A. Schreiber, M. Götze, E. Ulicna, W. Kattanek, „System design issues in advanced applications of wireless sensor networks," Internationales Wissenschaftliches Kolloquium, Ilmenau, 2006.
[2] M. Eifart, „Entwicklung einer Lokalisierungslösung für mobile Knoten innerhalb drahtloser Sensornetzwerke für Freifeldanwedungen," Diploma Thesis, Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH, Ilmenau, 2007.
[3] T. Rossbach, „Aufbau eines Mesh-Netzwerkes und Optimierung in Bezug auf relevante Kennwerte," Diploma Thesis, Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH, Ilmenau, 2007.
[4] M. Abolhasan, T.A. Wysocki, and E. Dutkiewicz, "A Review of Routing Protocols for Mobile Ad hoc Networks", In: Elsevier Journal of Ad hoc Networks, 2 (2004), 1-22.
[5] H. Dubois-Ferrière, R. Meier, L. Fabre, and P. Metrailler, "TinyNode: A Comprehensive Platform for Wireless Sensor Network Applications." In: Information Processing in Sensor Networks (IPSN 2006), 2006.
[6] <http://www.tinynode.com/>
[7] <http://www.tinyos.net/>
[8] Philip Levis, Nelson Lee, Matt Welsh, David Culler, "TOSSIM: Accurate and Scalable Simulation of Entire TinyOS Applications." In: Proceedings of the First ACM Conference on Embedded Networked Sensor Systems (SenSys 2003).
[9] < http://www.omnetpp.org/>
[10] Intel Research Laboratory, "Great Duck Island, In-Situ Sensor Networks for Habitat Monitoring," <http://www.coa.edu/html/motes.htm>
[11] "WHMS - Wearable Health Monitoring Systems," <http://www.ece.uah.edu/~jovanov/whrms>

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