-SomSed-
The Evolution of an Experimental Wireless Sensor Network Towards a Research Platform

Felix Hackbarth[1], Thomas Meyerhoff[2], Harald Sauff[3], Bryce T. Bradford[4], Luis Torres[5], Helge Klimek[6], Björn Gressmann[6], Christian Renner[6], Martin Stemick[2], Sebastian Georgi[2], Christoph Weyer[6]
[1]Institute of Automation, [2]Institute of Telecommunications, [3]Institute of Security in Distributed Applications, [4]Institute of Microsystems Technology, [5]Institute of Communication Networks, [6]Institute of Telematics,
Hamburg University of Technology
Email: https://somsed.tu-harburg.de/junior/phdstudents

***Abstract*—The exploratory focus of the SomSed research field is the interdisciplinary research on self organizing mobile sensor and data networks. Since the founding of SomSed in 2007, great progress in scientific research has been achieved and much practical knowledge has been gathered using a prototype network permanently installed. This prototype network, from hereon referred to as CampusNet, is the basis for further investigations and offers the possibility to perform long term measurements in a large scale and real environment. The scope of this paper is to outline the current status of the SomSed research field and to briefly discuss future developments.**

I. Introduction

Self organizing mobile Sensor and data networks (SomSed) is a research field at the Hamburg University of Technology. While the cooperation among the professors of the institutes is common, doing research in cooperation between undergraduates and Ph.D. students of different institutes is rare. As announced in a previous paper [1] the institutes work together in a matrix like organization structure on topics concerning wireless sensor networks. In doing so, the institutes can concentrate on their core competences concerning this research field. The unique collaboration of several institutes forms a broad basis for research.

The Ph.D. students branch of SomSed focuses on their own special research topics and implemented a wireless sensor network on the campus of the Hamburg University of Technology. The cooperation on undergraduate and Ph.D. student level also profits from this approach and leads to additional synergy effects and knowledge transfer between the collaborating institutes.

The institutes themselves use the knowledge gained in SomSed. For example, experiences gained in SomSed are used to build up sensor networks for cruise and container vessels, and doing feasibility studies of using 2.4GHz applications in these environments [2]. Another approach is to investigate multi-coverage based broadcasting in order to increase reliability in a wireless sensor network, as presented in [3]. In this approach an Integer Linear Program (ILP) has been applied to multimedia data transmission inside an aircraft passenger cabin. The solution provides compact routing and scheduling of the relaying nodes.

II. CampusNet

During the last year SomSed-Active developed and deployed an experimental wireless sensor network on the campus referred to as CampusNet. The CampusNet consists of 26 fixed nodes of type IRIS from the company Crossbow Technology [4]. The nodes are based on an ATmega1281 microprocessor with an integrated 2.4 GHz IEEE 802.15.4 radio transceiver. The nodes run the open source operating system TinyOS version 2.x.

Before the construction of the CampusNet started a series of open field measurements of connectivity and signal strength of the IRIS nodes have been carried out. The results of these measurements were used to find an adequate placement in terms of connectivity for the participating nodes. The placement of the nodes is shown in Fig. 3 using small circles.

The software for the CampusNet can be divided into three parts: The sensor node firmware, which is responsible for routing, tree construction, sensing, power management and data buffering, and the frontend and backend software. The backend software just persists incoming data from the sensor network into a database and is the initiator of regularly occurring tree constructions. The frontend software is used for analysis and visualization of the stored information. The routing mechanism and the frontend software are described in more detail in the following sections.

A. Routing

The purpose of this network was at first to collect data about signal strengths and link quality for validation of a wireless sensor network of this dimension. Since this stage only measurements are to be obtained, a tree routing structure was implemented (see Fig. 3). Therefore there is only one sink in the network that writes all received packets into a database.

In order to fulfill the need of a long living or real time network, the CampusNet supports two operation modes: one active and one passive mode. In active mode measured data

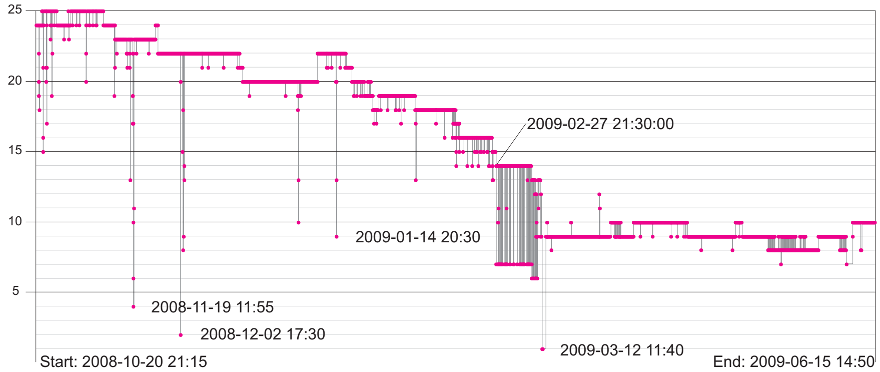

Fig. 1. Nodes participating in the tree over time.

will be forwarded on continuously in real time. This results in high energy consumption, because the transceivers of the nodes will be permanently switched on. In passive mode the participating nodes perform wake-sleep intervals of 15 minutes. After waking up, they send their own data and forward the packets received from other nodes to nodes closer to the sink. Then they go back to sleep mode in order to preserve battery power to extend their lifetime.

In either mode, a routing tree is generated every hour to determine the best route to the sink in terms of signal strength and link quality. This is necessary, because environmental conditions may change rapidly. For example, around lunch times the canteen is densely populated and many people are using wireless LAN. This can cause a reduction of the link quality between nodes nearby and has to be compensated by the routing algorithm. The generation of a new routing tree is initiated by a tree construction packet sent by the sink. This packet contains the type of the actual mode, a timestamp during which the new tree is valid and the local time of the data sink. The nodes receiving this packet use it to adjust their clock and to determine their parent node. If a node receives several tree construction packets sent by different nodes, the node with the highest received signal strength indicator (RSSI) is chosen as parent. By receiving several tree construction packets the nodes are capable of repairing a tree if one connection fails. If this is the case, an alternative parent is chosen. The connection parameters like link quality and signal strength and the clock synchronization offset of each node are recorded into the database. The collected data is currently being analyzed.

B. Frontend

In order to have a useful visualization and to store data measured by the CampusNet a web-based frontend was developed. This web-based frontend of the CampusNet is accessible via `http://www.sva.tu-harburg.de/~somsed/website/`. The Google-maps-API is used to show the positions of the nodes and the actual routing tree. A screenshot of the map showing the CampusNet is shown in Fig. 3. When a specific element is selected, an information frame shows all measured data of that selected element. For example, selecting a node displays several graphs showing its measured data, while selecting a tree branch displays its link quality indicator (LQI) and received signal strength indicator and packet success rate (PSR). Using a time shift function different points in the lifetime of the CampusNet can be visited and the different created trees can be seen in time lapse. If mobile nodes are participating in the network, their motion paths are also shown on the map.

Fig. 2. Solar power module for an iris node with emergency battery, solar panel, electronics with node adapter and rechargeable lead batteries.

The basis of the frontend is a database where all the measured data and statistics are stored.

III. Hardware Developments

In the last year several hardware developments have been made by SomSed-Active that added functionality to the CampusNet.

A. Solar Node

The solar node developed was subject of a diploma thesis [5]. The goal was the design of a cost effective and robust solar module, which is able to power the whole sensor node even under unfavorable weather conditions.

Therefore, a solar module with high efficiency and power rating had to be found. In order to bridge the gap of the solar power supply during nights and bad weather conditions, an additional battery charging system has been developed, too.

As a result of [5], a prototype of the solar node has been built and was successfully integrated into the CampusNet. The concept demonstrated its robustness over the past eight months until today, in spite of seasonal low solar radiation during the winter months. The developed module for the node is shown in Fig. 2.

Because of the success of the solar modules and the advantages of an independent power supply, ten more solar nodes are currently being built. Their deployment will result in a small energy autonomous sensor network, which will be subject of further investigations.

B. Over the Air Programming

Sensor nodes are usually programmed using an interface device which is connected to a computer. Once the sensor nodes are programmed and deployed at their locations, it is often difficult to install new software. Sensor nodes may be deployed in high altitudes, hazardous areas, or out of reach for other reasons. In these cases, programming sensor nodes becomes a significant challenge. Over the Air Programming (OTAP) is a technique which aims at eliminating this problem. It reduces the effort of maintaining a wireless sensor network, because the nodes do not have to be physically accessible for programming or maintenance.

An own OTAP module was developed for the CampusNet, as described in [6]. It provides an intuitive user interface and offers a set of important features:

- Several images on a node: Every sensor node is able to carry different program images from which one can be chosen for execution.
- ID of image name and version: IDs allow to identify and distinguish program images.
- Check OTAP compatibility: Safeguards have been implemented in order to prevent non-OTAP images to be written to a node.
- Golden image: In case of error, a fall-back image will be selected for execution, providing basic maintenance capabilities.
- Easy setup of nodes for OTAP: Once a node has been prepared with the initial image no further wired communication is necessary.
- Support for heterogeneous networks: The OTAP capabilities can simply be integrated in different programs.

The capability to store more than one image on a node provides the opportunity to easily switch between different software functionality. The configuration of the whole network can be changed with a minimum of effort. In case of an erroneous image, the golden image will be automatically selected as the working image to reestablish OTAP-functionality for reprogramming.

C. 4-Sensor-Board

The 4-Sensor-Board is an extension to the IRIS node. It measures temperature, ambient light intensity, relative humidity, and air pressure. An integrated solar power generation module keeps the on board rechargeable batteries charged. The task was to perform continuous measurements of the described parameters in the CampusNet. The board was designed to meet these measurement requirements, while also operating with very low power consumption. As an example: while sampling the environment once every ten seconds and transmitting the data every 40 seconds the average power consumption is 174μW, which corresponds to a battery life of more than four years.

IV. Experience gained with the CampusNet

Since the deployment of the CampusNet among others, almost 360.000 database entries containing measured sensor data have been stored. More than 820.000 entries containing neighborhood information have been recorded, each consisting of link quality indicator, received signal strength indicator, packet success rate, the number of duplicate packets, the amount of missed packets and the number of received packets. The data traffic at the sink was also documented. Given the recorded information, it is possible for any time in the past to reconstruct the trees that were created, their link properties and the sensor data. As already mentioned, this data is currently being analyzed with focus on the clockdrift-temperature and link quality-environment dependencies.

During the last months several lessons have been learned: The tree routing structure caused congestion of data packets near the sink. The reason is the increased channel utilization

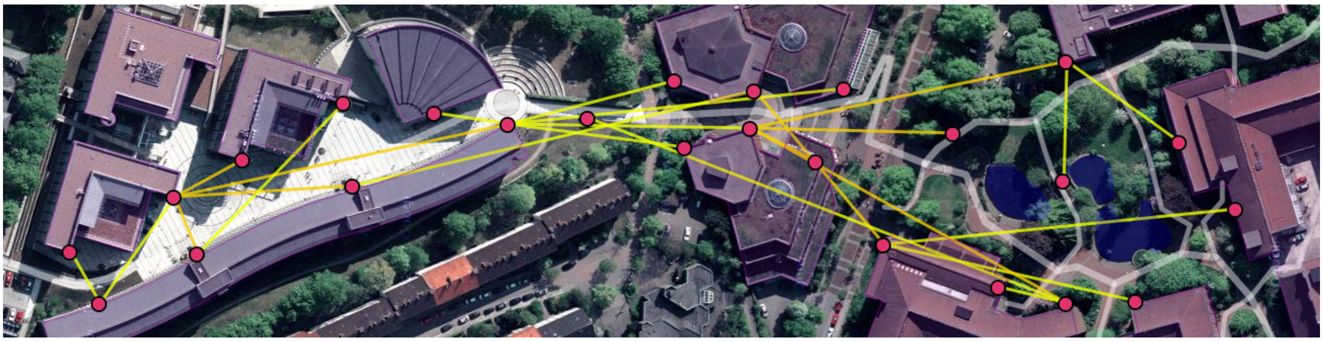

Fig. 3. Routing tree on the CampusNet on Nov. 1st 2008 0:00 am.

while data packets are traveling from a leaf node through the tree.

Another aspect is the asymmetry of links between nodes. More precisely, the tree is constructed taking the highest quality links downwards from the sink to the leaves. But the link quality upwards the same connection is not necessarily of the same quality. This may result in packet loss.

There were also problems with the casing of the nodes. These had the protection category of IP55. As it turned out, the bushings were not sealed against water intrusion. To add additionally waterproofing to the case, silicone was used as gasket. But acetic acid was exhaling from the silicone causing corrosion of some of the electronics. Moreover the temperature and humidity variation in combination with direct sunlight on the case and nightly temperature drops caused condensation that dripped onto the nodes electronics. Over the last months, the water in the cases only caused some node losses. After drying, these nodes were still fully functional.

For the next long-term deployment these problems have been solved.

Fig. 1 shows the nodes and node losses over time and also the stability of the trees. For example from February 27th on, the number of nodes in the tree varied from 14 to 7. This is a result of the elongated region that is covered by the CampusNet. If regions are connected through few bottleneck nodes, the tree is very sensitive to their failure. In the CampusNet, this bottleneck caused the cutoff of the lower campus (in Fig. 3 right part of the network).

V. Work in Progress

Currently the CampusNet is deployed and collecting data. The results of the evaluation of the collected data will be used to set up the next generation of the CampusNet.

The long term goal for the next generation wireless sensor network is to develop a platform for scientific research for students and staff of the university. Consequently, a modular design is currently being developed, which allows fast realization of research projects.

This design consists of the following modules:

- Extended OTAP-Module
- MAC-Layers
- Network-Layers
- TinySec-Security-Module
- Sensor-Interface-Module

The different modules form building blocks which are used to combine them into a node firmware which provides the infrastructure for individual research projects.

In general, it is desirable to not congest the network tree with additional data during experiment runs. On the other hand, it is often necessary to collect logging and performance data for later evaluation.

To meet these requirements, OTAP is enhanced with data persistence functionality. The new functionality enables a node to collect logging data for debugging. Aside from logging, the module can be used for structured data persistence of other data as well. Relatively large amounts of data can be stored on the node for later processing.

OTAP will use the large memory space which is also used to store program images to store its data. This allows for flexible assignment of nodes, depending on whether data collection assignments are expected.

The collected data will be transferred wirelessly like program images once experiment runs have finished. It is also planned to provide the developer with tools that help translating logging data, stored in compact form on the node, to human readable text.

A nodes firmware can be built to choose out of a set of MAC- and Network-Layer modules.

Additionally, a security layer can be included to enable secure communication.

Finally, a generalized sensor module interface provides uniform access to sensors attached to the nodes.

Since the network configuration can be switched fast from one application to another, easy sharing of the resource CampusNet among the participating institutes is possible.

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