

# 1 Research Group on Computer Networks and Distributed Systems

## 1.1 Personnel

<b>Head:</b>	Prof. Dr. T. Braun	Tel.: +41 31 511 2631 email: braun@iam.unibe.ch
<b>Office Manager:</b>	R. Bestgen	Tel.: +41 31 511 2630 email: bestgen@iam.unibe.ch
<b>Scientific Staff:</b>	M. Anwander*	Tel.: +41 31 511 2634 email: anwander@iam.unibe.ch
	M. Brogle*	Tel.: +41 31 511 2632 email: brogle@iam.unibe.ch
	Dr. K. Dolfus*	Tel.: +41 31 511 2639 email: dolfus@iam.unibe.ch (since April 2009)
	P. Hurni*	Tel.: +41 31 511 2640 email: Wälchli@iam.unibe.ch
	D. Milic*	Tel.: +41 31 511 2633 email: milic@iam.unibe.ch
	T. Staub*	Tel.: +41 31 511 2637 email: staub@iam.unibe.ch
	G. Wagenknecht*	Tel.: +41 31 511 2636 email: wagen@iam.unibe.ch
	M. Wälchli*	Tel.: +41 31 511 2638 email: Wälchli@iam.unibe.ch (until June 2009)

\* with financial support from a third party

## 1.2 Overview

The research group for Computer Networks and Distributed Systems (Rechnernetze und Verteilte Systeme, RVS) has been active since 1998 in several areas of computer communications and distributed systems.

**Multimedia Communications** The Internet is increasingly being used for multimedia data transfer (audio, video, data). We are investigating how services with high demands on the quality and reliability of communication systems and networks can be supported. Overlay networks and peer-to-peer systems are becoming more important for new Internet services, in particular to support communication within user groups. We are focusing on the design, development, and evaluation of methods to construct overlay networks supporting the quality-of-service requirements of distributed applications and using network resources efficiently.

**Wireless and Mobile Communication** Decentralized system architectures and self-organization are fundamental concepts of future wireless and mobile communication systems. These concepts are particularly important in application scenarios such as sensor networks, mobile ad hoc networks and wireless mesh networks. There is an urgent need for research on routing and transport protocols as well as on security and management mechanisms. In sensor networks, limited energy, computing and memory resources as well as limited reliability require special forms of distributed data processing and management.

**Security in Distributed Systems** The Internet simplifies access to distributed resources and services such as web services, e-learning contents, computer grids or sensor nodes. Traditional techniques for authentication and authorization are not very user-friendly and barely scalable. We investigate, design, implement, and evaluate novel schemes for efficient and secure authentication and authorization.

**Distance Learning** In all our lectures, we are using distance learning elements that are based on standard components but also on developments resulting from recent research projects. We are developing new methods and tools to support learners and teachers in e-learning environments. In particular, we aim to support practical experiments.

## 1.3 Research Projects

### **National Competence Center in Research for Mobile Information and Communication Systems (NCCR-MICS)**

The NCCR-MICS (<http://www.mics.ch>) project was launched in 2001. Its goal is to study fundamental and applied research questions raised by new generation mobile communication and information services, based on self-organization. Such systems have become very topical with the advent of mobile ad-hoc, peer-to-peer, and sensor networks. The 2nd phase of NCCR-MICS is composed of more than twenty research projects distributed over four clusters. The research project of the RVS group on “Distributed event detection and localization architecture for wireless sensor networks” (IP4) aims at designing and implementing a distributed event detection, event localization, and event classification framework. It includes efficient and reliable signaling protocols as well as mechanisms to dynamically reconfigure its specific sensor network applications.

We investigated the classification of discrete events, computed on tiny wireless sensor nodes. Three different classifiers have been evaluated: a Bayesian classifier, a fuzzy logic controller, and a neural network approach. We assume that no a priori knowledge about the event classes is available and events are only observable as collections of raw sensor data. Accordingly, event classes need to be learned from that raw training data. In our work, event classes are learned by a k-means clustering algorithm. Any subsequent classifier training is based on these extracted event classes. Thus, the resulting classifiers are completely self-learning. Event classes are learned from emitted signal strength estimations, which are collected and processed by dynamically established tracking groups. The resulting event estimates are reported to a base station, where the classifiers are trained. The learned classifier parameters are then downloaded onto the sensor nodes, where any subsequent classification and filtering is performed.

Furthermore, we developed a node-level decision unit of a self-learning anomaly detection mechanism for office monitoring with wireless sensor nodes. The node-level decision unit is based on Adaptive Resonance Theory (ART), which is a simple kind of neural networks. The Fuzzy ART neural network used is an adaptive memory that can store a predefined number of prototypes. Any observed input is compared and classified in respect to a maximum number of  $M$  online learned prototypes. The Fuzzy ART neural network is used to process, classify, and compress time series of event observations on sensor node level. Based on simple computa-

tions, each node is able to report locally suspicious behaviour. A system-wide decision is subsequently performed at a base station. The system has been used for the detection and reporting of abnormal building access with a wireless sensor network. An office room, offering space for two working persons, has been monitored with ten sensor nodes and a base station. The task of the system is to report suspicious office occupation such as office searching by thieves. On the other hand, normal office occupation should not throw alarms. In order to save energy for communication, the system provides all nodes with some adaptive short-term memory. Thus, a set of sensor activation patterns can be temporarily learned. Unknown event patterns detected on sensor node level are reported to the base station, where the system-wide anomaly detection is performed. The anomaly detector is lightweight and completely self-learning. The system can be run autonomously or it could be used as a triggering system to turn on an additional high-resolution system on demand. Our building monitoring system has proven to work reliably in different evaluated scenarios. Communication costs of up to 90% could be saved compared to a threshold-based approach without local memory.

Moreover, research on sensor MAC and routing protocols for sensor-based distributed monitoring applications has been performed. Contention-based MAC protocols following periodic listen/sleep cycles face the problem of virtual clustering if different unsynchronized listen/sleep schedules occur in the network. Border nodes, which maintain all respective listen/sleep schedules, are required to interconnect these virtual clusters. This is however a waste of energy, if locally a common schedule can be determined. We propose to achieve local synchronization with a mechanism that is similar to gravitation. Clusters represent the material, whereas synchronization messages sent by each cluster represent the gravitation force of the according cluster. Due to the mutual attraction caused by the clusters, all clusters merge finally. Moreover, we developed a routing backbone construction mechanism that exploits and uses the synchronization messages exchanged by synchronized contention-based MAC protocols. Due to the usage of synchronization messages no additional control traffic is required to setup the routing backbone. Every node running a synchronized contention-based MAC protocol follows a given listen/sleep cycle. Because routing is supported by the backbone, non-backbone nodes can temporarily turn off their radios for multiple listen/sleep cycles. Thus, additional energy can be saved. Accordingly, non-backbone nodes do not have to wake up in every listen/sleep cycle to synchronize with other nodes, but wake up only if they have to report some sensor readings to a base station. In this case, they synchronize to the

backbone, send their data, and go back to sleep after successful transmission. Our approach is applicable to rather static networks with mainly source-to-sink traffic. Most monitoring applications are of this kind.

**Research staff:** Markus Wälchli, Reto Zurbuchen, Samuel Bissig, Torsten Braun

**Financial support:** Swiss National Science Foundation Project No. 5005-067322 and University of Bern

## **Mobile IP Telephony (MIPTel)**

Wireless mesh networks (WMN) are evolving to an important access technology for wireless broadband services. They provide a cost efficient way to interconnect isolated networks as well as to enhance wireless network coverage. WMNs usually consist of static mesh routers and mobile or static mesh clients. Both support multi-hop communication and may act as routers. The mesh nodes might support multiple heterogeneous radio interfaces. WMNs offer a more robust and redundant communication infrastructure than many wireless networks deployed today. They provide communication facilities even in special situations where certain systems such as GSM are overloaded.

Our project aims at exploiting WMNs as an infrastructure for Mobile IP telephony. IP telephony requires short delays and moderate packet loss. In WMNs the quality of the routes may vary unpredictably because of the unreliable and erroneous wireless medium. Routes may break, if the network topology changes due to node or link failures. Links and nodes may become congested, which leads to larger delays or packet loss. This makes the deployment of a real time application such as IP telephony a challenging task.

We see two important approaches to improve the speech quality and to reduce outages in a Mobile IP telephony application in WMNs: path diversity and multi-stream coding. The characteristics of multiple paths are usually uncorrelated, i.e., the delay, jitter, and loss rate of the paths differ a lot from each other. Therefore, the transmission over multiple paths can be used to compensate for the dynamic and unpredictable nature of WMNs. In order to exploit this path diversity for improving the quality of the audio transmission, a robust multi-path routing protocol and a mechanism for selecting appropriate coding and path allocation for the given network conditions are needed.

ATOM (Adaptive Transport over Multipaths), which is an architecture to enable real-time communications in Wireless Mesh Networks, has been enhanced. ATOM reduces the problems of real-time transmissions over WMNs by using path diversity and multi-stream coding. At session establishment, ATOM decides on the used parameter set (encodings, paths etc.) considering current network conditions and collected historic data. After session establishment, the effect of this decision is continuously monitored and if necessary adapted.

Multi-stream coding is one of the key parts of the ATOM architecture. In order to evaluate video codecs, we have defined a video evaluation framework for the OMNeT++ simulator. At the source, a video file is transcoded by the open source library ffmpeg into streams with the defined codec/parameters and then transmitted through the simulated network. At the destination, the video is reconstructed from the received packets and then compared with the original file by quality metrics.

A heterogeneous real-world test bed has been established for the MIPTel project. The testbed consists of PCEngines Wireless Router Application Platform (WRAP), PCEngines ALIX, and Meraki Mini nodes. We tailored an embedded fully functional Linux with a small footprint to our three node types. The image build process is integrated in ADAM (Administration and Deployment of Adhoc Mesh networks). ADAM supports cross-compilation and individual build configuration for the three node types. The ADAM build and management system is highly modular and can be easily extended with additional software packages or ported to a new node type. It fully supports IPv6, flexible management nodes, and ad-hoc routing protocols. In addition, ADAM provides mechanisms for deployment and configuration a wireless mesh network. It guarantees the availability of the network despite configuration errors or faulty software updates by the mean of various fallback behaviors. It even provides a safe update of the operating system. ADAM has been selected as a candidate for the KuVS Communication Software award and has been presented to a wide audience at the KIVS conference.

We have revised VirtualMesh, which provides a virtualization of a complete wireless mesh network by using host virtualization (XEN) for the mesh nodes and redirecting their wireless network traffic to a network simulator. Our revisions include several performance enhancements and a new virtual wireless driver. For the Linux networking stack, the driver now behaves as a normal wireless driver although it is performing the traffic redirection to the simulator.

In addition, we have started the implementation of a temporary WMN based system to support video communication in large construction sites,

which faces the problem of missing communication facilities at the time of electric installation. By providing video communication over an “easy-to-install” temporary WMN, the requirement of costly on-site visits by an electrical engineer is reduced.

**Research staff:** Thomas Staub, Stefan Ott, Daniel Balsiger, Reto Ganzenbein, Christine Müller, Daniel Balsiger, Simon Morgenthaler, Roger Strähl, Torsten Braun

**Financial support:** Swiss National Foundation Project No. 200020-113677/1

## **Efficient and Robust Overlay Networks (ERON)**

The ERON projects aims at developing an efficient and robust overlay network. An overlay network is a virtual communication network built on top of an existing communication network such as the Internet. Overlay networks are used for different tasks such as routing of multicast messages. Since the full-mesh overlay network, in which every pair of participants is communicating directly with each other, is not scalable, overlay networks usually have other structures. One of the most important criteria for deciding, which overlay network participants get “connected” is the communication delay, since it is the limiting factor on the maximum effective bandwidth for the TCP connections. Similar to a full-mesh overlay network, measuring the communication delay between all overlay participants does not scale. To exploit the communication delay information, numerous communication delay prediction systems such as IDMaps, GNP, ICS, Vivaldi, S-Vivaldi etc. were developed. Most promising communication delay prediction systems are coordinates-based. In coordinates-based systems, communication partners are represented as points in an  $n$ -dimensional Euclidean space such that the distance function in that space predicts the communication delay.

In the last year, we have focused our research on building of topology aware overlay networks and assigning positions to end systems. The challenge of building an overlay network is the scalability. This means that the size of the overlay network should not be limited. If every end system participating in the overlay network would store the information about every other end system, the size of the overlay network would be limited by the memory available to end systems and this should be avoided. Instead, every end system should store a constant number of “neighbors” known to

him. This choice of neighbors is crucial for the performance of the overlay network. Most overlay networks choose the neighbors randomly or based on some criteria that does not correlate with the topology of the underlying network. For example, Chord chooses the neighbors in such a way, that the number of routing hops in the overlay network is minimized.

For building of an topology aware overlay network, we pursued the approach, where each end system should have a so called “fisheye view” of the overlay network. A “fisheye view” of the overlay network means that each end system makes a choice of limited number of neighbors in such a way, that this choice of neighbors resembles to a fisheye view. In this context, fisheye view means that the chosen neighbors are equally distributed in each direction around the end system (geographical diversity) and that the density of the neighbors decreases with increasing distance to the center of the view. As a result of our research, we were able to define a communication protocol that is able to build a fisheye view on each end system. We were also able to enhance this communication protocol in such a way, that the resulting graph of the overlay network is bi-directional. Having an overlay network that is a bi-directional overlay graph has an advantage that the graph is guaranteed to be connected. This means that there is at least one route for every pair of end systems participating in the overlay network. Simulations of our overlay network protocol have shown that the overlay network we create performs better than the overlay network created using another topology aware approach called binning in the terms of RTT stretch. Our approach for creating the overlay network does not require embedding of end systems into a virtual space. This makes it suitable for performing the embedding of end systems into a virtual space. After evaluating different methods, we have decided to an existing approach named VIVALDI as the basis for the embedding and to improve it. The main drawback of VIVALDI is its instability. Namely, in VIVALDI hosts tend to permanently change their positions even if the RTTs in the network do not change. Our improvements of VIVALDI included using our fisheye overlay network. We also improved VIVALDI in the sense of changing how end system changes its position. Both improvements combined resulted in an approach we named NetICE9. Our evaluation of NetICE9 has shown, that NetICE9 outperforms VIVALDI both in terms of precision of RTT embedding and stability of the end system positions. At the same time NetICE9 also performs better in terms of RTT embedding precision compared to GNP.

We also showed that our proposed approach for exploiting statistical properties of performed measurements of RTTs results in worse RTT predictions. Hence, we will not continue pursuing this idea.



**Research staff:** Dragan Milic, Roger Strähl, Torsten Braun

**Financial support:** Swiss National Foundation Project No. 200021-109270/1

## **E-learning in Distributed Data Network Laboratory (Edinet)**

Edinet (<http://www.svc-edinet.eu>) is a multilateral cooperation project in the 'Lifelong Learning Programme' of the European Commission. Its objectives are to a) analyse common pedagogical principles for blended learning (blended learning include several forms of learning tools) based on common understanding as a ground for curriculum development and implementation; b) promote virtual mobility by implementation of semi-virtual campus (a virtual campus where actually studies will be done with real equipment via network connections); c) enhance open education resources by sharing, integrating, and mutually improving local resources (including knowledge) and best practices by establishing a semi-virtual campus; and d) to promote the usage of expensive laboratory environment through an innovative blended eLearning system in the field of data network technology.

Our research group is mainly involved in two work packages. For the Edinet infrastructure we have developed the Authentication and Authorization Infrastructure (AAI). We have established a European AAI federation for Edinet, which is comparable and compatible to the SWITCHai. This includes the creation of a software package and an installation guide for an identity provider (IdP) as well as supporting partners during setup and maintenance. In addition, we integrated the existing IdP of the University of Bern in the Edinet federation (multi-federated IdP).

An e-learning module on TCP congestion control has been developed and several contributions to other work packages like for the pedagogical framework of the Edinet virtual campus have been provided.

**Research staff:** Markus Anwander, Thomas Staub, Torsten Braun

**Financial support:** Staatssekretariat für Bildung und Forschung SBF, LLP/Erasmus, Edinet, SBF-No. LLP/07/06-E

## **Energy-efficient Management of Heterogeneous Wireless Sensor Networks**

This project investigates efficient and reliable communication mechanisms for the operation of a wireless sensor network (WSN) management framework. Reliable and robust transport protocols are needed to distribute operating system / application level code and node parameters efficiently as well as to solicit specific node information.

ESB, tmote SKY, BTnodes and micaZ nodes have been chosen to build a heterogeneous sensor network. For the backbone a Wireless Router Application Platform Board (WRAP) has been selected. The mesh network allows to interconnect WSNs with sensor nodes of different types.

In order to realize such interconnection between the WSN and an external network without any proxies or middle-boxes, we propose to use TCP/IP as the standard protocol for all network entities, e.g., for configuration and uploading application code to the sensor nodes. We developed the TSS (TCP Support for Sensor Nodes) protocol, which enables using TCP in wireless sensor networks. TCP/IP allows to connect a WSN to other networks such as the Internet. Thus, a user can monitor, control and manage WSNs remotely. The TSS protocol is located between IP and TCP. It contains a number of mechanisms, such as caching packets, local retransmission, aggressive acknowledgment regeneration and recovery. Packets are cached on intermediate nodes on the path from the sender to the receiver. In case of a lost packet a end-to-end retransmission is avoided. This reduces the number of transmitted packets and thus energy consumption. In case of lost acknowledgment packets the intermediate node can regenerate the acknowledgment to avoid unnecessary retransmissions.

We developed a MAC protocol called BEAM (Burst-enabled Energy-Efficient Adaptive MAC) implementing the MAC layer of nonbeacon-enabled personal area networks defined in the IEEE 802.15.4 standard for peer-to-peer topologies. It provides multihop communication and is the first implementation in this way. The MAC protocol holds a buffer of configurable size to store the incoming frames from the lower layer (radio transceiver) and the upper layers (H2HR). To ensure a reliable hop-to-hop transmission we use explicit acknowledgments and implicit acknowledgments. The energy efficiency is ensured using adaptive duty cycles.

A good way to support end-to-end reliability is to ensure hop-to-hop reliability between two neighbor nodes. We developed the H2HR (Hop-to-Hop Reliability) protocol. Informed by the MAC protocol, H2HR reacts on two different kinds of problems. A packet can be lost due to interferences or

due to congestion. If a packet has been transmitted, but there are no implicit or explicit acknowledgements, the packet is considered lost due to interferences by a hidden node. In this case the transmission is retried immediately. If the transmission has failed, because the channel is busy, congestion is detected. H2HR initiates the retransmission after a random time.

To optimize the performance of the protocols interchanging cross layer information is necessary. Thus, we designed a cross layer interface. Every protocol can subscribe for information from another protocol. Thus, protocols on different layers can better collaborate. For example, the physical layer can provide additional information about the transmissions. The radio transceiver provides information about the channel and the signal to the MAC protocol, which decides whether a frame can be transmitted to a neighbor node. The MAC and the H2HR protocol exchange information about retransmission state of a frame. This information is important for reliability and congestion control mechanisms.

The protocols have been implemented in the OMNeT++ simulator and evaluated with several scenarios. We compared a pure TCP and UDP implementation and a TCP and UDP implementation with H2HR. To compare our approach with other related work, we implemented RMST as well and compared the performance using H2HR. Our simulations showed that in general, hop-to-hop reliability mechanisms affect the performance of TCP, UDP, and RMST significantly in WSNs.

In management scenarios such as code updates it is necessary to transmit the same data to many sensor nodes. Multicast communication on transport layer would reduce the amount of transmitted packets. We implemented SNOMC (Sensor Node Overlay Multicast) protocol which realizes a source driven decentralized multicast scheme. Thus, the number of transmitted packets is decreased significantly. As less packets are in the network at the same time as less interferences and less packet loss can occur. Thus less packets have to be retransmitted and the transmission time decreases significantly as well.

**Research staff:** Markus Anwander, Gerald Wagenknecht, James Math-  
eka, Simon Morgenthaler

**Financial support:** Hasler Foundation under grant number ManCom  
2060 and the Swiss National Science Foundation under grant number  
200020-113677/1

## Wireless Sensor Network Testbeds (WISEBED)

The *WISEBED* project (<http://www.wisebed.eu>) started in June 2008. It aims to provide a multi-level infrastructure of interconnected testbeds of large-scale wireless sensor networks for research purposes, pursuing an interdisciplinary approach that integrates the aspects of hardware, software, algorithms, and data. In the *WISEBED* project, researchers are implementing recent theoretical results on algorithms, mechanisms and protocols. The project intends to later make these distributed laboratories available to the European scientific community, so that other research groups will take advantage of the federated infrastructure. Our research group is involved as task leaders in several work packages.

Within WP1 (*Hardware Installation*) we have been installing a persistent testbed of 20 TelosB sensor nodes, using a backbone of 10 mesh nodes. The sensor/mesh nodes network spans over 5 floors of the building Neubrückstrasse 10. The 20 TelosB sensor nodes are attached via USB cables to the USB ports of the mesh node, which also forms the power supply for the TelosB nodes.

Within WP2 (*Testbed operation, access, and management*) we have designed and implemented a first prototype of a Testbed Architecture for Wireless Sensor Networks (TARWIS), an experiment and testbed management system for wireless sensor network testbeds. TARWIS is currently running on our WISEBED portal server and hosts a web-based user interface over which each user of the WISEBED project can operate the testbed. The TARWIS server component prepares and controls the experiment execution steps and connects to the individual sensor nodes. The system has been designed to remain independent of the type and the operating system of the sensor nodes, but relies on a set of APIs to access the sensor nodes and obtain experiment data. During the next project phase, each partner will start integrating the TARWIS system at their testbed site.

Real-world environmental data is of major importance for significant simulation results. The idea of the sub-task *Producing traces for hardware* of WP4 is to feed recorded data back into the simulator. Together with the WISEBED project partners, UBERN is in the process of defining a common data representation language WiseML.

**Research staff:** Philipp Hurni, Markus Anwander, Gerald Wagenknecht, Torsten Braun

**Financial support:** EU project ICT-2008-224460

## **Traffic Adaptivity in Wireless Sensor Networks**

Energy efficiency is a major concern in the design of Wireless Sensor Networks (WSNs) and their communication protocols. As the radio transceiver typically accounts for a major portion of a WSN node's power consumption, researchers have proposed Energy-Efficient Medium Access ( $E^2$ -MAC) protocols that switch the radio transceiver off for a major part of the time. Today's  $E^2$ -MAC protocols are able to deliver little amounts of data with a low energy footprint, but introduce severe restrictions with respect to throughput and latency. Regrettably, they yet fail to adapt to varying traffic loads and changing requirements of the imposed traffic load.

Strong restrictions with respect to throughput and latency may be tolerable in networks with low quality of service requirements. However, many event-based scenarios require reasonable quality of service during short periods of intense activity, and a high energy-efficiency and lower quality of service during long periods of inactivity. Such scenarios can be found e.g. in monitoring systems for the healthcare system, in disaster-aid-systems, but also in the broad area of environmental monitoring. Varying, temporarily high traffic can further be expected to appear in the emerging field of multimedia sensor networks WMSNs. Once an event has been triggered, e.g., a patient's pulse monitor registering anomalies in a hospital or geriatric clinic, the MAC protocol's primary objective should shift towards delivering good quality of service (high throughput, low delay) rather than saving energy. In such scenarios, today's existing  $E^2$ -MAC protocols do not provide reasonable flexibility, as most of them were designed under the assumption of very sparse low-rate traffic.

The issue of  $E^2$ -MAC protocol adaptivity with respect to changing traffic load has yet only been used as an ambiguous but popular buzzword in many WSN studies. There is no consistent notion of how to assess or measure traffic adaptivity. We have defined a notion of *traffic adaptivity* in the context of  $E^2$ -MAC protocols as *the ability of the protocol to dynamically and autonomously react to changing traffic requirements with (de)allocation of the respective resources needed to handle the imposed traffic with adequate quality of service at run-time*. We have introduced a tri-partite metric to quantify the *traffic-adaptivity* of an  $E^2$ -MAC protocol, and applied this metric to experimental results of a selection of today's  $E^2$ -MAC protocols.

We have further explored the design space of today's most frequently cited  $E^2$ -MAC protocols with respect to their ability to react to changing traffic conditions in state-of-the-art network simulation environments. By comparing against an idealized concept of an  $E^2$ -MAC protocol, we have shown how far today's  $E^2$ -MAC protocols still are from the goal of being able to truly allocate the radio transceiver in an *on-demand manner*. Many of today's  $E^2$ -MAC protocols exhibit a very high energy-efficiency - some of them yet come close to the theoretic lower bounds. This gain in efficiency however comes at the cost of severely restrained maximum throughput, as well as massively increasing end-to-end packet latency. We envisage advance towards an  $E^2$ -MAC protocol that is able to achieve a very high efficiency in case of low traffic, but that is capable to adapt its behavior in case of higher traffic. In such situations,  $E^2$ -MAC protocol should be able to exploit the entire channel capacity and achieve a throughput that is similar to that of energy-unconstrained CSMA. Such a maximally-adaptive behavior would be very advantageous in many event-based WSN application scenarios, and would constitute a real novelty in the design space of  $E^2$ -MAC protocols.

**Research staff:** Philipp Hurni, Torsten Braun

## **Wireless Mesh Networks for Interconnection of Remote Sites to Fixed Broadband Networks**

This technology transfer project intends to evaluate the usefulness and feasibility of wireless mesh networks (WMNs) in meteorological monitoring applications. We try to identify application and usage scenarios for WMNs. We investigate whether and how the used hardware and software components are appropriate for the intended application scenarios and whether the application requirements such as bandwidth, delay, reliability, recovery times etc. can be met. Potential weaknesses and bottlenecks will also be identified.

We investigate whether wireless mesh networks (WMNs) are appropriate for connecting sensor networks or other devices deployed in remote areas, where no fixed network access is available, to a fixed broadband network. To support a variety of application scenarios, the WMN must meet reliability requirements and bandwidth in the 10 Mbps range over distances of several 10 km, e.g., by using directional radio transmission. During the project a WMN based on IEEE 802.11a/h (5 GHz) has to be deployed in

the area of Neuchâtel and Payerne.

Our three industry partners have manifold interests in the project. MeteoSwiss, the operator of the meteorological network of Switzerland, has approximately 130 weather stations (distances between them are 30 km in average) with environmental sensing equipment deployed all over Switzerland. WMNs are a possibility to interconnect weather stations or even some sensors with an own broadband network. WMNs would allow SWITCH, the provider of the Swiss national research and education network, to extend the geographic coverage of their fiber network and to offer broadband services to further locations that are not close to the fiber network. PCEngines provides us with their mesh nodes and expect to extend its business with the results.

For the project we have mounted one mesh node on the roof of the University of Neuchâtel and another mesh node on the roof of SwissMeteo at Payerne. Intermediate nodes equipped with solar equipment (panels, chargers, and batteries) have been placed on the hills in the area to interconnect Payerne with the fiber network in Neuchâtel.

The network has been first tested on a small area in front of the weather station. Afterwards, the nodes have been moved to their final locations. First measurements show the necessity of a careful selection of the node locations, a good alignment of the antennas, and a strong tensioning of the antenna masts. In addition, aspects like birds using masts as raised blinds, storms, and the subsidence of tripod due to rain have to be considered during the deployment.

With the experiences gained from the deployment, we are now able to easily dimension further outdoor wireless mesh networks (approved equipment, possible distances, planning and setup time).

**Research staff:** Thomas Staub, Markus Anwander, Marc Brogle, Torsten Braun

**Financial support:** Swiss Commission for Technology and Innovation under grant number 9795.1 PFES-ES and the industry partners (Swiss-Meteo, SWITCH, and PCEngines)

## **Testbed for Mobile and Internet Communications**

Our research group maintains its own testbed network for various purposes. The testbed is used to build networks of experimental routers and end systems in order to be able to evaluate the behavior of new networking

procedures and architectures in a realistic environment. The testbed also forms a productive network of Linux PCs and provides the storage capacity and CPU power for many of the RVS group's projects. The ERON project for example uses the available CPU power to compute embeddings of network distances into Euclidean space. An educational laboratory network for students' training is also connected and being extended by the OSLab project. The RVS group also takes part in PlanetLab (<http://planet-lab.org>), an open platform for developing, deploying, and accessing planetary-scale services. For this purpose we are hosting four PlanetLab nodes in our testbed network. The RVS group owns a number of sensor nodes: Embedded Sensor Board (ESB), Modular Sensor Board (MSB), tmote SKY nodes, BTnodes, TelosB nodes, and micaZ nodes. A testbed consisting of multiple mesh nodes (17 x PCEngines WRAP, 10 x Meraki Mini, 6 x PCEngines ALIX) has been deployed throughout the building and work environment of the research group. In this testbed, multi-channel communication, multi-path routing and the management framework ADAM have been evaluated. The testbed is currently used by several student projects.

**Research staff:** All members of the RVS research group

## 1.4 Ph.D. Theses

- Markus Wälchli: Distributed Event Detection in Wireless Sensor Networks, May, 2009

## 1.5 Master and Diploma Theses

- Daniel Balsiger: Administration and Deployment of Wireless Mesh Networks, April, 2009
- Reto Zurbuchen: Backbone Construction Based on Sync-Messages and Energy-Savings in Wireless Sensor Networks, March, 2009

## 1.6 Bachelor Theses and Computer Science Projects

- Stefan Ott: Experimental Evaluation of Multi-Path Routing in a Wireless Mesh Network Inside a Building, February, 2009



- Abdalla Hassan: Simulations on Multipath Routing Based on Source Routing, August, 2008

## **1.7 Further Activities**

### **Memberships**

- Chair of ERCIM working group on eMobility (Torsten Braun)
- Secretary General of ERCIM working group on eMobility (Marc Brogle)
- Erweitertes Leitungsgremium Fachgruppe "Kommunikation und Verteilte Systeme", Gesellschaft für Informatik (Torsten Braun)
- Integration Coordination Board and Steering Committee of EU IST project Wisebed (Torsten Braun)
- SWITCH Stiftungsrat (Torsten Braun)
- SWITCH Stiftungsratsausschuss (Torsten Braun)
- Kuratorium Fritz-Kutter-Fonds (Torsten Braun)
- Expert for Diploma Exams at Fachhochschule Bern (Torsten Braun)

### **Editorial Boards**

#### **Torsten Braun**

- Editorial Board of Elsevier's Computer Communications Journal
- Editorial Board of Elsevier's Computer Networks Journal
- Editorial Board of Informatik Spektrum / Springer-Verlag
- Editorial Board of Journal of Internet Engineering (Editor in Chief)

## Conference Chairs

- General Chair of 3<sup>rd</sup> ERCIM Workshop on eMobility, May 27-28, 2009, University of Twente, The Netherlands (Torsten Braun)
- TPC Co-Chair of 3<sup>rd</sup> ERCIM Workshop on eMobility, May 27-28, 2009, University of Twente, The Netherlands (Marc Brogle)
- TPC Chair of 2<sup>nd</sup> International Workshop on OMNeT++ (OMNeT++ 2009) , March 6, 2009, Rome, Italy (Torsten Braun)

## Conference Program Committees

### Torsten Braun

- 5<sup>th</sup> International Wireless Communications and Mobile Computing Conference (IWCMC 2009), Leipzig, Germany, June 21–24, 2009
- IEEE International Conference on Communications (ICC 2009), Dresden, June 14–18, 2009
- 2<sup>nd</sup> International Workshop on Sensor Network Engineering (IWSNE'09), Marina Del Rey, CA, USA, June 10, 2009
- 4<sup>th</sup> IEEE Workshop on advanced EXPerimental activities ON WIRELESS networks & systems (EXPONWIRELESS09), Kos, Greece, June 15, 2009
- 11<sup>th</sup> IFIP/IEEE International Symposium on Integrated Network Management (IM 2009), Long Island, NY, USA, June 1–5, 2009
- 3<sup>rd</sup> GI/ITG KuVS Workshop on the Future Internet, Munich, Germany, May 28, 2009
- 7<sup>th</sup> International Conference on Wired / Wireless Internet Communications (WWIC 2009), University of Twente, The Netherlands, May 27–29, 2009
- 8<sup>th</sup> IFIP Networking 2009, Aachen, Germany, May, 11–15, 2009
- 16. ITG/GI - Fachtagung Kommunikation in Verteilten Systemen (KiVS 2009), Kassel, Germany, March 2–6, 2009
- 1<sup>st</sup> Workshop on Overlay and Network Virtualization, in conjunction with KiVS 2009, Kassel, Germany, March 6, 2009

- 5<sup>th</sup> Workshop on Mobile Ad-Hoc Networks (WMAN 2009) in conjunction with KiVS 2009, Kassel, Germany, March 6, 2009
- 6<sup>th</sup> European Conference on Wireless Sensor Networks (EWSN 2009), Cork, Ireland, February 11–13, 2009
- 4<sup>th</sup> IEEE Conference on Wireless Communication and Sensor Networks (WCSN 2008), Allahabad, India, December 27-29, 2008
- 1<sup>st</sup> Workshop on Wireless Broadband Access for Communities and Rural Developing Regions - WIRELESS4D'08, Karlstad University, Sweden, December 11–12, 2008
- 4<sup>th</sup> IEEE Broadband Wireless Access Workshop, New Orleans, LA, USA, November 30 - December 4, 2008
- IEEE Global Communications Conference 2008 (GLOBECOM 2008), New Orleans, LA, USA, November 30 - December 4, 2008
- 11<sup>th</sup> Asia Pacific Network Operations and Management Symposium (APNOMS 2008), Beijing, China, October 22–24, 2008
- 33<sup>rd</sup> IEEE Conference on Local Computer Networks (LCN 2008), Montreal, Quebec, Canada, October 14–17, 2008
- 2<sup>nd</sup> IEEE International Workshop on Enabling Technologies and Standards for Wireless Mesh Networking (MeshTech'08), Atlanta, GA, USA, September 29, 2008
- 16<sup>th</sup> IEEE LAN/MAN Workshop on Local and Metropolitan Area Networks (LANMAN 2008), Cluj-Napoca, Transylvania, Romania, September 3–6, 2008
- 34<sup>th</sup> EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA), Parma, Italy, September 3–5, 2008
- 8<sup>th</sup> IEEE International Conference on Next Generation Wired/Wireless Networking (NEW2AN 2008), St. Petersburg, Russia, September 3–5, 2008
- 17<sup>th</sup> International Conference on Computer Communications and Networks (ICCCN 2008), St. Thomas, Virgin Islands, USA, August 3–7, 2008

## **Ph.D. Jury Memberships**

### **Torsten Braun**

- Licentiate Thesis, Marcel Cavalcanti de Castro, Karlstads University

## **Reviewing Activities**

### **Torsten Braun**

- IEEE Journal on Selected Areas in Communications
- IEEE Network Magazine
- IEEE Transactions on Network and Service Management
- IEEE Transactions on Parallel and Distributed Systems
- Mobile Networks and Applications, Springer
- Simulation: Transactions of the Society for Modeling and Simulation International
- Research Council of Norway
- Swiss National Science Foundation
- Qatar National Research Fund
- Vinnova, Sweden
- Royal Melbourne Institute of Technology

## **Invited Talks and Tutorials**

- Thomas Staub: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, May 12, 2009, Schwarzenburg, Switzerland
- Thomas Staub: Réseaux de communications, cours de cadres pour chefs de la télématique, Office fédéral de la protection de la population, November 25, 2008, May 12, 2009, Schwarzenburg, Switzerland
- Thomas Staub, Torsten Braun: Wireless Mesh Networks for Meteorological Monitoring (SAHNS 2009), Keynote Talk, July 26, 2009, Montreal, Canada

- Torsten Braun: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, November 25, 2008, May 26, 2009, Schwarzenburg, Switzerland
- Cognitive Wireless Mesh Networks, Dagstuhl Seminar Architecture and Design of the Future Internet, April 16, 2009, Schloss Dagstuhl, Germany
- Energy-efficient and Adaptive Protocols for Wireless Sensor Networks, Computer Science Colloquium, June 3, 2009, Karlstad, Sweden
- Quality-of-Service in Overlay Multicast, Dagstuhl Seminar Bandwidth on Demand, February 10, 2009, Schloss Dagstuhl, Germany
- Optimizing Communication Protocols for Wireless Sensor Networks, Queensland University of Technology, December 18, 2008, Brisbane, Australia
- Optimizing Routing and MAC Protocols for Wireless Sensor Networks, NICTA, December 15, 2008, Sydney, Australia
- Effiziente und adaptive Kommunikationsprotokolle für drahtlose Sensornetze, Informatikkolloquium, RWTH Aachen, May 4, 2009, Aachen, Germany
- Energy-efficient Protocol Design in Wireless Sensor Networks, Tutorial at PIMRC 2008, September 15, 2008, Cannes, France

## **Organized Events**

- Organizing a Computer Science Summer School seminar together with the TNS group of University Fribourg and the IIUN of University Neuchâtel, at Münchenwiler, Switzerland, June 10–12, 2009

## **Awards**

- Communications-Software-Award (Communications-Software-Preis für die beste “Software aus einem KMU, einem Forschungsprojekt an einer Hochschule oder einem Forschungsinstitut”), awarded by the GI/ITG Fachgruppe “Kommunikation und Verteilte Systeme” (KuVS) for the Multicast Middleware to Marc Brogle, Dragan Milic and Torsten Braun.

## 1.8 Publications

Publications submitted in the academic year 2008/2009 and appearing in 2009/2010 or later are not listed.

### Books

- Y. Koucheryavy, G. Giambene, D. Staehle, F. Barcelo-Arroyo, Torsten Braun, V. Siris: Traffic and QoS Management in Wireless Multimedia Networks, Lecture Notes in Electrical Engineering, Vol. 31, June, 2009, Springer, ISBN 978-0-387-85572-1
- Marc Brogle, Geert Heijen, Torsten Braun, Dimitri Konstantas: Proceedings of the Third ERCIM Workshop on eMobility, University of Twente, Enschede, The Netherlands, May 27 - 28, 2009, ISBN 978-90-365-2846-7
- Torsten Braun, Michel Diaz, Jos Enrquez Gabeiras, Thomas Staub: End-to-End Quality of Service Over Heterogeneous Networks, August 14, 2008, Springer, ISBN 978-3-540-79119-5

### Reviewed Journal and Conference Papers

- Gerald Wagenknecht, Markus Anwander, Torsten Braun: Hop-to-Hop Reliability in IP-based Wireless Sensor Networks - a Cross-Layer Approach, International Conference on Wired/Wireless Internet Communications 2009 (WWIC'09), Enschede, The Netherlands, Vol. 5546/2009, May 27 - 29, 2009, pp. 61-72, Springer LNCS, ISBN 978-3-642-02117-6
- Thomas Staub, Marc Brogle, Kurt Baumann, Torsten Braun: Wireless Mesh Networks for Interconnection of Remote Sites to Fixed Broadband Networks, Third ERCIM Workshop on eMobility, University of Twente, Enschede, The Netherlands, May 27 - 28, 2009, pp. 97-98, ISBN 978-90-365-2846-7
- Markus Wälchli, Reto Zurbuchen, Thomas Staub, Torsten Braun: Gravity-based Local Clock Synchronization in Wireless Sensor Networks, Networking 2009, Aachen, Germany, Vol. 5550/2009, May 11 - 15, 2009, Springer LNCS, pp. 907-918, ISBN 978-3-642-01398-0

- Philipp Hurni, Torsten Braun: Calibrating Wireless Sensor Network Simulation Models with Real-World Experiments, Networking 2009, Aachen, Germany, Vol. 5550/2009, May 11 - 15, 2009, pp. 1-13, Springer LNCS, ISBN 978-3-642-01398-0
- Markus Wälchli, Torsten Braun: Efficient Signal Processing and Anomaly Detection in Wireless Sensor Networks, 6th European Workshop on the Application of Nature-inspired Techniques for Telecommunication Networks (EvoCOMNET 2009), Tübingen, Germany, Vol. 5484/2009, April 15 - 18, 2009, pp. 81-86, Springer LNCS, ISBN 978-3-642-01128-3
- Thomas Staub, Reto Gantenbein, Torsten Braun: VirtualMesh: An Emulation Framework for Wireless Mesh Networks in OMNeT++, The 2nd International Workshop on OMNeT++ (OMNeT++ 2009) held in conjunction with the 2nd International Conference on Simulation Tools and Techniques, Rome, Italy, March 6 - 7, 2009, ISBN 978-963-9799-45-5
- Philipp Hurni, Thomas Staub, Gerald Wagenknecht, Markus Anwander, Torsten Braun: A Secure Remote Authentication, Operation and Management Infrastructure for Distributed Wireless Sensor Network Testbeds, First Workshop on Global Sensor Networks (GSN 09) co-located with KiVS 09, Kassel, Germany, Vol. 17, March 6 - 7, 2009, Electronic Communications of the EASST, ISSN 1863-2122
- Thomas Staub, Stefan Ott, Torsten Braun: Experimental Evaluation of Multi-Path Routing in a Wireless Mesh Network Inside a Building, 5th Workshop on Mobile Ad-Hoc Networks - WMAN 2009 - in conjunction with the 16th bi-annual Conference on Communication in Distributed Systems (KiVS), Kassel, Germany, Vol. 17, March 5 - 6, 2009, Electronic Communications of the EASST, ISSN 1863-2122
- Philipp Hurni: Unsynchronized Energy-Efficient MAC and Routing in Wireless Sensor Networks, 16th bi-annual Conference on Communication in Distributed Systems (KiVS), Kassel, Germany, Vol. 17, March 2 - 6, 2009, pp. 321, Springer, ISBN 978-3-540-92665-8
- Gerald Wagenknecht, Markus Anwander, Torsten Braun: MARWIS: A Management Platform for Heterogeneous Wireless Sensor Networks, Ercim News, Nr. 76, January, 2009, pp. 18-19, ERCIM EEIG, ISSN 0926-4981

- Philipp Hurni: Unsynchronized Energy-Efficient MAC and Routing in Wireless Sensor Networks, Praxis der Informationsverarbeitung und Kommunikation, Vol. 09, Nr. 1, January, 2009, pp. 38-44, K. G. Saur, ISSN 0930-5157
- Thomas Staub, Torsten Braun: Supporting Real-time Communication in Wireless Mesh Networks, 1st Workshop on Wireless Broadband Access for Communities and Rural Developing Regions - WIRELESS4D'08 held at 1st International Conference on M4D, Karlstad University, Sweden, Vol. 2008, Nr. 62, December 11 - 13, 2008, Karlstad University Press, ISBN 978-91-7063-222-8
- Markus Wälchli, Torsten Braun: Event Classification and Filtering of False Alarms in Wireless Sensor Networks, 3rd International Workshop on Intelligent Systems Techniques for Ad hoc and Wireless Sensor Networks (IST-AWSN'08), Sydney, Australia, December 10 - 12, 2008, pp. 757-764, IEEE Computer Society, ISBN 978-0-7695-3471-8
- Marc Brogle, Dragan Milic, Torsten Braun: Quality of Service for Peer-to-Peer based Networked Virtual Environments, P2P-NVE 2008 Workshop at the 14th IEEE International Conference on Parallel and Distributed Systems (ICPADS'08), Melbourne, Victoria, Australia, December 8 - 10, 2008, pp. 847-852, IEEE Computer Society, ISBN 978-0-7695-3434-3
- Matthias Scheidegger, Torsten Braun, Benjamin Zahler: An Internet Distance Prediction Service based on Passive Measurements, Australasian Telecommunications Networking and Application Conference (ATNAC 2008), Adelaide, Australia, December 7 - 10, 2008, pp. 28-32, ISBN 978-1-4244-2602-7
- Philipp Hurni, Torsten Braun, Bharat Bhargava, Yu Zhang: Multi-Hop Cross-Layer Design in Wireless Sensor Networks: A Case Study, 4th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Avignon, France, October 12 - 14, 2008, pp. 291-296, IEEE Computer Society, ISBN 978-0-7695-3393-3
- Philipp Hurni, Torsten Braun: Evaluation of WiseMAC on Sensor Nodes, 10th IFIP International Conference on Mobile and Wireless Communications Networks (MWCN2008), Toulouse, France, Vol.



284, September 29 - 30, 2008, pp. 187-198, Springer, ISBN 978-0-387-84838-9

- Gerald Wagenknecht, Markus Anwander, Marc Brogle, Torsten Braun: Reliable Multicast in Wireless Sensor Networks, 7. GI/ITG KuVS Fachgespräch Drahtlose Sensornetze, Berlin, Germany, September 25 - 26, 2008, pp. 69-72, Freie Universität Berlin, Fachbereich Mathematik und Informatik, Tech. Report B 08-12
- Philipp Hurni, Torsten Braun: Energy-Efficient Multi-Path Routing in Wireless Sensor Networks, 7th International Conference on AD-HOC Networks & Wireless (AdHoc-NOW 2008), Sophia Antipolis, France, Vol. 5198/2009, September 10 - 12, 2008, pp. 72-85, Springer LNCS, ISBN 978-3-540-85208-7
- Dragan Milic, Torsten Braun: Enhancing RTT Prediction Schemes Using Global Function Minimization, Fifth International Conference on Broadband Communications, Networks, and Systems (BROAD-NETS 2008), London, UK, September 8 - 10, 2008, ISBN 978-1-4244-2392-7

## Technical Reports

- Mesut Gunes, Qasim Mushtaq, Philipp Hurni et al: Initial Hardware Installation, WISEBED Deliverable D1.2, June, 2009
- Geoff Coulson, Barry Porter, Philipp Hurni et al: Report on the Implementation of the Software Infrastructure, WISEBED Deliverable D2.2, June, 2009
- Stefan Fischer, Dennis Pfisterer, Philipp Hurni et al: Design of the Hardware Infrastructure, Architecture of the Software Infrastructure, and Design of Library of Algorithms, WISEBED Deliverable D1.1, D2.1, and D3.1, December, 2008
- Marc Brogle, Dragan Milic, Markus Anwander, Gerald Wagenknecht, Markus Wälchli, Torsten Braun, R. Kummer, Markus Wulff, R. Standtke, H. Sturzrehm, E. Riviere, P. Felber, S. Krenn, C. Ehret, C. Latze, Philipp Hurni, Thomas Staub: BeNeFri Summer School 2008 on Dependable Systems, Quarten, Switzerland, November 18, 2008, IAM-08-003