3 Research Group on Communication and Distributed Systems

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* with financial support from a third party

3.2 Overview

The research group for Communication and Distributed Systems (formerly: Rechnernetze und Verteilte Systeme, RVS) has been active since 1998 in several areas of computer communications and distributed systems. We are investigating how multimedia applications and 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.

3.3 Research Projects

Traffic Adaptivity in Wireless Sensor Networks

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 Traffic Adaptivity in Wireless Sensor Networks (TRAWSN) project, which started in October 2009 and successfully ended in January 2012. 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 and have since then been working on a) software-based energy estimation mechanisms as well as 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, which are operated by our management infrastructure TARWIS.
Another activity pursued within TRAWSN is our study on the potential of Forward Error Correction (FEC) mechanisms and dynamic/run-time adaptive FEC variants in WSNs. 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. They 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.

Moreover, we implemented and evaluated a WSN network stack supporting energy efficient and robust packet-oriented radio modules. We performed simulations and conducted experiments in real world testbeds. Packet-oriented radio modules require several times less energy and time to forward data than bit/byte-oriented radio modules that are used by common energy efficient MAC protocols. Our new WSN network stack implements a novel traffic load measuring technique, called traffic prediction, to enhance the adaptivity of the radio sleep cycles to the current traffic load. We developed a congestion detection mechanism, which is able to identify and correctly handle intra-flow and inter-flow interferences as well as congestion. To enhance network connectivity and reusability of our protocols, the WSN network stack supports IEEE 802.15.4, IP, UDP and TCP.

FEC codes that showed promising results on bit/byte-oriented radio modules deliver only low reliability performance and low energy efficiency on packet-oriented radio modules. Therefore, we additionally evaluated the impact of the Hamming (12,8) FEC code and the Reed-Solomon (255,225) FEC code to packet-oriented radio modules. We compared the performance of both FEC codes on a bit/byte bit/byte-oriented radio module and on a packet-oriented radio module. We added the FEC codes to our energy efficient and reliable WSN network stack based on a packet-oriented radio module. Although both FEC codes are able to reduce the required transmission attempts, they can neither reduce the energy usage nor enhance the reliability of our real world WSN network stack supporting energy-aware reliability mechanisms on a packet-oriented radio module.

Finally, we have worked on optimizing TCP performance in WSNs on top of several MAC protocols such as X-MAC, LPP, and ContikiMAC. Since the appearance of downsized and simplified TCP/IP stacks, single nodes in Wireless Sensor Networks (WSNs) have become directly accessible from the Internet with commonly used networking tools and applications (e.g., Telnet or SMTP). However, TCP has been shown to perform poorly in wireless networks, especially across multiple wireless hops. Our TCP performance optimizations are based on distributed caching and local retrans-

mission strategies of intermediate nodes in a TCP connection. We also developed extended techniques to these strategies. We studied the impact of different radio duty-cycling MAC protocols on the end-to-end TCP performance when using the proposed TCP optimization strategies in an extensive experimental evaluation on a real-world sensor network testbed.

Research staff: Philipp Hurni, Markus Anwander, Sebastian Barthlomé, Torsten Braun, Ulrich Bürgi

Financial support: Swiss National Foundation Project No. 200021-126718/1

Energy-efficient Management of Heterogeneous Wireless Sensor Networks

Wireless sensor networks consist of wireless sensor nodes, which host different applications for the purposes of event detection, localization, tracking, monitoring. These applications run on different types of sensor nodes. This results in a heterogenous WSN. Furthermore, an application needs to be configured and continuously updated throughout the lifetime of the network. Such tasks can occur rather frequently, especially during the deployment phase. There are several challenges to the configuration and update process. Configuration and updating should be done over the air.
We developped a novel management architecture for heterogeneous wireless sensor networks (WSNs) called MARWIS. It supports common management tasks such as monitoring, (re)configuration, and updating program code in a WSN. MARWIS considers specific characteristics of WSNs and restricted physical resources of the nodes such as battery, computing power, memory or network bandwidth as well as link quality. To handle large heterogeneous WSNs we propose to subdivide the sensor network into smaller sensor subnetworks. Each subnetwork contains sensor nodes of one type. A wireless mesh network (WMN) operates as backbone and builds the communication gateway between the different sensor subnetworks. The mesh nodes operate also as a communication gateway between the different sensor subnetworks and perform management tasks. All management tasks are controlled by a management station located in the Internet.
In contrast to the predominant multipoint-to-point communication in WSNs for data retrieval, management traffic, especially for code updates, follow a point-to-multipoint pattern. Using multicast communication in WSNs is

an efficient way to disseminate code updates to multiple sensor nodes. For this purpose a multicast protocol has to support bulky traffic (typical traffic pattern for code updates) and end-to-end reliability. In addition, we are interested in energy-efficient operations due to the limited resources of sensor nodes. We proposed the SNOMC (Sensor Node Overlay Multicast) protocol, an overlay multicast protocol, which supports reliable, time-efficient, and energy-efficient data dissemination of bulky data from one sender to many receivers. The protocol performance in terms of transmission time, number of totally transmitted packets and energy consumption is compared to other data dissemination protocols. Our results show superior performance of SNOMC independent of the underlaying MAC protocol.

Research staff: Gerald Wagenknecht, Torsten Braun

Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks

The Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks (A^4-Mesh) project has been carried out as part of the AAA/SWITCH-e-Infrastructure for e-Science programme. It is an interdisciplinary collaboration between SWITCH and two networking research groups, UniBE IAM and UniNe IIUN, plus several potential WMN users, namely the environmental researchers from UniBE GIUB and the IT services from UniBE IT and UniNE SITEL. The goal of the project is to develop a fully functional wireless mesh network supporting the authentication, authorization, accounting and auditing (A^4) functionalities.

To successfully use Wireless Mesh Networks (WMNs) in the area of Swiss higher education, WMNs have to support authentication, authorization, accounting, and auditing functionalities. To be able to do that, a WMN must be seamlessly integrated into the organizations' authentication and authorization infrastructure (AAI), like SWITCHaai. Furthermore, as there are usually multiple concurrent users of the network, a WMN has to support accounting to enable charging and network management. Finally, 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.

In the course of the first year of the project together with UniNe, we have designed and implemented a) a fully functional innovative machine au-

thentication and authorization mechanisms based on SWITCHaai, and b) a short-term accounting and monitoring mechanism based on Netflow. Moreover, we have set up a wireless mesh network in the area of Crans-Montana in the Swiss Alps where the project has demonstrated the great potential of wireless mesh networking for environmental research. Our application scenario in the Swiss Alps considers an extensive hydro-meteorological monitoring network that has been set up for estimating and modeling water availability under present and future conditions. This hydro-meteorological monitoring network consists of different measurement devices and these all produce a large amount of data, which needs to be transferred from the different remote sites to the university campus, preferably in near real-time. A wireless communication mesh network serves accordingly the purpose of a (temporary) measurement infrastructure, giving researchers low-cost broadband network access in virtually any remote area.
The current setup of the wireless mesh network in the Swiss Alps consists of seven wireless mesh nodes interconnecting the hydrological sensors to the university campus network. For the future we plan to work on the integration of the authentication, authorization, accounting and auditing (A^4) mechanisms into this hydro-meteorological monitoring wireless mesh netowork, and to use the gained experience to deploy another outdoor test beds at the University of Bern. This outdoor testbed aims use wireless mesh networking to easily extend the campus WLAN network coverage.

Research staff: Markus Anwander, Torsten Braun, Almerima Jamakovic, Sandro Beffa, Teodor Macicas, Benjamin Nyffenegger, Thomas Staub

Financial support: AAA/SWITCH Project UNIBE.6

Integral Indoor 3D Guidance and Access-Control System

The key innovation of the project is a method for uniquely identifying mobile phones without actually decrypting their transmissions and using this information for enabling location-based and access control services.
The central idea of the project in technical terms is to develop a system running on a software defined radio (SDR) system that is able to intercept traffic from both base stations and mobile devices, independently of a subscriber, in order to enable localisation algorithms based on the time difference of arrival (TDOA). The main challenge in this aspect is to capture

transmissions on the uplink (from mobile devices) and to be able to identify the devices. Concerning the former most if not all available software only deals with the downlink; concerning the latter network operators take special measures to protect the identity of their users, which aggravates the problem.
In the first months of the project we have focussed on two tasks, namely, the development of the GSM sensor that is able to intercept GSM signals and testing the hardware ability to support TDOA approach. For the preparation of the GSM sensor we have performed detailed analysis of the GSM specification to gain insights about signal processing during system design. In parallel we investigated several available solutions towards GSM sniffing such as GNU Radio plus Airprobe or OpenBTS. It was decided to reuse as many available elements as possible but develop additional functionality that we may need. For the preparation of the TDOA approach we performed tests to establish the time synchronisation discrepancies among the sensors that may affect the approach.
We are using the USRP N110 and E110 equipment from Ettus Research. An embedded Linux system built with the Administration and Deployment Adhoc Mesh (ADAM) framework, developed at the University of Bern, has been ported to the devices. On top of that the GNUradio software package was integrated and several other modules, borrowed from the Airprobe project, were incorporated into it for processing and interpretation of the GSM signals. The current version of the system is able to capture signals on the downlink and interpret the messages allowing us to derive valuable information for the processing of the uplink. The system was extended to allow multiple-channel reception.

Research staff: Desislava Dimitrova, Islam Alyafawi, Zan Li, Stefan Ott, Torsten Braun

Financial support: Eurostars E!6429, BBT Vertragsnummer INT.2011.0035

Location Based Analyser

The main goal of the Location Based Analyser (LBA) project was 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 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).
The project targets the evolving market of business intelligence based on location data and statistics on customers behaviour (in time and space).
The technological problem that LBA is trying to solve is a designing a scalable, low-cost system that is at the same time able to locate subjects with sufficient accuracy. Moreover, the system should not interfere with the customers privacy.
In the scope of the project a test-bed based on Gumstix Overo sensors was deployed first in a single space and later over several rooms on a single or multiple floors of the IAM building. The sensor nodes were running an in-house developed embedded Linux distribution (ADAM), which accommodates all functionality necessary to enable signal capturing. The system was also successfully tested on other sensor platforms such as Panda and Beagle boards.
Series of measurements were performed to gain insights on the environment, in which the system should operate and on the system performance. In the first group of measurements the impact of various factors such as manufacturer, device orientation and obstacles was investigated. In the second group several approaches towards the localisation algorithm were considered, e.g., fingerprinting, propagation model-based, etc. It was decided to focus on two directions, namely, adaptive propagation models and advanced proximity algorithms. An adaptive propagation model makes use of regular readings on channel propagation (between two sensor nodes) to derive more accurate information of the path loss. An enhanced proximity algorithm does not only consider the node closest to the target sensor node but combines feedback from several sensor nodes to improve the precision of the system. For both directions measurements were collected to evaluate the feasibility of the proposal and to test the system performance.
In addition, we also addressed several practical issues in the deployment

of an indoor localisation system such as accessibility, visualisation (done by DFRC) and scalability. For the latter we developed intelligent filtering and aggregation approaches.

Research staff: Desislava Dimitrova, Islam Alyafawi, Thomas Staub, Torsten Braun, Ivo Noppen

Financial support: Eurostars E!5533, BBT Vertragsnummer INT.2010.0027

Enhanced Mobile Communication with Content-Centric Networks

Content-Centric Networking (CCN) as a new paradigm for the Future Internet is a promising approach for mobile communication, because routing is not based on specific forwarding nodes but content names. If an individual forwarder becomes unavailable, any node in the vicinity that has overheard the content transmission or holds the corresponding content may replace the former forwarder's functionality.
In this project, we focus our research on resource constrained wireless mesh nodes that transmit content over IEEE 802.11 WLANs. The research work is divided into three areas: memory management, energy efficient operation and content discovery/delivery. Memory management is required since wireless mesh nodes have only a limited amount of RAM. Caching mechanisms need therefore to be extended to secondary storage on flash memory. Efficient caching strategies and tradeoffs, e.g., availability vs. reliability, are required. Energy-efficient operation is important for resource constrained devices to extend the battery lifetime. We aim to improve the communication efficiency by adaptively address messages via unicast or multicast communication. If only one node is interested in a content object, it is not required to broadcast and process it all nodes. Additionally, we plan to exploit the inherent bidirectional Interest-Data message exchange to employ duty cycles and synchronize activity periods. Finally, efficient content discovery and delivery mechanisms are required to enable mobile (multi-hop) communication. We aim to develop suppression mechanisms that reduce the number of unnecessarily transmitted duplicates without significantly decreasing connectivity. Additionally, dynamic routing mechanisms are required that quickly adapt to changing node connectivity due to mobility.

Since Content-Centric Networking is a new communication paradigm, no standard evaluation tools exist. In the past year, we developed and refined a CCN framework for the OMNeT++ network simulator, which is based on an accurate implementation of the CCN daemon in CCNx, the open source implementation of CCN. In the future, the simulator will allow us to quickly evaluate new processing and routing algorithms in arbitrary environments. We are currently implementing an extension applying network coding. One crucial aspect of CCN is naming. Knowledge of available content names is required to express Interests in these. We therefore developed two opportunistic discovery algorithms and implemented it using the original CCNx open source implementation. The evaluation was performed with VirtualMesh, a hybrid emulation tool for wireless ad hoc networks that is based on the emulation of CCNx and the simulation of the wireless communication. A project goal is also the deployment of our mechanisms on wireless mesh nodes. We therefore extended our embedded operating system by CCNx and performed first communication tests. Since mesh nodes have limited RAM, we implemented a resume capability, which transfers data in case of disruptions from volatile cache to persistent storage and and resumes the communication at the next opportunity.

Research staff: Carlos Anastasiades, Arian Uruqi, Tobias Schmid, Jürg Weber, Alexander Striffeler, Torsten Braun

Financial support: Swiss State Secretariat for Education and Research (SER), SER No. C10.0139

Wireless Networking for Moving Objects

The Future Internet 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. The Future Internet 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). For this purpose, we have contributed to two white papers on Content-Centric Architectures for Moving Objects and on Joint Modeling for Networks of Moving Objects. In the context of the context of the former white paper, two Short Term Scientific Missions (STSMs), one at Xanthi and one at Bern, have been funded by the COST Action. Another STSM at Barcelona was performed to investigate Localization strategies for moving objects. Other related activities include our ongoing work on Enhanced Mobile Ad-hoc Communication with Content-Centric Networks and Routing for highly Mobile Ad-hoc Networks.

In the Delay Tolerant Communication with Content-Centric Networks (CCN) STSM (Carlos Anastasiades at Demokritus University of Thrace, Greece), the application of CCN in intermittently connected terrestrial mobile ad-hoc networks was investigated. In distributed environments, CCN communication may improve scalability of mobile ad-hoc communication and the relevance of requested information. Three reference scenarios were identified based on which the investigation was performed. The scenarios included location-based information collection, message ferrying and alarming. Since naming is essential in all three scenarios, a naming scheme was defined to support efficient location-based communication. Another central requirement for location-based communication is adaptivity. Various existing adaptive mechanisms and their potential for CCN communication were identified. These build a basis for further investigations. To support intermittent communication in environments, where no end-to-end connectivity can be achieved, agent-based collection protocols and notification mechanisms have been defined. These protocols help collecting information by delegating tasks to other nodes and obtaining user-awareness immediately when new content becomes available.

Prof. Dr. Vasilis Siris visited the CDS group for an STSM on Content-Centric Networking Architectures for Moving Objects. The visit focused on two main topics: source mobility and service support in information-centric networks (ICN). In source mobility, two issues were identified: finding a mobile source's location and supporting session continuity to avoid data loss and to enable seamless mobility. During the STSM several source mobility approaches and scenarios were investigated and characterized. Source mobility solutions depend on multiple aspects including duration and types of mobility, scenarios and ICN architectures. Location independent naming facilitates caching while identity-locator splits support flexible mobility support. Based on the considered scenarios, limitations and tradeoffs were identified. Within the second topic, requirements and architectures to support service-centric networking (SCN) were investigated. The SCN concept, which has been developed at the CDS group, is a gen-

eralization of content-centric networking enabling requesting nodes to ask for services and not only content. As a result, the flexibility of requests is increased.
In October 2011 Desislava Dimitrova made a research visit to the Universidad Polytecnica de Catalunya, Spain. The two main purposes of the STSM were (1) to share knowledge and experience in the field of localisation of indoor applications and (2) to identify research topics of common interest, which will trigger cooperation among the parties. Meetings with researchers at UPC but also CTAE (Aerospace Research and Technology Centre) were held. As result two research initiatives were started - (1) measurements in the CDS test-bed to estimate the feasibility of a dynamic adaptation of path loss readings; and (2) a combined effort towards evaluating the usability of fingerprinting mechanisms, which can work with RTT measurements, for localization.

Research staff: Torsten Braun, Carlos Anastasiades, Desislava Dimitrova, Zhongliang Zhao

Financial support: European Science Foundation

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 Energy-efficient Wireless Networking, which aims to investigate energy efficient concepts for wireless communication. Related work in this area has been performed in our research project on Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks and Traffic Adaptivity in Wireless Sensor Networks. In a joint research activity together with the Universities of Würzburg and Coimbra, we have investigated tradeoffs of energy efficiency and Quality-of-Experience for video transmission over wireless networks.

Research staff: Torsten Braun, Markus Anwander, 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. Service-centric networking can be beneficial for saving network resources and reducing response time for service invocation as well as supporting location-based services. A first prototypical implementation of SCN has been realized. As an example service we used a still image format conversion service, which enables CCN routers to convert bitmap images into JPEG encoding, if a requested JPEG image is not available but only the bitmap image.

Research staff: Torsten Braun, Elham Cheriki

Opportunistic Routing for highly Mobile Ad-hoc Networks

In the first project year of the Opportunistic Routing for highly Mobile Ad-hoc Networks (ORMAN) project, we proposed and developed a simulation framework for evaluating different opportunistic routing protocols in the OMNeT++ simulator. In the second project year, we targeted on the development and evaluation of various routing protocols using the framework. We implemented and performed a systematic performance analysis of representative opportunistic routing protocols, namely ExOR and MORE. The goal is to investigate under which situations the opportunistic routing approach may achieve better results than traditional mobile ad-hoc networks routing protocols. Our simulation results show that opportunistic routing may achieve significant performance gain in lossy wireless network environments, and it will reach a better improvement under high bit rate traffic scenarios. Also the number of potential forwarders has strong influence on the performance of the protocols. A high number of forwarders may introduce collisions that will eliminate the benefits it brings.
We also analyzed topology control issues in the highly mobile environment, i.e. Unmanned Aerial Vehicle (UAV) swarms. UAVs are usually flying within a certain formation. The relative positions of all UAVs are important

for information sharing between each other and for collision avoidance. We proposed an agent-based topology control approach which is faster and more efficient than the centralized solution. We take into account both the distance between flying UAVs, via the GPS module embedded within the UAVs, and communication link signal quality, via the received signal strength indicator (RSSI). Our proposal will make a joint decision based on both the distance and RSSI value between UAVs to control the movement of the UAV swarm and the relative movement of each UAV within the swarm.
Moreover, we developed UAVNet, a framework focusing on the autonomous deployment of a flying wireless mesh network (WMN), using small quadrocopter UAVs. Every UAV carries a lightweight wireless mesh node, which is directly connected to the flight electronic of the UAV via a serial interface. The flying wireless mesh nodes are automatically interconnected to each other and are building an IEEE 802.11s WMN. Every wireless mesh node works as an Access Point (AP) and provides access for regular IEEE 802.11g wireless devices, such as notebooks, smart-phones, and tablets. UAVNet includes a concept and a prototype implementation of an autonomously deployable flying WMN. Additionally, an iPad or iPhone, with a customized software running on it, can be used to simplify the configuration, deployment, and monitoring of UAVNet. Our evaluations have shown that UAVNet can optimize network performance. They have proven that the performance of a flying network is much better than a ground-based approach, due to the better network coverage.

Research staff: Zhongliang Zhao, Simon Morgenthaler, Markus Anwander, Torsten Braun, Thomas Staub

Financial support: Swiss National Foundation Project No. 200021-130211

Mobile Multi-Media Wireless Sensor Networks

Wireless sensor network technology is becoming more and more mature and sensors are being used in many applications in the area of security, environment monitoring and e-health. Sensor networks include both discrete sensor data (e.g., temperature, passive infrared levels, and sound levels) and continuous multi-media flows (e.g., continuous audio and video flows). Moreover, in future wireless sensor networks, the issue of mobility becomes more important. First, objects to be monitored (cars, persons)

might be mobile. Second, these objects might carry sensors such that sensors become mobile. Third, the objects or special mobile devices such as robots or unmanned aerial vehicle may carry base stations to collect multimedia sensor data in order to provide them to processing elements, e.g., in a cloud computing environment, for further processing. This project proposes to build an experimental research platform including both the communication in wireless sensor networks (University of Bern, Swiss partner) and processing sensor data in cloud computing environments (University of Science and Technology of China, Chinese partner). The research platform will be based on existing solutions developed and used in previous projects at both partner-sides.
The research platform will then be used by researchers to support their experimental research work on mobile multi-media sensing. First, we investigated and designed a general scalable network architecture for mobile multi-media wireless sensor networks. Second, we investigated a multimedia sensor system for object detection and tracking based on steerable cameras that are triggered and steered based on discrete sensor data. Third, we will investigate how opportunistic forwarding can be used to support the delivery of multi-media sensor data, when sensors are mobile. Last, we will investigate mobile base stations visiting sensors for collecting multi-media sensor data. In this case, energy consumption at the sensors should be decreased by minimizing the activation of the transceivers used for communication between sensors and base stations.

Research staff: Zhongliang Zhao, Denis Lima do Rosario, Gerald Wagenknecht, Torsten Braun, Björn Mosler

Financial support: Joint research project of Nano-Tera.ch and the Sino Swiss Science and Technology Cooperation (SSSTC)

Low-Cost Network Coding for Collaborative Video Streaming

The widespread deployment of wireline/wireless communication systems and the proliferation of digital media created the recent surge in multimedia streaming research. With emerging applications such as wireless low-power surveillance, multimedia sensor networks, and portable devices with multimedia coding and communication capabilities, the traditional multimedia coding and streaming architectures are being challenged. For efficient multimedia streaming in overlay networks many often contradictory

tools as video coding, channel coding, coding strategies at intermediate network nodes and network protocols should be considered. Specifically, video coding aims at removing data redundancy to reduce the volume of the transmitted data, while channel coding adds some redundancy to the stream to make it more resilient to errors. Network protocols offer efficient transmission mechanisms to cope with the best-effort nature of networks which does not guarantee any quality of services. However, such protocols demand for knowledge of the end-to-end network statistics and are difficult to be maintained due to network dynamics. To this aim, coding at peers such as network coding becomes popular as it assists communications systems to improve network throughput, reduce delay and eliminate the need for reconciliation among peers. Essentially network coding is a special class of channel codes that permits on-the-fly adaptation of the added redundancy. Despite the appealing features of network coding, its efficient application is not straightforward and many challenging problems should be still addressed.

This project focuses on the deployment of low-cost network coding methods for video streaming in overlay networks. It is the follow up work of the Ambizione project with reference number PZ00P2-121906. In that project, we have proposed among others low complexity network coding schemes, prioritized network codes to address clients heterogeneity, inter-session network codes, and techniques for approximate network codes decoding. In detail, we have already presented a low-cost network coding method based on Raptor codes that first achieves close to linear decoding and encoding times. For decentralized systems, we have proposed another system that employs randomized network coding and restricts the coding operations in selective positions. It is shown that few network coding nodes in large overlay networks are enough to notice large gains in terms of throughput and delay. To keep the computational complexity low all other nodes are store-and-forward. We have defined a game that decides about the network coding positions based on the willingness of network nodes to perform network coding. We have coped with the problem of clients receiving an insufficient number of packets to fully recover the transmitted data. Thus, we have developed a method that uses data correlation to enhance data reconstruction. This scheme is the only one that provides a systematic framework for data recovery in case of severe losses that is applicable to various types of data. We have also considered the case of multiple concurrent streams that compete for the network resources and first present a general methodology that scales to any arbitrary number of sources. Finally, we have designed a receiver driven protocol based on network coding for video communication. This distributed system solves a

simple optimization algorithm to find the optimal coding strategy at nodes. It allows system users to improve their experience and exploit better their resources.
The developed randomized network coding method for multiple concurrent streams requires centralized knowledge about network topology and statistics. We aim to extend this technique to distributed systems. For low complexity, we will also consider the application of Raptor network coding. Novel source and channel rate allocation algorithm will be devised to take into account the multiple concurrent sources and remove the need for resource allocation algorithms that pre-allocate the bandwidth to the concurrent streams. We have shown that in many cases the sparse application of network coding is very efficient. Here, to further improve resiliency of the developed network coding techniques to network dynamics we will apply online learning methods. This will enable on-the-fly decision about the optimal coding operations and provide maximal quality streams with minimal delay. The designed approximate decoding techniques have made apparent that for rank deficient systems and correlated sources, decoding is possible by taking into account the correlation. To further enhance the performance of systems employing approximate decoding, we propose to benefit from the data correlation at encoding. For example, in wireless communication nodes can exploit overheard data from other nodes and the fact that they interfere with each other.

Research staff: Nikolaos Thomos

Financial support: Ambizione award from Swiss NSF (PZ00P2-137275)

Testbed for Mobile and Internet Communications

Our research group maintains its own comprehensive and heterogeneous network testbeds for various purposes. A wired testbed is used to build networks of experimental routers and end systems 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 to provide a major European GpENI concentrator point. We are connected to the University of Kansas, the ETH Zürich and the University of Zürich.
Moreover, our research group runs wireless testbeds. The 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, multipath 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 CDS research group

3.4 Ph.D. Thesis

- Philipp Hurni: Traffic-Adaptive and Link-Quality-Aware Communication in Wireless Sensor Networks, December 22, 2011

3.5 Master's Theses

- Ulrich Bürgi: Performance Optimization for TCP-based Wireless Sensor Networks, August 2011

- Simon Morgenthaler: UAVNet: A Prototype of a Highly Adaptive and Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles (UAVs), July 2012

- Elham Cheriki: Design and Implementation of a Conversion Service for Content Centric Networks, Master Thesis at FH Bern, January 2012

3.6 Bachelor's Theses

- Björn Mosler: Opportunistic routing algorithm implementation for OMNeT++ 4.0, March 2012

3.7 Awards

- IAM Alumni award for outstanding PhD work to P. Hurni on Traffic-Adaptive and Link-Quality-Aware Communication in Wireless Sensor Networks

3.8 Further Activities

Memberships

Torsten Braun

- Chair of ERCIM working group on eMobility
- Erweitertes Leitungsgremium Fachgruppe "Kommunikation und Verteilte Systeme"', Gesellschaft für Informatik
- Vice President of SWITCH foundation
- SWITCH Stiftungsrat
- SWITCH Stiftungsratsausschuss
- Kuratorium Fritz-Kutter-Fonds
- Expert for Diploma Exams at Fachhochschule Bern
- Expert for Matura Exams at Gymnasium Hofwil
- Expert for Matura Exams at Gymnasium Thun-Schadau
- Management committee member of the COST Action IC 0804 Energy-Efficiency In Large Scale Distributed Systems
- Management committee member of the COST Action IC 0906 Wireless Networking for Moving Objects (WiNeMO)
- External Advisory Board Member of Space Internetworking Center (SPICE) at Democritus University of Thrace, Greece

- Board Member (Gesellschafter) of VGU Private Virtual Global University, Berlin, Germany

Editorial Boards

Torsten Braun

- Editorial Board Member of Elsevier's Computer Communications Journal
- Editorial Board Member of Informatik Spektrum, Springer-Verlag
- Editorial Board Member of Journal of Internet Engineering (Editor in Chief)
- Guest Editorial Board Member of Special Issue on "Recent Advances in the Design of MAC Protocols for WSNs" in Hindawi's International Journal of Distributed Sensor Networks

Conference Chairs

Torsten Braun

- Local Co-Chair of ACM EuroSys 2012, April 10-13, 2012, Bern
- Program Co-Chair of IEEE/ACM IWQoS 2012, 20th International Workshop on Quality-of-Service, June 4–5, 2012, Coimbra, Portugal
- General Chair of 6th Joint ERCIM eMobility and MobiSense Workshop, co-located to WWIC 2012, June 8, 2012, Island of Santorini, Greece, June 8, 2012
- General Co-Chair of 1st International Workshop on Novel approaches to Energy Measurement and Evaluation in Wireless Networks, June 15, Ottawa, Canada

Conference Program Committees

Torsten Braun

- 11th International Conference on Telecommunications for Intelligent Transport Systems, St. Petersburg, Russia, August 23 - 25, 2011

- 4th International Workshop on Multiple Access Communications, Trento, Italy, September 11-13, 2011
- 36th IEEE Conference on Local Computer Networks, Bonn, Germany, October 4-7, 2011
- 3rd International Congress on Ultra Modern Telecommunications and Control Systems, Budapest, Hungary, October 5-7, 2011
- 5th IEEE International Workshop on Enabling Technologies and Standards for Wireless Mesh Networking, Valencia, Spain, October 17, 2011
- 7th International Conference on Network and Service Management, Paris, France, October 24-28, 2011
- 1st IEEE Symposium on Network Cloud Computing and Applications, Toulouse, France, November 21-23, 2011
- 7th IEEE Broadband Wireless Acess Workshop, co-located with IEEE GLOBECOM 2011, Houston, Texas, USA, November 2011
- 2nd IEEE Workshop on Pervasive Group Communication, held in conjunction with IEEE GLOBECOM 2011, Houston, TX, USA, December 9, 2011
- IEEE Global Communications Conference, in Houston, Texas, USA, December 5-9, 2011
- 10th IEEE Consumer Communications and Networking Conference, Las Vegas, USA, January 14-17, 2012
- 26th ACM Symposium On Applied Computing, Taichung, Taiwan, March 21-24, 2011
- 1st Workshop on Emerging Design Choices in Name-Oriented Networking, co-located with IEEE Infocom, Orlando FL, USA, March 25-30, 2012
- 27th Symposium On Applied Computing, Riva del Garda (Trento), Italy, March 26-30, 2012
- IEEE Wireless Communications and Networking Conference, Paris, France, April 1-4, 2012

- IEEE/IFIP Network Operations and Management Symposium, NOMS 2012, Maui, Hawaii, USA, April 16-20, 2012
- 2nd Baltic Congress on Future Internet Communications, Vilnius, Lithuania, April 25-27, 2012
- 11th IFIP Networking, Prague, Czech Republic, May 21-25, 2012
- 6th International Conference on Autonomous Infrastructure, Management and Security (AIMS 2012), University of Luxembourg, Luxembourg, June 4-8, 2012
- 10th International Conference on Wired/Wireless Internet Communications, Santorini Island, June 6-8, 2012
- 6th Joint ERCIM eMobility and MobiSense Workshop, co-located to WWIC 2012, Island of Santorini, Greece, June 8, 2012
- IEEE International Conference on Communications, Ottawa, Canada, June 10-15, 2012
- 4th IEEE International Workshop on Hot Topics in Mesh Networking, San Francisco CA, USA, June 25, 2012
- 5th International Workshop on Sensor Networks, co-located with ICCCN, Munich, July 30-August 2, 2012

Desislava Dimitrova

- W3 workshop, 2011, University of Twente, The Netherlands
- WISH seminar, 2012, University of Bern, Switzerland
- Joint ERCIM eMobility and MobiSense workshop, 2012, Santorini, Greece

Ph.D. Jury Memberships

Torsten Braun

- Krzysztof Piotrowski, Brandenburgische Technische Universität Cottbus, November 2011
- Christian Hübsch, Karlsruhe Institute of Technology, June 29, 2012

Project and Person Reviewing Activities

Torsten Braun

- Education Assessment Exercise at KTH Stockholm, Chair of Review Panel for School of Electrical Engineering
- Evaluation Committee for Research in Information and Communication Technology at Norwegian Universities, University Colleges and Selected Research Institutes
- Project Reviewer for 7th Framework Programme of the European Community for research, technological development and demonstration activities
- Hasler Foundation
- Swiss National Science Foundation

Journal Article Reviewing Activities

Torsten Braun

- ACM Transactions on Embedded Computing Systems
- Elsevier Journal of Network and Computer Applications
- EURASIP Journal on Wireless Communications and Networking
- IEEE Communications Magazine
- IEEE Communications Letters
- IEEE Transactions on Computers
- IEEE Wireless Communications Magazine
- IEEE Transactions on Network and Service Management
- IEEE Transactions on Wireless Communications
- International Journal of Network Management
- International Journal of Distributed Sensor Networks
- Journal of Communications and Networks

- Simulation: Transactions of the Society for Modeling and Simulation International
- Springer Journal of Medical Systems

Desislava Dimitrova

- Elsevier Computer Comunnications
- Elsevier Computer Networks

Almerima Jamakovic-Kapic

- Elsevier, the Transportation Research Part C Journal
- Elsevier, The International Journal of Critical Infrastructure Protection (IJCIP)
- IEEE Transactions on Reliability

Invited Talks and Tutorials

Carlos Anastasiades

- Evaluation of CCNx in Mobile Environments using VirtualMesh, CCNx Community Meeting, Palo Alto, CA, USA, September 9, 2011

Torsten Braun

- Experimental Research on Reliability and Energy-Efficiency in Wireless Sensor Networks, Keynote Talk at 3rd Workshop on Pervasive Applications of Wireless Technologies, Enschede, The Netherlands, September 27, 2011
- Delay Tolerant Networking and Content/Service-Centric Networking, Invited Talk at Workshop at Space Internetworking Center (SPICE), Xanthi, Greece, September 6, 2011
- Development and Evaluation of Energy-Efficient and Adaptive Protocols for Wireless Sensor Networks, Keynote Talk at IEEE 3rd Latin-American Conference on Communications - LATINCOM 2011, Belem, October 24, 2011
- Soziale Netze-Einsatzmöglichkeiten der Zukunft, Invited Talk at Entrepreneur Clubabend, Solothurn, October 27, 2011

- Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 22, 2011
- A4-Mesh: Authentication, Authorization, Accounting, and Auditing in Wireless Mesh Networks, AAA/SWITCH Info-Day, January 19, 2012, Bern
- Research Challenges in Networked Systems, Keynote Talk at the 5th VERDIKT Conference, Oslo, Norway, April 25, 2012
- Energy Consumption and Energy Efficiency On Hardware and Software Approaches to Monitor Wireless Mesh and Sensor Networks, Round Table on "Monitoring of energy consumption - are our tools sufficient?", organized by COST Action IC 0804 on Energy Efficiency in Large Scale Distributed Systems, Working Group 2: Characterization of energy consumption and energy efficiency, May 8, 2012, Madrid
- Content-Centric Networking in Delay/Disruption-Tolerant Networks, Invited Talk at WWIC 2012 Panel on Internetworking with Challenging Conditions, Santorini Island, June 7, 2012
- Reliable and Energy-Efficient Communication in Wireless Sensor Networks, Computer Science Colloquium, Western Michigan University, Kalamazoo MI, USA, June 13, 2012
- MobileCloud - Future Mobile Telecommunication Networks Using Cloud Technologies, Invited Talk at Open Cloud Day, Bern, June 19, 2012
- A4-Mesh: Authentication, Authorization, Accounting, and Auditing in Wireless Mesh Networks, 28th TERENA TF-Mobility and Network Middleware Meeting, Zürich, June 26, 2012

Thomas Staub

- Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 22, 2011

Nikolaos Thomos

- Network Coding for Multimedia Communications, University of Edinburgh, U.K., Dec. 2011

- Low-Cost Network Coding for Collaborative Video Streaming, University Carlos III & IMDEA networks, Spain, May 2012

- Network Coding for Multimedia Communications, University of Surrey, U.K., May 2012

- Low-Cost Network Coding for Collaborative Video Streaming, University of Edinburgh, U.K., May 2012

Organized Events

- The CDS group took part at "Fit in IT - Roadshow" organized at several high schools in Switzerland: Alte Kantonsschule Aarau, September 14, 2011, Kantonsschule Olten, November 8, 2011, Kantonsschule Rychenberg Winterthur, November 22, 2011 and Kantonsschule Zug, December 1, 2011.

- Europe day 2012 at the University of Bern, May 9, 2012: The CDS group took part at the Europe day 2012, where researchers from EU-funding projects could present their achievements. CDS presented, together with its partner DFRC AG, Zug, Switzerland, its two Eurostars projects - LBA and In3DGuide. A small demo was installed on the premises of the event that showed in real time statistics on the guests' presence and mobility.

- The seminar on Wireless Integration of Sensor networks in Hybrid (WISH) architectures at the University of Bern, March 15, 2012: The one-day seminar on Wireless Integration of Sensor networks in Hybrid architectures (WISH) took place at the University of Bern on March 15, 2012. The seminar was co-sponsored by the Nachwuchsförderungs-Projektpool of the University of Bern, the CDS group and the company 89grad.

- The EuroSys 2012 conference, jointly organized by the University of Bern and the University of Neuchâtel at University of Bern, Switzerland, April 10-13, 2012.

- Computer Science Summer School seminar, organized together with the Dependable Systems and Networks group and Distributed Systems group of University Neuchâtel, at La Vue-des-Alpes, Switzerland, July 4-6, 2012.

3.9 Publications

Publications submitted in the academic year 2011/2012 and appearing in 2012/2013 or later are not listed.

Books

- Thomas Staub: Development, Testing, Deployment & Operation of Wireless Mesh Networks: Addressing various challenges encountered in the life cycle of Wireless Mesh Networks, Südwestdeutscher Verlag für Hochschulschriften, July 18, 2012, ISBN 978-3-8381-3358-4

Reviewed Journal and Conference Papers

- Fausto Guzzo da Costa, Torsten Braun, J Ueyama, Gustavo Pessin, Fernando Santos: Arquitetura baseada em veculos areos no tripulados e redes de sensores sem fio para aplicaes agrcolas, VIII Congresso Brasileiro de Agroinformatica, SBIAGRO 2011, Bento Gonalves, Brazil, October 17-21, 2011, pp.1-5

- Philipp Hurni, Markus Anwander, Gerald Wagenknecht, Thomas Staub, Torsten Braun: TARWIS - A Testbed Management Architecture for Wireless Sensor Network Testbeds, International Conference on Network and Service Management (CNSM), Paris, France, October 24-28, 2011, pp.1-4, ISBN 978-1-4577-1588-4

- Vitor Bernardo, Marilia Curado, Thomas Staub, Torsten Braun: Towards Energy Consumption Measurement in a Cloud Computing Wireless Testbed, IEEE First Symposium on Network Cloud Computing and Applications (NCCA 2011), Toulouse, France, November 21-23, 2011, pp.91-98, ISBN 978-1-4577-1667-6

- Philipp Hurni, Ulrich Bürgi, Markus Anwander, Torsten Braun: TCP Performance Optimizations for Wireless Sensor Networks, 9th European Conference on Wireless Sensor Networks, Trento, Italy, February 15-17, 2012, pp.17-32, ISBN 978-3-642-28168-6

- Geoff Coulson, Barry Porter, Ioannis Chatzigiannakis, Christos Koninis, Stefan Fischer, Dennis Pfisterer, Daniel Bimschas, Torsten

Braun, Philipp Hurni, Markus Anwander, Gerald Wagenknecht, Sandor Fekete, Alexander Kröller, Tobias Baumgartner: Flexible Experimentation in Wireless Sensor Networks, Communications of the ACM, Vol.55, Nr.1, January 1, 2012, pp.82-90, ISSN 0001-0782

- Philipp Hurni, Markus Anwander, Gerald Wagenknecht, Thomas Staub, Torsten Braun: TARWIS A testbed management architecture for wireless sensor network testbeds, IEEE/IFIP Network Operations and Management Symposium (NOMS), Maui, Hawaii, USA, April 16-20, 2012, pp.611-614, ISBN 978-1-4673-0267-8

- Denis do Rosario, Rodrigo Costa, Helder Paraense, Kassio Machado, Eduardo Cerqueira, Torsten Braun: A smart multi-hop hierarchical routing protocol for efficient video communication over wireless multimedia sensor networks, 2nd IEEE International Workshop on Smart Communication Protocols and Algorithms, Ottawa, Canada, June 10-15, 2012, pp.8113-8117

- Almerima Jamakovic, Markus Anwander, Torsten Braun, Peter Kropf, Eryk Schiller, Jan Schwanbeck, Thomas Staub: A4-Mesh: Connecting Remote Sites, Switch Journal, March 1, 2012, pp.15-17

- Matthias Thoma, Klaus Sperner, Torsten Braun: Service Descriptions and Linked Data for Integrating WSNs into Enterprise IT, 34th International Conference on Software Engineering, Zürich, Switzerland, June 2-9, 2012, pp.43-48, ISBN 978-1-4673-1789-4

- Fausto Costa, Jo Ueyama, Torsten Braun, Gustavo Pessin, Fernando Osorio, Patricia Vargas: The use of Unmanned Aerial Vehicles and Wireless Sensor Networks in Agricultural Applications, IEEE International and Remote Sensing Symposium, Munich, Germany, July 22-27, 2012, pp.5045-5048, ISBN 978-1-4673-1158-8

- Zhongliang Zhao, Torsten Braun: Topology Control and Mobility Strategy for UAV Ad-hoc Networks: A Survey, Joint ERCIM eMobility and MobiSense Workshop, Santorini, Greece, June 8, 2012, pp.27-32, ISBN 978-3-9522719-3-3

- Gerald Wagenknecht, Markus Anwander, Torsten Braun: Performance Evaluation of Reliable Overlay Multicast in Wireless Sensor Networks, 10th International Conference on Wired/Wireless Internet Communications (WWIC), Santorini, Greece, June 6-8, 2012, pp.114-125, ISBN 978-3-642-30629-7

- Gerald Wagenknecht, Markus Anwander, Torsten Braun: SNOMC: An Overlay Multicast Protocol for Wireless Sensor Networks, 9th Annual Conference on Wireless On-demand Network Systems and Services (WONS), Courmayeur, Italy, January 9-11, 2012, pp.75-78, ISBN 978-1-4577-1721-5

- Desislava Dimitrova, Islam Alyafawi, Torsten Braun: Experimental Comparison of Bluetooth and WiFi Signal Propagation for Indoor Localisation, 10th International Conference on Wired/Wireless Internet Communications (WWIC), Santorini, Greece, June 6-8, 2012, pp.126-137, ISBN 978-3-642-30629-7

- Rossitza Goleva, Seferin Mirtchev, Dimitar Atamian, Desislava Dimitrova, Oleg Asenov: Experimental Analysis of QoS Provisioning for Video Traffic in Heterogeneous Networks, Joint ERCIM eMobility and MobiSense Workshop, Santorini, Greece, June 8, 2012, pp.62-69, ISBN 978-3-9522719-3

- Ivo Noppen, Desislava Dimitrova, Torsten Braun: Data ltering and aggregation in a localisation WSN testbed, 8th International ICST Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (Tridentcom), Thessaloniki, Greece, June 11-13, 2012

- Markus Anwander, Torsten Braun, Almerima Jamakovic, Thomas Staub: Authentication and Authorisation Mechanisms in support of Secure Access to WMN Resources, The Fourth IEEE International Workshop on Hot Topics in Mesh Networking (HOTMESH), San Francisco, USA, June 25th, 2012, ISBN 978-1-4673-1239-4

- Desislava Dimitrova, Hans van den Berg, Geert Heijenk, Remco Litjens: LTE uplink scheduling - flow level analysis, 4th international conference on Multiple access communications (MACOM), Trento, Italy, September 11-13, 2011, pp.181-192, ISBN 978-3-642-23795-9

- Islam Alyafawi: Towards Self-Learning Radio-Based Localization Systems, IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM PhD Forum), Lugano, Switzerland, March 19-23, 2012, pp.556-557, ISBN 978-1-4673-0905-9

Technical Reports

- Philipp Hurni, Torsten Braun: Link-Quality Aware Run-Time Adaptive Forward Error Correction Strategies in Wireless Sensor Networks, Universität Bern, Institut für Informatik und angewandte Mathematik, Bern, Switzerland, November 22, 2011, IAM-11-003

- Vasilios Siris, Chiara Boldrini, Raffaele Bruno, Marco Conti, Carlos Anastasiades, Torsten Braun, Marilia Curado, David Palma, Paulo Mendes, Bruno Batista, Ivana Zarko, Kresimir Pripuzic: Content-Centric Architectures for Moving Objects, COST Action IC0906 WiNeMO white paper, June 06, 2012