1 Research Group on Computer Networks and Distributed Systems

1.1 Personnel

Head:	Prof. Dr. T. Braun	Tel.: +41 31 511 2631 email: braun@iam.unibe.ch
Office Manager:	R. Bestgen	Tel.: +41 31 511 2630 email: bestgen@iam.unibe.ch
Scientific Staff:	C. Anastasiades*	Tel.: +41 31 511 2635 email: anastasi@iam.unibe.ch
	M. Anwander*	Tel.: +41 31 511 2634 email: anwander@iam.unibe.ch
	Dr. D. Dimitrova*	Tel.: +41 31 511 2633 email: dimdes@iam.unibe.ch (since 15.03.2011)
	P. Hurni*	Tel.: +41 31 511 2640 email: hurni@iam.unibe.ch
	B. Nyffenegger*	Tel.: +41 31 511 2632 email: nyffeneg@iam.unibe.ch (since 01.01.2011)
	Dr. T. Staub*	Tel.: +41 31 511 2637 email: staub@iam.unibe.ch
	G. Wagenknecht*	Tel.: +41 31 511 2636 email: wagen@iam.unibe.ch
	Z. Zhao*	Tel.: +41 31 511 2638 email: zhao@iam.unibe.ch
External Ph.D. Students:	A. Antonescu	email: antonescu@iam.unibe.ch (since 01.02.2011)
	M. Thoma	email: thoma@iam.unibe.ch (since 01.02.2011)
Guests BNF - Swiss qualification program:	P. Goode*	email: goode@iam.unibe.ch (until 10.08.2010)
	M. Darriulat*	email: darriula@iam.unibe.ch (until 30.11.2010)
	M. Oberle*	email: oberle@iam.unibe.ch (01.11.2010 - 18.12.2010)

| **Guests:** | Prof. G. Coulson | Lancaster University, UK August 2010 |
| | Dr. S. Duquennoy | Swedish Institute of Computer Science, (SICS), Sweden May 2011 |

* 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, mainly focused on Internet protocols. The Internet is increasingly being used for multimedia data transfer (audio, video, sensor data, etc.). We are investigating how services with high demands on the quality, reliability, and energy efficiency of communication systems and networks can be supported. The current focus of the research group are wireless networks with special emphasis on wireless mesh and sensor networks. Management architectures as well as protocols on link, routing, and transport layer are being investigated.

1.3 Research Projects

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 investigating new theoretical approaches on algorithms, mechanisms and protocols. The project's main aim is to make the distributed laboratories available to the European scientific community, so that other research groups can take advantage of a federated testbed infrastructure. Our research group is involved as task leaders in several work packages.

Within WP1 (*Hardware Installation*) we installed a persistent testbed of 42 TelosB and 7 MSB430 sensor nodes, using a wired backbone of mesh

nodes for code distribution and retrieval of debug/trace data. The sensor/mesh network spans over 5 floors of the building Neubrückstrasse 10 and over 2 floors at Schützenmattstrasse 14 in Bern. The TelosB and MSB430 sensor nodes are attached via USB cables to the mesh nodes, which also form the power supply. Using this reliable backbone infrastructure, all nodes can be reset, rebooted and reprogrammed remotely within a short time.

Within WP2 (*Testbed operation, access, and management*) we have designed and implemented the *Testbed Management Architecture for Wireless Sensor Networks (TARWIS)*, a generic experiment and testbed management system for wireless sensor network testbeds. TARWIS has been integrated into the testbed federation and is to-date already the management system of various testbeds of the all WISEBED project partners, as e.g., University of Lancaster and Technical University of Delft. Two major releases of the software have been published between July 2010 and July 2011. Major extensions are the support support for running concurrent experiments with subsets of nodes (of the same or different type), support for repeatability and batch processing of experiments, automated command entering, and the use of templates to to ease configuration of experiments. Further, many interoperability problems and problems related to inconsistencies and different WSDL-versions used have been solved. TARWIS is now fully interoperable with different backends, such as our perl-backend, gSOAP-backend from University of Lancaster, and the Jax-based backend from University of Lübeck. The current version is TARWIS 5.0.

Real-world environmental data is of major importance when it comes to real-world evaluation of protocol mechanisms. With yet no existing standard for real-world experimental data, the WISEBED project has developed the WiseML language, a XML-based XSD Schema that offers a uniform description of experiment trace data. Within WP4, we delivered to data sets: NULLMAC/XMAC and ECC-evaluation. For NULLMAC/XMAC the basic setup consists of a TCP server (receiving segments), a TCP client (sending segments), and a node chain of variable length, ranging from 2 to 6 hops. The experiments examined the behavior of TCP on top of Contiki's NULLMAC / CSMA-variant and 3 different radio duty-cycling protocols: X-MAC, Low-Power-Probing and ContikiMAC. For each setting, the amount of successfully delivered segments (of roughly 30 bytes each) was measured in 15 experimental runs of 15 minutes each. The ECC-evaluation data set was collected using the 7 MSB-430 sensor nodes operating with the ScatterWeb operating system. The performance of a selection of eight different Error Correction Codes (ECCs), ranging from simple bit-repetition schemes over hamming-based codes to complex and

powerful Bose-Chaudhuri-Hocquenghem (BCH) codes were evaluated.

All web interfaces of the WISEBED testbed infrastructure are protected by Shibboleth. Therefore, all WISEBED partners operate a Shibboleth identity provider (IDP) to administrate the users of the WISEBED federation. The IDP is responsible to authenticate users, which try to access a protected web resource (e.g., TARWIS, IDP administration, authorization management). We also implemented a sensor network authorization tool (SNA) to maintain the authorization of the different users at the existing TARWIS testbeds.

Within WP3, we finished the implementation of DYMO routing protocol and Eschenauer-Gligor key management algorithms for Shawn simulator. Beside this, we implemented the OLSR, DYMO routing protocols and Eschenauer-Gligor key management algorithms on real sensor nodes, such as TelosB and MSB430.

Traffic Adaptivity in Wireless Sensor Networks (TRAWSN)

Energy efficiency is a major concern in the design of Wireless Sensor Networks (WSNs) and their communication protocols. Today's energy-efficient (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.

We intend to bridge this gap with the TRAWSN project, which started in October 2009. Within TRAWSN, we have developed MaxMAC, an energy-efficient MAC protocol for WSN scenarios with varying traffic conditions. While MaxMAC operates similarly as existing E^2-MAC protocols in low traffic situations, it is able to maximally adapt to changes in the network traffic load at run-time. We have published simulation-based results of the MaxMAC protocol at the European Conference on Wireless Sensor Networks (EWSN), Europe's most selective conference on WSNs in 2010, and have since then been working on a) software-based energy estimation mechanisms in order to evaluate our contribution b) the real-world prototype implementation of MaxMAC and its evaluation on our indoor WSN testbed. This evaluation was again conducted on the distributed testbed

facilities set up within two buildings on the Engehalde Campus during the WISEBED project, and which are operated by our management infrastructure TARWIS.

Another activity pursued within TRAWSN with the subordinate topic of dynamic resource allocation schemes in WSNs is our study on the potential of Forward Error Correction (FEC) mechanisms and dynamic/run-time adaptive FEC variants in WSNs. Throughout the last year, we implemented eight different Error Correction Codes (ECCs) and have made them available in a publicly available ECC library. The implemented codes range across four different classes, from simple bit-repetition schemes via Hamming codes to complex and powerful Bose-Chaudhuri-Hocquenghem codes, and further contain our three proposed run-time adaptive FEC schemes which adapt the correctional power of ECCs to the current link quality. We have thoroughly evaluated the computational costs and the resulting benefits with respect to packet delivery rate (PDR) of the static and adaptive FEC schemes under real-world conditions in a wide range of experiments on our distributed WSN testbed laboratory which is operated by our management infrastructure TARWIS.

Research staff: Philipp Hurni, Sebastian Barthlomé, Torsten Braun

Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks (A^4-Mesh)

To successfully use Wireless Mesh Networks (WMNs) in the area of Swiss higher education, they have to support authentication, authorization, accounting, and auditing. They must also be seamlessly integrated into the organizations' authentication and authorization infrastructure. As there are usually multiple concurrent users of the network, a WMN has to support accounting to enable charging and network management. For a successful operation of a wireless mesh network, inconsistent and erroneous states in the network have to be detected and resolved. This requires constant auditing of network state and configuration. The auditing function may then trigger alarms or even perform self-healing of the network. The A4-Mesh project aims to develop a completely functional wireless mesh network infrastructure including support for authentication and authorization,

accounting, and auditing. In the first months of the project, we have developed concepts for user and machine authentication and authorization in a WMN using Shibboleth.

An indoor test bed, a pilot network for campus network extension, and a pilot network for environmental research are planned. We have set up the planned indoor test bed, which will be used for developing and testing the various A4-Mesh software components, at the University of Bern. The test bed includes 20 nodes consisting of an Alix 3D system board and featuring IEEE 802.11n connectivity. The goal of the pilot network for environmental research is to provide a broadband network service for measurement stations. Together with environmental researchers of the Institute of Geography (GIUB), the project MontanAqua was selected for the pilot network installation. The network consists of 11 mesh nodes, including four nodes installed at existing measurement stations sites (lysimeter, weather station, gauging station, IP camera), where they enable access to the measurement data through the network. We have completed a fully functiona nodel prototype, which is suitable for extreme weather conditions and may be powered by solar power only. This includes the completion of a tailored power supply box (solar panel, solar charger, and battery), a tailored mesh node box (up to 3 system boards), relay, custom mounts (antennas, supply box), as well as additions to ADAM Linux to meet the demands of the network. We have successfully tested the prototype on the roof of the IAM building. Currently, we are testing a mesh node, which is installed on the roof of the GIUB building and another one on the roof the ExWi building. In addition, we are preparing the installation of the pilot network in Crans Montana.

Wireless Mesh Networks

Besides the WMN for environmental monitoring and campus extenstion, there are further activities in the area of WMNs such as extensions of the framework for management and deployment of WMNs (ADAM), the extension of the WMN virtualization framework (VirtualMesh) to support WSNs and virtual mobility, the finalization of an '"easy-to-install" temporary network for video communication (OViS), and using wireless mesh technology

for unmanned aerial vehicles.

Administration and Deployment of Adhoc Mesh networks (ADAM) provides mechansims for fault-tolerant and safe deployment and configuration of WMNs as well as a build system for cross-compilation of tailored embedded Linux distribution with a very small footprint for the mesh nodes. ADAM has been extended to support the Gumstix Overo board, an ARM-8 based computer module. We updated the software with newer Linux kernels. In order to increase the self-healing capabilities, we added support for hardware watchdog and a specialised backup node using UMTS. ADAM is used in several ongoing projects such as LBA and A^4-Mesh.

VirtualMesh is an emulation framework for WMNs and provides new testing facilities during the development of architectures and protocols for WMNs. It virtualizes a complete wireless mesh network by using host virtualization (XEN) for the mesh nodes and redirecting their wireless network traffic to a network simulator. In order to use our wireless device driver enabled network emulation in WSNs, we designed a concept for supporting virtual mobility in WSN test beds (e.g., WISEBED). Our virtual mobility support for WSN test beds is currently being implemented.

On-site Video System (OViS) reduces the number of costly visits of engineers on construction sites by providing an easily deployable temporary video communication infrastructure. At the time of electrical installations, electricians may face unknown problems or plan deviations, which require consultations with a remote engineer. In-building communication networks, as well as electrical installations, are set up very lately in the building construction process. In addition, communication over cellular mobile networks is often not possible inside buildings, especially in basements. To support telepresence of the engineer, a temporary communication network has to be deployed. Our approach is to use a battery powered WMN supporting automatic configuration and an electronic wizard that guides the user through the deployment process of the network. We extended our prototype with electronic wizards for iPhones/iPads and Android smartphones. In addition, we enhanced OViS to support multi-channel communication.

Finally, we developed an *airborne communication network (UAVNet)*. A WMN is automatically deployed using small quadrocopters as *unmanned aerial vehicles (UAVs)*. They provide communication facilities in case of natural disasters such as floodings or earthquakes. The UAVs with the wireless mesh nodes position themselves automatically to enable communication between two distant communication peer (airborne relay) or to cover a defined area (airborne mesh). In our first UAVNet prototype, we connected small wireless mesh nodes to quadrocopters by a se-

rial interface and implemented an API to steer and coordinate the UAVs over the IEEE 802.11g-based WMN. Our research focus is on automatic deployment, replacement and routing. In order to simplify the deployment of UAVNet, we developed a control and monitoring application for iPhone/iPad. The prototype is further used in the ORMAN project.

Research staff: Thomas Staub, Paul Kim Goode, Stefan Ott, Simon Morgenthaler, Adrian Hänni, Marcel Stolz, Markus Anwander, Dhara Shah Manojkumar, Ulrich Bürgi, Gabriel Martins Dias, Geoff Coulson, Torsten Braun

Location Based Analyser (LBA)

The main goal of the LBA project is to develop a practical solution - from the design to deployment phase - which is able to locate and track Bluetooth and WiFi modules, embedded in personal devices, e.g., mobile phones. The solution is based on low cost wireless sensor networks (WSNs) and collects statistical information for personal devices on the (indoor) premises. These statistics can be used, for example, by network operators to adapt capacity provisioning or by businesses to improve their services. Privacy is protected since the system is passive and does NOT retrieve any data with which the phone's owner may be identified.

LBA is a technology transfer project in cooperation with DFRC AG and Wellness Telecom as industry partners. DFRC provides feedback on implementation and deployment issues and tries to bring the product to the market. In order to ensure the product quality and improve the development, DFRC provided us realistic measurements from already deployed networks in Singapore, Sevilla (Spain), Tel Aviv (Israel) and Zug (Switzerland).

During the project, contact was established with researchers from the Technical University of Catalonia (Spain) and the Aerospace Research and Technology Centre (Spain) who work on the development of indoor positioning systems based on WiFi.

The technological problem that LBA is trying to solve is a "non-cooperative" system able to track devices in indoor environments with sufficient accuracy. The system should scale well, i.e., no upper limit on the number of devices tracked, and should not interfere with the customer's privacy. The project targets the evolving market of business intelligence based on location data, which aims to provide businesses information on their customers' behavior (in time and space).

An initial WSN, using embedded Linux running on the Gumstix sensor nodes, was deployed in an indoor test location. Series of measurements were performed in order to gain insights on the indoor propagation of Bluetooth signals (for a 15-node WSN in a single room) and on the signal's sensitivity to various factors such as distance, obstacles, manufacturer and smart phone specifics and device orientation. Subsequently, we used our own embedded Linux platform (ADAM) on the Gumstix nodes.

Analysis of the collected measurements with Bluetooth showed that high precision positioning based on a single technology and a single parameter is not possible - room level precision is achieved. Then, we looked at the Received Signal Strength Indicator (RSSI) and the Response Rate (of a scan). Combining the information from both parameters offers improved results, e.g., proximity to a node, but is still insufficient for a precision of a few meters. Therefore, we move towards positioning algorithm based on combined analysis of Bluetooth and WiFi signals.

The number of deployed sensor nodes also has major impact on the location estimate. A grid of sensor nodes is better in providing a reliable estimate but also more costly than a few nodes on key positions. A middle-way solution that showed positive results is to work with the maxima of the measured RSSIs and to aggregate data from near sensor groups in order to explore signal diversity.

From the measurements we observed that the signal degrades quickly with the increase of distance, which in combination with the unreliable indoor propagation conditions is the biggest challenge to high-precision positioning. Further, the factor with most significant impact on received powers showed to be device orientation; manufacturer and smart phone specifics have negligible effects.

Research staff: Desislava Dimitrova, Thomas Staub, Ulrich Bürgi, Gabriel Martins Dias, Torsten Braun

Enhanced Mobile Communication with Content-Centric Networks

With the increased proliferation of modern smart phones, mobile data communication and network density has increased drastically. Current delay-tolerant communication solutions are not suited to these dense, mostly ur-

ban, environments due to the limited capacity of the wireless medium and inefficient communication schemes, i.e., hosts exchange content in multiple unicast transmissions without having the possibility to cache content at chunk level.

In this project, which started in May 2011, we will investigate the feasibility of Content-Centric Networks (CCNs) in the context of mobile ad hoc networks. Although CCNs as proposed by Van Jacobson et. al. mainly target wired Internet communication, they feature also many advantages over traditional host-based wireless communication. A user interested in specific content broadcasts Interest messages to receive available broadcasted Data message in response. Current scalability and security problems may be addressed by exploiting the inherent broadcast property of the wireless medium and signing content individually. In case of lost connectivity due to mobility, nearby hosts that hold the requested content may resume the data transfer.

We will base our investigations on available CCN implementations and adapt it to the needs of resource constraint devices. The project targets three main research areas: 1. Memory management to control the limited router cache storage. 2. Energy-efficient operation to optimize the lifetime of battery operated devices. 3. Efficient content discovery and delivery mechanisms to reduce the number of unnecessarily transmitted redundant broadcast messages without significantly decreasing connectivity.

Within this project, we have implemented a CCN framework in OMNeT++, inspired by the available CCNx implementation by PARC. Specific modifications were required to adapt the design to wireless and mobile networks. Similar to CCNx, a CCN layer processes all communication between an upper CCN application layer and the lower UDP transport layer. Received Data and Interest messages are stored and forwarded to the appropriate network interfaces or the application layer. Currently, the framework supports three node types: Wifi, Ethernet, and hybrid nodes. This simulation framework will allow us in a later stage to quickly assess our ideas in different simulation scenarios. We have also set up a VirtualMesh testbed consisting of several hosts that have the current CCNx-0.4.0 implementation installed. We have conducted basic communication tests and plan to implement a basic CCNx application for more elaborated performance testing.

Research staff: Carlos Anastasiades, Arian Uruqi, Torsten Braun

Wireless Networking for Moving Objects

The Internet of the Future will incorporate a large number of autonomous wireless objects moving with diverse patterns and speeds while communicating via several radio interfaces. Examples of such objects may include humans, cars or unmanned aerial vehicles, with every object acting as a networking device generating, relaying and/or absorbing data. Achieving the Internet of the Future will require global interoperability among objects/devices. To overcome current shortcomings, a number of research challenges have to be addressed in the area of networking, including protocol engineering, development of applications and services, as well as realistic use-cases. The COST Action IC0906 coordinates research efforts of national and international projects in the area of Wireless Networking for Moving Objects (WiNeMO). Two Short Term Scientific Missions (STSMs) have been funded by the COST Action. Other related activities are our work on Enhanced Mobile Communication with Content-Centric Networks and Opportunistic Routing for highly Mobile Ad-hoc Networks.

The *Resource allocation in a hybrid sensor - mobile network* STSM focused on the resource allocation dynamics at the border of a mobile and a sensor network. In particular, it was investigated how different types of sensor traffic, e.g., continuous, burst, affect the resource management in a mobile network, i.e., radio bandwidth allocation, and how these inter-network dynamics can be modeled at best. Terminal mobility, of both mobile devices and sensor nodes, had central importance for the research. It was determined that two types of sensor traffic have the strongest impact - multimedia streams and large, simultaneous notifications burst. Eventually, a modeling approach was proposed that captures specifics of both mobile and sensor traffic and, hence, can represent the behavior of the combined system. The approach is based on the concept of Markov chains adapted to represent the traffic changes of a mobile network.

The *Testbed Architecture for Mobile Wireless Sensor and Mesh Networks* STSM further developed the proposed architecture for a mobile wireless sensor and mesh network testbed. The design is based on the concept of virtual mobility, cf. Virtual Mesh in the Wireless Mesh Networks research activity. Virtually mobile nodes can be physical, simulated or emulated, and virtual mobility for all three types is treated uniformly by embedding the nodes in a virtual space. In operation, the traffic of virtually-mobile nodes is intercepted and redirected to a mobility model from where it is selectively forwarded to other nodes that are virtually in range. A distributed implementation architecture that potentially allows the simulation/emulation of large-scale wireless sensor networks with large numbers of virtually-

mobile nodes has been designed. The architecture has strong scalability and can reuse existing simulation software components.

Energy Efficiency in Large Scale Distributed Systems

The COST Action IC0804 proposes realistic energy-efficient solutions to share distributed information technology resources. As large scale distributed systems gather and share more and more computing nodes and storage resources, their energy consumption is exponentially increasing. While much effort is nowadays put into hardware specific solutions to lower energy consumptions, the need for a complementary approach is necessary at the distributed system level, i.e., middleware, network and applications. The Action characterizes the energy consumption and energy efficiencies of distributed applications. Our research group is contributing to the Action's focus group on green wireless, which aims to investigate energy efficient concepts for wireless communication. Related work performed in this area has been performed in the research activities on Wireless Mesh Networks and Traffic Adaptivity in Wireless Sensor Networks.

The *Energy Measurements of Wireless Network Devices* STSM aimed to explore the energy consumption of different network technologies, e.g., WLAN, WiMAX, GPRS/UMTS, etc. Detailed knowledge about energy consumption is urgently needed to design and evaluate new mechanisms to save the energy of mobile devices in mobile cloud computing scenarios. It is a prerequisite to select the appropriate combination of network technologies for given application requirements. We established a measurement and evaluation methodology using modified USB extension and power supply cables looping in a high performance digital multimeter. Using our methodology and the established test bed at the University of Coimbra, we are able to provide detailed measurements of the energy consumption of different network technologies, such as WiMAX, WLAN, or UMTS, in mobile cloud computing scenarios. We can identify potential energy saving gains of arbitrary combinations of these network technologies. With the test bed, we can evaluate novel energy saving mechanisms. Moreover, the gathered data set enables the development of a software based energy model, which could be used in future energy saving mechanisms and

their evaluation.

Research staff: Torsten Braun, Thomas Staub, Philipp Hurni

Financial support: European Science Foundation

Service-Centric Networking

Content-centric networking is a novel paradigm for the Future Internet. We argue that content-centric networking should be generalized towards a service-centric networking (SCN) scheme. We propose a service-centric networking design based on an object-oriented approach, in which content and services are considered objects. We identified implementation architectures for example services and how these can benefit from service-centric networking. Service-centric networking can be beneficial for saving network resources and reducing response time for service invocation as well as supporting location-based services. SCN has been presented at two international workshops and two invited talks.

Research staff: Torsten Braun

Financial support: Bell Labs, Holmdel, NJ

Opportunistic Routing for highly Mobile Ad-hoc Networks (ORMAN)

The ORMAN project started in April 2010 and aims to investigate, develop and evaluate novel routing and forwarding schemes based on opportunistic routing schemes. Existing mobile ad-hoc networks protocols are not appropriate for the highly mobile node application scenario such as unmanned aerial vehicle (UAV) ad hoc networks, because a packet source is unable to calculate a complete route to the destination. Opportunistic routing protocols do not calculate an end-to-end communication path, the forwarding choice is performed on a hop-by-hop basis. Therefore, an opportunistic routing scheme seems to be a possible solution for the highly mobile application scenario. We aim to develop a geographic opportunistic routing protocol exploiting the multi-channel capabilities to reduce interference and maximize throughput. In order to maintain basic connectivity required to apply the routing protocol, we aim to develop an appropriate

topology control protocol that not only achieves connectivity but also minimizes interference. Besides the simulation work, real implementations using unmanned aerial vehicles and interconnected test-beds has to be performed in order to prove feasibility of the developed concepts.

In the first year of the ORMAN project, our contribution targeted on the development of a common simulation framework that supports comprehensive and meaningful evaluation of different opportunistic routing schemes. In order to receive comparable results, we developed a framework for the OMNeT++ simulator that provides common building blocks for the implementation of opportunistic routing protocols. The framework decoupled the opportunistic routing schemes into four modules, and provided additional functions which are necessary for opportunistic routing protocol implementation.

We also validated, via simulation, the poor performance of traditional MANET routing protocols in the highly mobile ad-hoc networks environment. This result affirms the inapplicability of traditional MANET routing strategies in an intermittent environment, where speed and directions of node vary significantly. This observation confirms the importance of opportunistic routing in highly mobile networks.

The current research focus are novel opportunistic routing protocols design and mobility models in highly dynamic environments. We proposed to use bio-inspired technology.

Research staff: Zhongliang Zhao, Torsten Braun

Testbed for Mobile and Internet Communications

Our research group maintains its own comprehensive and heterogeneous 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 protocols and architectures in realistic environments. The testbed also forms a productive network of Linux PCs and provides the storage capacity and CPU power for many of our research group's projects. An educational laboratory network for students' training is also connected and has been used for teaching in thr Bachelor program. Our research group also takes part in PlanetLab (http://planet-lab.org) and GpENI (https://wiki.ittc.ku.edu/gpeni/). PlanetLab is an open

platform for developing, deploying, and accessing planetary-scale services. For this purpose we are hosting three PlanetLab nodes in our testbed network.

GpENI is a distributed set of sites, interconnected at layer 2 (or layer 2 tunnels) to enable experimentation at layers 3 and higher. For this purpose we are hosting three GpENI nodes, two GpENI routers and one GpENI controller node in our testbed network. Moreover, we have installed three Cisco routers. Each of them is terminating a L2TP connections in order to provide a major European GpENI concentrator point (https://wiki.ittc.ku.edu/gpeni/Image:GpENI-Euro-topo.png). We are connected to the University of Kansas, the ETH Zürich and the University of Zürich.

Our research group owns a number of sensor nodes: Embedded Sensor Board (ESB), Modular Sensor Board (MSB), tmote SKY nodes, BTnodes, TelosB nodes, and micaZ nodes. Some of these nodes are operated as part of the Wisebed infrastrucuture. Another testbed consisting of multiple wireless 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 Ph.D. theses and student projects.

Research staff: All members of the RVS research group

1.4   Ph.D. Theses

- Thomas Staub: Development, Testing, Deployment and Operation of Wireless Mesh Networks, May 27, 2011

1.5   Master and Diploma Theses

- Milan Nikolic: GEZORA: A Self-Scalable Content Distribution Network, December 2010

- Benjamin Nyffenegger: Evaluation and Calibration of Software-based Energy Estimation Methodologies on MSB430 Sensor Nodes, December 2010

- Alican Gecyasar: Implementation and Evaluation of the Multicast File Transfer Protocol (MCFTP), December 2010

- Andreas Rüttimann: Quality of Service, End to End Delays and Overlay Multicast for Structured P2P Networks like Chord, March 2011

- Sebastian Barthlomé: Investigating Forward Error Correction Strategies on MSB430 Sensor Nodes, May 2011

- Gabriel Martins Dias: Implementing a Reliable Overlay Multicast Protocol on Wireless Sensor Nodes, July 2011

- Stefan Ott: Automated Deployment of a Wireless Mesh Communication Infrastructure for an On-Site Video-Conferencing System, July 2011

1.6 Bachelor Theses and Computer Science Projects

- Christoph Knecht: Secure Key Distribution in Wireless Sensor Networks (WSNs), December 2010

1.7 Awards

- Fritz Kutter Award 2010 for Reto Gantenbein's Master thesis "VirtualMesh: An Emulation Framework for Wireless Mesh Networks in OMNeT++"

1.8 Further Activities

Memberships

- Chair of ERCIM working group on eMobility (Torsten Braun)

- 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)

- SWITCH AAI Advisory Committee (Thomas Staub)

- Kuratorium Fritz-Kutter-Fonds (Torsten Braun)

- Expert for Diploma Exams at Fachhochschule Bern (Torsten Braun)

- Expert for Matura Exams at Gymnasium Hofwil (Torsten Braun)

- Management committee member of the COST Action IC 0804 Energy-Efficiency In Large Scale Distributed Systems (Torsten Braun)

- Management committee member of the COST Action IC 0906 Wireless Networking for Moving Objects (WiNeMO) (Torsten Braun)

- External Advisory Board Member of Space Internetworking Center (SPICE) at Democritus University of Thrace, Greece (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 5th ERCIM Workshop on eMobility, June 14, 2011,Universitat Politecnica de Catalunya, Vilanova i la Geltru, Spain (Torsten Braun)

Conference Program Committees

Torsten Braun

- 10th International Conference on Next Generation Wired/Wireless Networking, St. Petersburg, Russia, August 23 - 25, 2010

- 3rd Workshop on Economic Traffic Management, Amsterdam, The Netherlands, September 6, 2010

- 35th IEEE Conference on Local Computer Networks, Denver CO, USA, October 11-14, 2010

- 2nd Second IEEE International Workshop on Mobile Computing and Networking Technologies, Moscow, October 18-19, 2010

- 2nd International Congress on Ultra Modern Telecommunications and Control Systems, Moscow, Russia, October 18-20, 2010

- 16th Asia-Pacific Conference on Communications, Auckland, New Zealand, October 31 - November 3, 2010

- 4th IEEE International Workshop on Enabling Technologies and Standards for Wireless Mesh Networking, San Francisco CA, USA, November 8, 2010

- 6th Fachgespräch Future Internet, GI/ITG-Fachgruppe "Kommunikation und Verteilte Systeme" (KuVS), Hannover, Germany, November 22, 2010

- 7th International Conference on Wireless Communication and Sensor Networks, Allahabd, India, December 5-9, 2010

- 1st IEEE Workshop on Pervasive Group Communication, Miami, FL, USA, December 6, 2010

- 5th IEEE International Workshop on Heterogenous, Multi-Hop, Wireless and Mobile Networks, Miami FL, USA, December 6, 2010

- 6th IEEE Broadband Wireless Access Workshop, Miami FL, USA, December 6, 2010

- IEEE Global Communications Conference 2010, Miami FL, USA, December 6-10, 2010

- 4th Workshop on Real-World Wireless Sensor Networks, Colombo, Sri Lanka, December 16-17, 2010

- 8th International Conference on Wireless On-demand Network Systems and Services, Bardonecchia, Italy, January 26-28, 2011

- 17th Conference on Communication in Distributed Systems 2011, Kiel, Germany, March 8-11, 2011

- 6th Workshop on Wireless and Mobile Ad-Hoc Networks, Kiel, March 10, 2011

- 4th International Workshop on OMNeT++, Barcelona, Spain, March 21, 2011

- IEEE Wireless Communications & Networking Conference, Cancun, Mecico, March 21-23, 2011

- 26th ACM Symposium On Applied Computing, Taichung, Taiwan, March 21-24, 2011

- 3rd International Workshop on Communication Technologies for Vehicles, German Aerospace Center (DLR), Oberpfaffenhofen, Germany, March 23-24,2011

- 2nd Baltic Congress on Future Internet Communications, Rigq, Latvia, April 25-27, 2011

- 3rd International ICST Conference on Mobile Lightweight Wireless Systems, Bilbao, Spain, May 9-11, 2011

- 10th IFIP Networking, Valencia, Spain, May 9-13, 2011

- Colloque Francophone sur l Ingenierie des Protocoles, Sainte-Maxime, May 10-13, 2011

- 1st Workshop on Sustainable Networking, Valencia, Spain, May 13, 2011

- 12th IFIP/IEEE International Symposium on Integrated Network Management, Dublin, Ireland, May 23-27, 2011

- 2nd International Conference on Energy-Efficient Computing and Networking, Columbia University, New York, USA, May 31-June 1, 2011

- IEEE International Communications Conference, Kyoto, Japan, June 5-9, 2011

- 19th International Workshop on Quality of Service, San Jose CA, USA, June 6-7, 2011

- 5th International Conference on Autonomous Infrastructure, Management and Security, Nancy, France, June 13-17, 2011

- 9th International Conference on Wired/Wireless Internet Communications, Vilanova i la Geltru,Spain, June 15-17, 2011.

- 12th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, Lucca, June 20-23, 2011

- 4th International Workshop on Sensor Networks, Minneapolis MN, USA. June 20-24, 2011

- 3rd International Workshop on Specialized Ad Hoc Networks and Systems, Minneapolis, MN, USA, June 23, 2011

Ph.D. and Licentiate Jury Memberships

Torsten Braun

- Desislava Dimitrova, Ph.D., University of Twente, The Netherlands, November 24, 2010

- Cristina Cano, Ph.D., Universitat Pompeu Fabra, Barcelona, Spain, March 4, 2011

- Niclas Finne, Licentiate, Uppsala Universitet, Sweden, May 30, 2011

Project and Person Reviewing Activities

Torsten Braun

- Academia of Finland

- The University of Kansas, Lawrence KS, USA

- Research Council of Norway

- Royal Melbourne Institute of Technology, Melbourne, Australia

- Forschungs- und Wissenschaftsstiftung Hamburg, Germany

- Universität Ulm, Germany

Article Reviewing Activities

Torsten Braun

- ACM Transactions on Embedded Computing Systems

- Elsevier Integration, the VLSI Journal

- EURASIP Journal on Wireless Communications and Networking

- IEEE Transactions on Aerospace and Electronic Systems

- IEEE Transactions on Computers

- IEEE Transactions on Mobile Computing

- IEEE Transactions on Network and Service Management

- IEEE Transactions on Vehicular Technology

- IEEE Transactions on Wireless Communications

- IEEE/ACM Transactions on Networking

- International Journal of Network Management

- Journal of Communications and Networks

Invited Talks and Tutorials

- Torsten Braun: Performance Evaluation of Adaptive and Energy-efficient MAC Protocols for Wireless Sensor Networks, COST Action IC0804 on Energy Efficiency in Large Scale Distributed Systems, FG Wireless Networks Meeting, Coimbra, November 9, 2011

- Torsten Braun: Design and Evaluation of an Adaptive and Energy-Efficient MAC Protocol for Wireless Sensor Networks, Seminar on Wireless Sensing, St. Andrews University, November 11, 2010

- Torsten Braun: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 16, 2010

- Thomas Staub: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 16, 2010

- Torsten Braun: Design and Evaluation of an Adaptive and Energy-Efficient MAC Protocol for Wireless Sensor Networks, WiSe/DACS colloquium, University of Twente, Enschede, November 24, 2010

- Torsten Braun: Design and Evaluation of Energy-Efficient Wireless Sensor Network Protocols, Colloquium, Universidade de Sao Paulo at Sao Carlos, Brazil, December 2, 2010

- Torsten Braun: Design and Evaluation of Energy-Efficient Wireless Sensor Network Protocols, Colloquium, Universidade Federal de Sao Carlos, Brazil, December 13, 2010

- Torsten Braun: Service-Centric Networking, Forschungsseminar, Karlsruhe Institute of Technology, Institut für Telematik, Germany, January 11, 2011

- Torsten Braun: User and Machine Authentication and Authorization Infrastructure for Distributed Testbeds, Security at CERIAS, Purdue University, West Lafayette, IL, January 26, 2011

- Torsten Braun: Design and Evaluation of an Adaptive and Energy-Efficient MAC Protocol for Wireless Sensor Networks, Colloquium, Computer Science Department, Purdue University, West Lafyette IL, USA, January 28, 2011

- Torsten Braun: Development, Test, Deployment and Operation of (Mobile) Wireless Mesh Networks, Keynote, 6th Workshop on Wireless and Mobile Ad-Hoc Networks, Kiel, Germany, March 10, 2011

- Torsten Braun: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, March 22, 2011

- Thomas Staub: Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, March 22, 2011

- Torsten Braun: Content and Service-Centric Networking for Cloud Computing, Net!Works/NetWorld Workshop on European Research Strategy for Cloud Computing, Service, and Application Platforms, SAP, Walldorf, Germany, May 10, 2011

- Torsten Braun: Service-Centric Networking, Session I.1 Information-Centric Networking, Future Internet Assembly, Budapest, Hungary, May 18, 2011

- Torsten Braun: Solar-powered Wireless Mesh Networks for Environmental Monitoring, COST Action IC0804 on Energy Efficiency in Large Scale Distributed Systems, FG Wireless Networks Meeting, Budapest, May 20, 2011

- Torsten Braun: Langfristige Switch Strategie, Kommission Informatikdienste, Universität Bern, May 23, 2001

- Torsten Braun: Adaptive and Energy-Efficient Protocols for Wireless Sensor Networks, Keynote, Conference on Next Generation Internet 2011, Kaiserslautern, Germany, June 27, 2011

- Torsten Braun: Development of Adaptive and Energy-Efficient Protocols for Wireless Sensor Networks, Warsaw University of Techology, June 28, 2011

- Thomas Staub: Development, Testing, Deployment and Operation of Wireless Mesh Networks, invited lecture, University of Coimbra, Portugal, June 29, 2011

Institutional Research Cooperation

During his sabbatical, Prof. Torsten Braun performed several visits and established research collaborations at various research organizations. At Bell Labs, Holmdel NJ, USA (July 26 September 27, 2010), he worked in the group of Dr. Markus Hofmann on extending the paradigm of content-centric networking towards its applicability for more general services. This resulted in the novel concept of Service-Centric Networking (SCN). At Lancaster University, UK (September 19 November 12, 2010) he worked at the Infolab21 Department in the area of mobile sensor networks and content-centric networks. From November 28 to December 18, 2010, he visited Universidade de Sao Paulo in Sao Carlos, Brazil and collaborated on combining cloud computing and wireless sensor networks as well as scenarios and protocols for highly mobile ad-hoc networks etc. Finally, he visited the Department of Computer Science at Purdue University at West Lafayette IL, USA, from January 24 to February 2, 2011.

1.9 Publications

Publications submitted in the academic year 2010/2011 and appearing in 2011/2012 or later are not listed.

Books

- Torsten Braun, Markus Anwander, Philipp Hurni, Markus Waelchli: MAC Protocols for Wireless Sensor Networks, Next Generation Mobile Networks and Ubiquitous Computing, IGI Global, Hershey, New York, USA, October 01, 2010, pp. 165 - 174, ISBN 978-1-60566-250-3

- Marc Brogle, Xavier Masip Bruin, Torsten Braun, Geert Heijenk: Proceedings of the Fifth ERCIM Workshop on Emobility, Technical University of Catalonia, Barcelona, Spain, June 14, 2011, ISBN 978-84-920140-3-3

Reviewed Journal and Conference Papers

- Dragan Milic, Torsten Braun: NetICE9: A Stable Landmark-Less Network Positioning System, 35th Annual IEEE Conference on Local Computer Networks, Denver, Colorado, USA, October 11-14, 2010, pp. 96-103, ISBN 978-1-4244-8388-4

- Kirsten Dolfus, Torsten Braun: An Evaluation of Compression Schemes for Wireless Networks , International Congress on Ultra Modern Telecommunications and Control Systems, Moscow, Russia, October 18–20, 2010, pp. 1-6, ISBN 978-1-4244-7286-4

- Torsten Braun, Volker Hilt, Markus Hofmann, Ivica Rimac, Moritz Steiner, Matteo Varvello: Service-Centric Networking, 6th GI/ITG KuVS Workshop on Future Internet, Hannover, Germany, November 22, 2010

- Thomas Staub, Reto Gantenbein, Torsten Braun: VirtualMesh: an emulation framework for wireless mesh and ad hoc networks in OMNeT++, SIMULATION: Transaction of the Society for Modeling and Simulation International, Special Issue: Software Tools, Techniques and Architectures for Computer Simulation, Thousand Oaks, CA, USA, Vol. 87, Nr. 1-2, January 01, 2011, pp. 66-81, ISSN 0037-5497

- Torsten Braun, Geoff Coulson, Thomas Staub: Towards Virtual Mobility Support in a Federated Testbed for Wireless Sensor Networks, 6th Workshop on Wireless and Mobile Ad-Hoc Networks (WMAN 2011), Kiel, Germany, March 10-11, 2011, ISSN 1863-2122

- Philipp Hurni, Torsten Braun, Benjamin Nyffenegger, Anton Hergenroeder: On The Accuracy of Software-based Energy Estimation Techniques, European Conference on Wireless Sensor Networks (EWSN), Bonn, Germany, February 23-25, 2011, pp. 49-64, ISBN 978-3-642-19185-5

- Torsten Braun, Volker Hilt, Markus Hofmann, Ivica Rimac, Moritz Steiner, Matteo Varvello: Service-Centric Networking, Forth International Workshop on the Network of the Future, Kyoto, Japan, June 09, 2011, ISBN 978-1-61284-954-6

- Thomas Staub, Benjamin Nyffenegger, Desislava Dimitrova, Torsten Braun: Operational Support of Wireless Mesh Networks Deployed for Extending Network Connectivity, 1st International Workshop on Opportunistic Sensing and Processing in Mobile Wireless Sensor and Cellular networks (MobiSense), Bilbao, Spain, May 09-11, 2011, pp. 1-8, ISBN 978-1-936968-07-7

- Desislava Dimitrova, Geert Heijenk, Torsten Braun: Analysis Methodology for Flow-level Evaluation of a Hybrid Mobile-Sensor Network, 1st International Workshop on Opportunistic Sensing and Processing in Mobile Wireless Sensor and Cellular networks (MobiSense), Bilbao, Spain, May 09-11, 2011, pp. 1-9, ISBN 978-1-936968-07-7

- Gustavo Pessin, Fernando Osorio, Jo Ueyama, Denis Wolf, Torsten Braun: Mobile Robot Indoor Localization Using Artificial Neural Networks and Wireless Networks, First Brazilian Conference on Critical Embedded Systems (CBSEC), Sao Carlos, Brazil, May 11-13, 2011, pp. 89-94, ISBN 978-85-86686-63-4

- Thomas Staub, Simon Morgenthaler, Daniel Balsiger, Paul Kim Goode, Torsten Braun: ADAM: Administration and Deployment of Adhoc Mesh Networks, 3rd IEEE Workshop on Hot Topics in Mesh Networking (IEEE HotMESH 2011), Lucca, Italy, June 20-24, 2011, ISBN 978-1-4577-0351-5/11

- Zhongliang Zhao, Torsten Braun : OMNeT++ based Opportunistic Routing Protocols Simulation: A Framework, 10th Scandinavian Workshop on Wireless Ad-hoc Networks (ADHOC '11), Stockholm, Sweden , May 10-11, 2011

- Thomas Staub, Stefan Ott, Torsten Braun: Videoconferencia, RTI - Redes, Telecom e Instalacoes, revista brasileira de infra-estructura e tecnologias de comunicacao, Vol. XII, Nr. 133, June 30, 2011, pp. 80-85, ISSN 1808-3544

- Desislava Dimitrova, Ulrich Bürgi, Gabriel Martins Dias, Torsten Braun, Thomas Staub: Inquiry-based Bluetooth Parameters for Indoor Localisation - an experimental study, 5th ERCIM workshop on e-Mobility, Vilanova i la Geltru, Spain, June 14, 2011, pp. 13 - 21, ISBN 978-84-920140-3-3

- Gustavo Pesin, Fernando Osorio, Jo Ueyama, Jefferson Souza, Denis Wolf, Torsten Braun, Patricia Vargas: Evaluating the Impact of the Number of Access Points in Mobile Robots Localization Using Artificial Neural Networks, Fifth International Conference on Communication System software and middleware (COMSWARE), Verona, Italy, July 14–15, 2011, pp. 1-9

Technical Reports

- Geoff Coulson, Torsten Braun, Thomas Staub: Adding Virtual Mobility to a Federated Testbed for Wireless Sensor Networks: a Proposal, Universität Bern, Institut für Informatik und angewandte Mathematik, Bern, Switzerland, August 30, 2010, TR IAM-10-004

- Philipp Hurni, Torsten Braun: Real-World Experiences with the Maximally Traffic Adaptive Medium Access Control Protocol, Universität Bern, Institut für Informatik und angewandte Mathematik , Bern, Switzerland, April 29, 2011, TR IAM-11-001

- Mesut Gunes, Torsten Braun, Philipp Hurni, et al.: Hardware Capabilities, Maintenance and Future Dimensions, WISEBED Deliverable D1.5, May 01, 2011

- Koen Langendoen, Torsten Braun, Philipp Hurni, et al.: Compendium of Experimental Scenarios, Traces and Benchmarks, WISEBED Deliverable D4.3, May 01, 2011

- Stefan Fischer, Dennis Pfisterer, Philipp Hurni, et al.: Final Report on Dissemination and Joint Research Activities, WISEBED Deliverable D5.5, May 01, 2011

- Sandor Fekete, Torsten Braun, Zhongliang Zhao, et. al.: Library of Algorithms for Wireless Sensor Networks , WISEBED Deliverable D3.4, May 01, 2011