

3 Research Group on Communication and Distributed Systems

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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 cloud computing services with high demands on the quality, reliability and energy efficiency of mobile communication systems and networks can be supported. Moreover, we are investigating localization mechanisms for wireless devices as well as new Future Internet paradigms such as Information-Centric Networking.

3.3 Research Projects

Mobile Cloud Networking

Mobile Cloud Networking (MCN) is a EU FP7 large-scale Integrating Project (IP) funded by the European Commission. The MCN project was launched in November 2012 for a period of 36 months. In total top-tier 19 partners from industry and academia commit to jointly establish the vision of Mobile Cloud Networking.

The project is primarily motivated by an ongoing transformation that drives the convergence between the mobile communication and cloud computing industry, enabled by the Internet. These observations led to a number of objectives to be investigated, implemented and evaluated over the course of the project. The top-most objectives of the MCN project are to: a) extend the concept of cloud computing beyond data centres towards the mobile end-user, b) to design an 3GPP-compliant Mobile Cloud Networking architecture that exploits and supports cloud computing, c) to enable a novel business actor, the MCN provider, and d) to deliver and exploit the concept of an end-to-end MCN for novel applications and services. Translated into a research problem, the key research and innovation issues that the MCN project is expected to tackle are the following: a) how to virtualise the Radio Access Networks (RAN), b) how to design a cross-domain Infrastructure-as-a-Service (IaaS) control plane, c) how to upgrade virtualisation and cloud computing middleware to support highly demanding, real-time network applications and services, d) how to design, deploy and operate 3GPP software components to attain and fully benefit from cloud computing attributes, e)

how to ensure QoE with advanced content and service migration mechanisms for mobile cloud users and f) how to support multiple cross-domain aspects that must service a multitude of business actors and stakeholders.

The CDS group is involved in the following technical work packages (WP): WP3 on Mobile Cloud Infrastructural Foundations, WP4 on Mobile Network Cloud and WP5 on Mobile Platform. Besides, the CDS group is leading the work package on Dissemination, Exploitation, Standardisation activities.

The scope of work within WP3 (T3.5) of the project is to offer comprehensive testing framework for the LTE radio access network (RAN). In particular, the framework should allow the development of novel algorithms for the RAN such as load balancing among virtualised base stations, cooperation between different radio technologies (LTE, WiFi) and collection of metrics to support mobility and content prediction models. To achieve the goal existing simulation and emulation LTE frameworks will be extended with novel functionality required to represent the network virtualisation. Since the framework should enable demonstration scenarios and its composition depends on the developed RAN architecture, we are actively involved in these two activities within WP2. The purpose is, on the one hand, to develop a novel testing platform for virtualized LTE radio access and, on the other hand, in developing computational models for virtualized LTE base stations.

The scope of WP4 is to develop a novel Mobile Core Cloud concept in support of the on-demand and dynamic deployment of mobile core network in a cloud computing environment. The research within this work package has three directions, enabling the development of a complex vision on the future cloud-based mobile core networks. First, the components of the Mobile Core Cloud network and their interaction are designed considering the new flexibility characteristics of the underlying cloud platform. Second, a set of algorithms specific to the management of the Mobile Core Cloud network will be developed. Third, the functionality for the deployment of the mobile core network as a service will be studied including the interaction with the subscribers.

A key contribution of WP5 is to design and implement the follow-me cloud concept, which aims to provide cloud services and data to the mobile user as close as possible to minimize delays and improve performance. Content-distribution networks as well as Information-Centric Networking

are two technologies, which are used to design and implement the follow-me cloud concept. This allows strategic movement and placement of contents/services as well as caching. We have led the architecture development within Task 5.2 "Follow-Me Cloud and Algorithms for Distribution and Migration of Content and Applications", which also influenced the overall Mobile Cloud Networking architecture. Thus, we contributed to the WP2 (Scenarios, Requirements, Business Models, and Overall Architecture) deliverable on "Reference Scenarios and Technical System Requirements Definition".

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Financial support: EU FP7 Large-scale Integrating Project (IP), contract number CNECT-ICT-318109

Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks

The Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks (WMNs) project (A⁴-Mesh) 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, CDS at University of Bern and IIUN at University of Neuchatel (UniNE) plus several WMN users, namely the environmental researchers from UniBE GIUB and the IT services from UniBE IT and UniNE SITEL.

The goal of the A⁴-Mesh project was the development and the integration of innovative authentication and authorization, auditing, and accounting (A⁴) mechanisms into a fully functional wireless mesh network infrastructure, and its deployment in several application scenarios. The first application scenario considered an environmental monitoring scenario in the Swiss Alps. The setup of the wireless mesh network in the Crans-Montana-Sierre region (Valais) consisted of seven wireless mesh nodes interconnecting the hydrological sensors to the university campus network. As a result researchers were able to access their measurement devices and onsite data storages directly from the university. In addition, the network users being on-site were able to access the Internet at any

time. The second application scenario considered the deployment of two outdoor pilot networks, one at UniBE and another at UniNE. These outdoor networks were used for extending campus network connectivity at UniBE, and for testing the backup connectivity between buildings at UniNE.

Furthermore, the integration of the authentication and authorization mechanisms into the A⁴-Mesh wireless mesh network made it possible to access the deployed networks in a secure way because of its integration into the authentication and authorization infrastructure (AAI) of Swiss higher education based on SWITCHaaI mechanisms. Furthermore, the A⁴ mechanisms offered detailed accounting functions, which provided information about traffic consumptions of each particular network user. The A⁴-Mesh monitoring infrastructure allowed the monitoring of every parameter provided by the ADAM wireless mesh node operating system: it might be an amount of free memory on the ALIX node, or number of retransmissions on the particular interface. The monitoring web interface had the ability to be easily configured by the administrator.

Research staff: Markus Anwander, Torsten Braun, Almerima Jamakovic-Kapic, Sandro Beffa, Teodor Macicas

Financial support: AAA/SWITCH Project UNIBE.6

Easily Deployable A⁴ Wireless Mesh Networks

The Easily Deployable A⁴ Wireless Mesh Networks (WMNs) project (eA⁴-Mesh) has been carried out as part of the AAA/SWITCH-e-Infrastructure for e-Science programme. The eA⁴-Mesh project is an extension of the A⁴-Mesh project, in which a collaboration between the project partners of the A⁴-Mesh project and a new user group of environmental researchers of the Centre for Hydrogeology and Geothermics from University of Neuchatel (UniNE CHYN) took place.

The A⁴-Mesh project and its extension eA⁴-Mesh considered several application scenarios of wireless mesh network technologies. The main application scenario has been focusing on support for environmental research. In the A⁴-Mesh project, the A⁴-Mesh network has been deployed in the Crans-Montana-Sierre region (Valais), while in the eA⁴-Mesh project the network was deployed in the area of Emmental, both to support

environmental research. Specifically, in eA⁴-Mesh, the wireless mesh network was used to investigate how ground water flow systems used for water supply will react to dry periods that are expected to occur more frequently under future climatic conditions. Here the wireless network infrastructure, which was used to continuously transfer environmental data measured by various environmental sensors, was in addition coupled to a database feeding a hydrogeological modeling and simulation system with the aim to make the environmental research process more efficient.

Similar to the A⁴-Mesh project, special care was taken to allow easy access to the wireless mesh network by integrating authorisation and authentication into SWITCH's own authentication and authorisation infrastructure (AAI), grouped into a federation and based on Shibboleth (SWITCHaai). Furthermore, the accounting function provided specific traffic statistics, which contribute to the traffic based charging module. It operates in a SWITCHaai compatible wireless mesh network, which allows the network administrator to have full visibility of the forwarded traffic including the source, destination, and the forwarding nodes (organizations) involved. With this data the organisations can be properly charged for their traffic.

Research staff: Markus Anwander, Torsten Braun, Almerima Jamakovic-Kapic, Sandro Beffa, Teodor Macicas

Financial support: AAA/SWITCH Project UNIBE.10

Swiss Academic Compute Cloud

The Swiss Academic Compute Cloud project (SwissACC) sustains the cloud-related activities of the AAA/SWITCH-e-Infrastructure for e-Science program and bridges the activities that are expected to become relevant for the upcoming SUK-Program 2013-2016 "Wissenschaftliche Information: Zugang, Verarbeitung und Speicherung". For the A⁴-Mesh contribution to the project, the main goal is to perform a feasibility study on the A⁴-Mesh integration into the Swiss Academic Compute Cloud to become a platform for storage and processing of the collected sensor data.

The A⁴-Mesh network, deployed in two Swiss regions, namely Valais and Emmental, stores the environmental sensor data continuously on a server at UniBe CDS group premises. This is the typical use case where a researcher stores the data on his/her own infrastructure. Additionally, once

the researcher has left, it is often very difficult for other persons to reuse the data. Hence, the primary aim of this project is to investigate a solution for users who may benefit from storing their experimentation data on a distributed computing and/or data storage infrastructure, such as Grid and/or Cloud. In addition, it will output a feasibility study on the possibility of using SwissACC as a processing platform for the collected sensor data to be fed into the modeling and simulation system to make the environmental research process more efficient.

Research staff: Almerima Jamakovic-Kapic, Teodor Macicas, Torsten Braun

Financial support: AAA/SWITCH Sustainability Project

Integral Indoor 3D Guidance and Access-Control System

The central idea of the project in technical terms is to develop a software defined radio (SDR) system that is able to intercept GSM 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 first issue most if not all available software only deals with the downlink; concerning the second issue network operators take special measures to protect the identity of their users, which aggravates the problem.

In the first year of the project we developed a GSM sensor that is able to intercept GSM signals on the downlink and tested it for several locations in cooperation with our partners. Prior to the development we performed detailed analysis of the GSM specification to gain insights about signal processing during system design. In the second year we extended the GSM sensor for uplink scanning. During the testing process we came across other interesting research challenges such as impact of user diversity and power distributions. In terms of TDOA investigations we first tested the hardware ability to support the algorithm, which was followed by detailed analysis on the achievable synchronisation accuracy. We developed a novel algorithm that allows highly precise time synchronisation evaluations and that can be used for a larger range of applications and not only localisation. Subsequently, we are working on the comparison

of two methods for accurate timestamping, which should allow us to establish a minimum theoretically achievable positioning accuracy as well as practically achievable results.

We are using the USRP N110 and E110 equipment from Ettus Research as SDR platform. 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 N210 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 GSM signals on both uplink and downlink, attach high accuracy timestamps and interpret the messages, allowing us to derive valuable positioning information. Ongoing efforts focus on tracking a single mobile user, testing the performance of the TDOA algorithm in different propagation environment and UMTS feasibility analysis.

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

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

Enhanced Mobile Communication with Content-Centric Networks

Content-Centric Networking (CCN) as a new paradigm for the Future Internet is a promising approach for opportunistic 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 opportunistic networks, storage management is important because of two reasons: limited memory on resource constrained devices and lacking continuous connectivity between network nodes.

In the first year of the project, we started to implement a memory extension that can store incomplete content on persistent storage and resume it later from where it stopped. In the second year, we refined the implementation and deployed it on wireless mesh nodes. Evaluations showed that the

developed extension enables content transmission even in case of short opportunistic contacts, where regular content transmission is not possible, at the expense of no additional overhead. The extension can differentiate between real-time and delay-tolerant traffic based on the content's validity time, which is defined by the *freshnessSeconds* parameter. Although all received objects are stored in the cache and a LRU replacement strategy is applied, only delay-tolerant traffic is stored on persistent storage. Real-time traffic is automatically removed if new content is received.

A planned task in the second year was the application of energy-efficient operation to avoid battery depletion of resource constrained devices. We evaluated the energy consumption of wireless mesh nodes for different roles, i.e. requester, content source, passive bystander that does not send any messages, during unicast and multicast transmission. The results showed that multicast communication requires considerably more energy than unicast communication if there is one requester and one content source but that the relative energy consumption drops drastically the more requesters concurrently request the content.

Since mobile environments may change quickly, forwarding entries defining where to forward received Interests, cannot be configured statically or by using prefix announcements that are distributed via Internet link-state interior gateway protocols such as OSPF. A task that was planned for the third year was the automatic inclusion of data prefixes from overheard multicast communication. This functionality has already been implemented in the second year and was tested on wireless mesh nodes. To limit the processing overhead and FIB size, several optimizations were implemented such as merging of multiple similar prefixes, limiting the validity time and number of entries of dynamically included FIB entries as well as limiting the processing frequency of overheard packets without storing additional state information. The processing overhead was low on wireless mesh nodes and negligible on devices with faster processing capabilities.

Since opportunistic communication is based on one-hop communication, requests need to be forwarded in case of lacking direct connection. We designed and implemented an agent-based content retrieval for delay-tolerant communication. In a three-way handshake protocol a requester can find and select an appropriate agent node that will request the content for him/her. The agent stores the retrieved content including meta information and signatures of the original publisher in the repository

of his/her mobile device and informs the original requester when the complete content is retrieved. The repository on the agent's mobile device is regularly synchronized with the agent's content proxy, which is his/her home repository continuously connected to the Internet. If in range, the original requester can retrieve the content from the agent directly or if connected to the Internet from the content proxy. We are currently deploying and testing this mechanism on Android smart phones.

We have previously shown that content-centric data discovery is advantageous in opportunistic networks, where the same content objects may be stored on one or multiple hosts. By expressing Interests in name space prefixes, a user can request content that is stored on multiple hosts concurrently. The more name components a name space has, the more subsequent Interest requests need to be transmitted and consequently more time is required to discover available content objects in the name space. In dynamic environments, it is important to detect available resources quickly because contacts may be short. Therefore, two different supporting mechanisms are proposed: a naming scheme and content notifications. The naming scheme comprises broadcast components and alias mappings. The same broadcast components can be used by multiple publishers to describe content or publishers enabling quick discovery of alternative content sources. Alias mappings are content objects that link descriptive ambiguous specifiers comprising broadcast components to unique content names. Content notifications are important if a content source needs to quickly inform multiple nodes about events such as alarms or the availability of content. Since regular content-centric communication is request based, two notification mechanisms are developed based on Interest and Data messages. Due to lacking scalability of emulation frameworks and wireless test beds, we are currently evaluating both mechanisms in large mobile scenarios using our CCN-OmNeT++ simulator implementation. To get more meaningful simulation results, the implementation was extended by a more accurate application layer implementation including our memory management scheme as well as more realistic mobility models.

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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). In the context of the research action Dr. Boris Bellalta from the Polytechnical University of Catalunya visited the CDS group to discuss collaboration in the area of cooperation among heterogeneous wireless sensor networks. Vitor Bernardo, PhD candidate from the University of Coimbra, also visited the group related to joint research on energy-efficient networking. Other related activities include our ongoing work on Enhanced Mobile Ad-hoc Communication with Content-Centric Networks and Opportunistic Routing for highly Mobile Ad-hoc Networks.

The diversity of wireless sensor networks (WSNs) nowadays is large enough to validate questions such as "Do we need all data?", "Which data is relevant?", "How can I use this data?". The answers are further challenged by the large numbers of mobile phones that can act as sensors themselves. In order to answer such questions one needs to deal with data semantics and data (content) representation as well as with formalising the communication among heterogeneous nodes. Formal representation of content is necessary to allow the easy extraction of relevant parameter and the quick decision on whether the data is of interest for an external network. For example, if we consider monitoring systems for fire detection they can rely on information from specifically deployed for the purpose sensors but also on reading from meteorological sensors. Moreover, the data collected by the sensors may be of interest for other networks to optimise their performance. Such scenario will require collaboration between the different, diverse networks on several layers, including content discovery and (aggregated) data propagation. The foundations of establishing such collaboration, together with defining an application scenario, were discussed during the research visit.

During his research visit at the CDS group Vitor Bernardo addressed work in the area of energy-efficiency for moving devices with IEEE 802.11n connectivity. The opportunity to connect various sensors, actuators and other devices to the Internet, usually referred to as Internet of Things (IoT), raises new challenges in the deployment of those devices. One of the most important challenges is related to the device's battery lifetime, directly affected by the communication activity. The work conducted during the research visit focused on the optimization of energy consumption in end-user devices by investigating on the usability of techniques such as aggregation mechanisms, power saving mechanisms and error correction techniques.

Research staff: Torsten Braun, Carlos Anastasiades, Desislava Dimitrova

Financial support: European Science Foundation, COST Action IC0906

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 trade-offs of energy efficiency and Quality-of-Experience for video transmission over wireless networks.

Research staff: Torsten Braun, Markus Anwander, Philipp Hurni, Almerima Jamakovic-Kapic

Financial support: European Science Foundation, COST Action IC0804

Service-Centric Networking

Content-centric network (CCN) is a new and promising networking paradigm. CCN aims at moving from host-to-host communication style to a new paradigm that focuses on content as the building block of the Internet rather than hosts. In other words, CCN is about what users want, not where it is. With this new paradigm, the concepts of security, routing, and group communication are more natural and robust because of decoupling senders from receivers. The goal of CCN is to achieve a network architecture that better suits the common use of networks today with respect to content distribution and mobility.

However, CCN does not consider the concept of services in its architecture. We believe that services, rather than content, should be the center of focus in future network architectures. This is due to the fact that content is just a subset of services and what applies to services can easily apply to content, but not the other way around.

Service-centric network (SCN) is a new networking paradigm where services are at the heart of its architecture. SCN is an object-oriented architecture where services and contents are considered as objects. Our research aims at building the SCN architecture based on CCN with extensions regarding service naming, name resolution, service routing, and service management.

Research staff: Dima Mansour, Torsten Braun

Financial support: Swiss National Science Foundation Project No. 146376

Opportunistic Routing for highly Mobile Ad-hoc Networks

In the first two project years of ORMAN, we proposed and developed a framework for simulating and analyzing opportunistic routing protocols. Based on that, we implemented different OR protocols and evaluated their performance using our framework. In the third project year of ORMAN, we continued our work to design and evaluate a Topology and

Link quality-aware Geographical opportunistic routing protocol for mobile wireless ad-hoc networks.

Most of the existing OR protocols define a candidate list such that only the nodes within the list can compete for packet forwarding. However, the idea of pre-defining a candidate list reduces the freedom of opportunism and the list will be no longer valid when nodes are mobile. This is because the list is built statically prior to data transmission to learn link conditions, and when a node moves, the network topology will change. Therefore, the prediction of the candidates' priorities can not reflect the real situation at the moment of packet transmission. Additionally, due to node mobility, the predefined priority list will not hold any more. This list will also prevent that a non-listed node might move to a better position and become a more suitable candidate. Based on this observation, TLG does not include a candidate list when selecting the relay node. All nodes could participate in packet relaying during the process of packet transmission.

TLG takes different network metrics into account to make a joint routing decision. It uses the idea of dynamic forwarding delay (DFD) by considering link quality, node progress, and remaining energy to compute the dynamic delay function. When the source node has data to transmit, it includes the geographical information of itself and also of the final destination into the packet and broadcasts it. The neighbors that receive the packet will first check whether they are closer to the final destination than the last hop. If not, they drop the packet. Otherwise, they are considered as possible relay nodes, and apply a DFD function. DFD was designed to give a delay timer before a node rebroadcasts the received packet. The node that generates the smallest delay will rebroadcast the packet first. By overhearing this transmission, other candidates stop the scheduled transmission and drop the packet. In the meantime, the re-broadcasted packet is used as a passive acknowledgement, and the sender knows which node has been selected as the forwarder. Therefore, the sender transmits subsequent packets using unicast to reduce the drawbacks introduced by broadcasting. In TLG, the duration of this unicast transmission should depend on the validity time of the link between the sender and the selected relay node.

To validate the performance of the proposed proposal, we evaluate TLG under both static and mobile wireless ad hoc networks using both Quality of Service (QoS) and Quality of Experience (QoE) metrics. We compare TLG with well-known existing solutions and simulation results show

that TLG can provide efficient and robust routing in both static and mobile environments, and it outperforms others in terms of both QoS and QoE metrics.

Research staff: Zhongliang Zhao, Denis Lima do Rosario, Torsten Braun

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

Mobile Multi-Media Wireless Sensor Networks

This project, Mobile Multi-Media Wireless Sensor Network (M3WSN), combines the research experiences of both University of Science and Technology of China (USTC) in China and University of Bern (UBERN) in Switzerland. M3WSN aims to integrate several testbeds and experimentation facilities to a single one, which can host and support more complex experiments.

First, we built a comprehensive experimentation infrastructure to experiment with Internet of Things and wireless sensor networks. We implemented a heterogeneous wireless network test-bed. Second, we designed and implemented a general multi-tier network architecture for mobile multi-media sensing. Our architecture consists of different types of sensors deployed in different hierarchical layers and the higher layer sensors are only woken up by the lower layer sensors when needed. Based on that, we evaluated a multi-media sensor system for object detection and tracking based on steerable cameras that are triggered and steered based on discrete sensor data.

Simulation results show that the proposed multi-media sensor system is more energy-efficient and achieves better scalability and reliability. Last, we designed and implemented a new opportunistic routing mechanism for forwarding multimedia packets in a mobile network. Simulation results show that our proposal outperforms other solutions in terms of throughput, delay, and quality of experience metrics.

Research staff: Zhongliang Zhao, Denis Lima do Rosario, Torsten Braun

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. Here, we plan to continue the exciting work and promising developments of the early part of the project that due to time limitations we were not able to complete. In the PZ00P2-121906 project, we have proposed among others low complexity network coding schemes, prioritized network code to address clients heterogeneity, inter-session network codes, and techniques for approximate network codes decoding. In details, 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 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 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 UEP 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. In this project, we will 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 project from Swiss National Science Foundation (PZ00P2-137275)

Adaptive Network Coding for Video Communications

During the past decade the emergence of peer-to-peer and social networks has provided a new means of communications. Network users connect through ad-hoc overlay networks to exchange multimedia data (images, video, music, etc.) with other users. This explosion of the communicated time-sensitive data challenges current streaming architectures and creates a surge for novel data distribution algorithms that respect the delivery deadlines of the multimedia. The latter is especially critical for real-time streaming applications, as data arriving after the decoding deadline is useless. Network coding is an example of techniques that enable timely delivery of multimedia data. It compensates for the missing quality of services of the best effort IP. Network coding departs from the typical paradigm followed by today's networks where network nodes simply forward the received packets. Network coding permits nodes to combine the received packets deterministically or randomly in finite fields enhancing this way the exploitation of the available resources. With network coding the max-flow min-cut limit of the underlying communication graph can be reached. In parallel, network coding can improve the error resiliency, remove the need for complex scheduling algorithms and decrease the delivery delay. However, the application of network coding is not trivial. There is a tradeoff among the improved throughput, decoding delay and communication overhead. Furthermore efficient communication systems should deal with the heterogeneous needs of the network users, which typically have different demands in terms of multimedia data and qualities.

The main disadvantage of the current network coding based streaming approaches is that they assume the existence of a single generation per time instant in the network. However, such an assumption might lead to suboptimal coding decisions, as each Group of Pictures (GOP) of the video is associated with a different expiration time (a client should decode the packets of a generation before their expiration time) which depends on the generation order in the video sequence and its initial playback time. To overcome the above drawback, we have studied the transmission of scalable video in

overlay networks under the realistic assumption that multiple generations may concurrently flow in the network. We have developed a framework that works for a server-client scenario that is based on Markov Decision Processes (MDP) to decide what is the optimal coding policies and the optimal streamed video quality. Here, we plan to extend our framework to the multiple-servers multiple-clients case, considering the bandwidth constraints. In order to allow the application of our framework to real-time systems we will explore the application of online learning methods instead of MDP. In addition, in order to accelerate the convergence time, we will examine quantization of the state and action space of the MDP model. As a final step of the project, we will adapt the proposed algorithms to large overlay networks. This is a challenging task, as in general we cannot predict precisely the current state of each node's buffer.

Research staff: Nikolaos Thomos

Financial support: Hasler Foundation

YouStream 3D: Immersive Context-Aware Personal Communications

We are witnessing an integration of computer-communication technologies on an unprecedented scale. People, devices, and computers interact in ways unforeseen before. Future predictions speak of even more fundamental changes lying ahead spurred by the ever increasing amount of digital content pervading our lives. At the heart of these technological advances lies our drive to interconnect and share information, anywhere and anytime. In particular, social networking applications are increasingly becoming a landmark of our online existence. For instance, according to recent statistics, we spend on average 15 minutes on YouTube every day and more content is uploaded there in 60 days than all three major US networks created in 60 years. The unparalleled scale and massive content production of online social networks raise a new set of challenges for the reliable delivery and understanding of content in such environments. Even the most powerful content delivery networks today such as Akamai and Limelight are not capable of serving such large audiences, simultaneously. The anticipated personalization of the streaming process in the future, according to different viewing times, client devices, and viewing angles, e.g., as in online games, will only augment the complexity of the problem further. Equally important, the fusion of online communities and media

sharing sites has brought to the forefront unfamiliar phenomena such as audience-content interaction and interdependencies. Finally, the proliferation of smart mobile devices has promoted yet another layer of complex context-driven time-varying interrelations between people, locations, and data. The project investigated intelligent multimedia systems that will address the new engineering and scientific challenges that are introduced by the fusion of community sites, content production tools, the proliferation of multi-camera arrays, and the advent of virtual worlds.

Research staff: Jakov Cakareski

Financial support: Ambizione project from Swiss National Science Foundation (PZ00P2-143101)

Velo Sensor

The Velo Sensor project has been performed in collaboration with Sciyent GmbH, Zürich. We implemented a system that is able to detect the presence of a bicycle, which is equipped with a sensor node. Moreover, it should be possible to query the system for the overall time, which the bicycle was in the perimeter of one of the system's base stations. The used sensor node of the bicycle should have the longest possible lifetime, therefore the system has to be optimized concerning the energy-efficiency of the bicycle sensor node.

We choose the Z1 sensor node from Zolertia as the development platform. This platform features the same hardware as the well-know TmoteSky platform, except an additional accelerometer. Contiki was chosen as the operating system running on the sensor. To detect a bicycle, a base station is needed to be deployed in the parking area. We choose ALIX x86 embedded PC, which is developed and distributed by PCEngines. Voyage Linux, which is a Debian derivate, is the operating system running on the base station.

A central server is used to collect the data from the base station. The server is running in our group lab as a XEN virtual machine. On this VM, Apache and MySQL are running to maintain the real-time data collected from the base station. Besides, to show the results in a user-friendly way, we also developed a simple web application using CakePHP. This web

application implements a web service to receive the data pushed by the server.

Research staff: Sandro Beffa, Zhongliang Zhao, Torsten Braun

Financial support: Sciyent GmbH

Enterprise Integration of WSNs and IoT-devices

The aim of the project is to investigate new methodologies to enable interoperability between wireless sensor networks (in general various heterogeneous Internet of Thing devices (IoT) devices) and enterprise IT systems. The project assumes that the lower layers of a typical IoT/WSN protocol stack is mature and concentrates on application layer protocols, service-based integration of devices and (semantic) data content abstraction. We implemented a novel enterprise integration platform, based on a semantic service description language (Linked USDL). It supports modeling IoT/WSN specific details, including technical interface descriptions, data representation (input/output) as well as different communication patterns. For enterprise IT systems that do not support a specific application layer protocol the semantic descriptions enable algorithmic solutions for automatic conversion between technical interfaces and automatic creation of further technical interfaces. The semantic representation of services and things support seamless integration of various heterogeneous devices and abstracts the things monitored by a WSN away from the actual sensing devices, allowing a domain expert to model a business process or business rules easily without the need of having specific technical knowledge about the sensing devices. First evaluation results show that the performance of the platform is very promising and the overhead imposed by the semantic layer is reasonable compared to alternatives such as WSDL.

Research staff: Matthias Thoma (external Ph.D. student), Torsten Braun

Financial support: SAP (Switzerland) Inc.

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 the 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 infrastructure. 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 CDS research group

WSN Lab

The Nano-tera Wireless Sensor Network Laboratory project (WSN Lab) used and extended the existing Wisebed wireless sensor network (WSN) test-bed facility to support hands-on programming and experimentation exercises in wireless sensor networks. The implemented course modules are available for Master level students in Computer Science or related fields such as Electrical Engineering. The extension of the existing

Wisebed test-bed sites at University of Bern and University of Geneva are conducted in the following ways: the integration of established WSN test-bed sites into SWITCHaai has been done; a development environment allowing compilation and linking of sensor node programs has been provided; WSN test-bed was complemented by multiple sensor types; a number of course modules were implemented to train Master level students in designing, implementing, and testing WSN mechanism.

The developed course modules include topics on time synchronization protocols, WSN routing protocols, forward error correction mechanisms, topology control protocols, message authentication mechanisms, and clustering algorithms.

Research staff: Zhongliang Zhao, Torsten Braun

Financial support: Nano-Tera.ch E&D project

3.4 Ph.D. Theses

- Markus Anwander: "Reliability in Energy-efficient Wireless Sensor Networks", December 18, 2012
- Gerald Wagenknecht: "Energy-efficient Management of Heterogeneous Wireless Sensor Networks, May 6, 2013

3.5 Bachelor's Theses

- Sandro Beffa: "Implementing and Evaluating Communication Protocols for reliable multicast in Wireless Sensor Networks", August 28, 2012
- Jürg Weber: "Automatic Detection Of Forwarding Opportunities In Intermittently Connected Content-Centric Networks", March 13, 2013
- Tobias Schmid: "Data Exchange In Intermittently Connected Content-Centric Networks", March 13, 2013

3.6 Awards

- Best Paper Award, EE-LSDS 2013 conference for Vitor Bernardo, Marilia Curado and Torsten Braun for the paper entitled "Enhancing IEEE 802.11 Energy Efficiency for Continuous Media Applications", April 2013
- AAA/SWITCH Award, AAA/SWITCH - e-Infrastructure for e-Science program for the A4-Mesh project as *The project overcoming the most hurdles in getting started*, June 2013

3.7 Further Activities

Memberships

Torsten Braun

- Chair of ERCIM working group on eMobility
- Erweitertes Leitungsgremium Fachgruppe "Kommunikation und Verteilte Systeme", Gesellschaft für Informatik
- SWITCH Stiftungsrat
- SWITCH Stiftungsratsausschuss
- Vice President of SWITCH foundation
- Kuratorium Fritz-Kutter-Fonds
- Expert for Diploma Exams at Fachhochschule Bern
- Expert for Matura Exams at Gymnasium Kirchenfeld, Bern
- 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 Informatik Spektrum, Springer-Verlag
- Editorial Board Member of Journal of Internet Engineering (Editor in Chief)
- Guest Editorial Board Member of Special Issue on "Deploying Real-Life WSN Applications: Challenges, Solutions, and Future Directions" in Hindawi's International Journal of Distributed Sensor Networks

Conference Chairs

Torsten Braun

- IEEE ICC Workshop Mobile Cloud Networking 2013, Budapest, Hungary, June 13, 2013
- Wired/Wireless Internet Communications 2013, Steering Committee, St Petersburg, Russia, June 5-7, 2013
- 2nd Joint ERCIM eMobility and MobiSense workshop, St Petersburg, Russia, June 4, 2013
- International Symposium on Quality of Service 2013, Steering committee, Montreal, Canada, June 3-4, 2013

Desislava Dimitrova

- 2nd Joint ERCIM eMobility and MobiSense Workshop, St Petersburg, Russia, June 4, 2013

Almerima Jamakovic-Kapic

- IEEE ICC Workshop Mobile cloud Networking 2013, Budapest, Hungary, June 13, 2013

Conference Program Committees

Torsten Braun

- International Conference on Next Generation Wired/Wireless Advance Networking, St Petersburg, Russia, August 28-30, 2012
- ICCCN International Workshop on Sensor Networks, Munich, Germany, July 30 - August 2, 2012
- International Congress on Ultra Modern Telecommunications and Control Systems 2012, St Petersburg, October 3-5, 2012
- IEEE International Conference on Network and Service Management 2012, Las Vegas, USA, October 22-26, 2012
- Notere Colloque francophone sur l'ingénierie des protocoles 2012, Anglet, France, October 29-31, 2012
- IEEE Local Computer Networks 2012, Clearwater, USA, October 22-25, 2012
- International Workshop on Multiple Access Communications 2012, Dublin, Ireland, November 19-20, 2012
- IEEE Globecom 2012, Anaheim, USA, December 3-7, 2012
- Workshop on Secure and Dependable Middleware for Cloud Monitoring and Management (SDMCMM) held in conjunction with ACM/IFIP/USENIX ACM International Middleware Conference, Beijing, China, December 4, 2012
- IEEE IEEE Symposium on Network Cloud Computing and Applications, London, UK, December 3-4, 2012
- IEEE Globecom Workshop Wireless Networking and Control for Unmanned Autonomous Vehicles, Anaheim, USA, December 7, 2012
- IEEE Consumer Communications and Networking Conference, Las Vegas, USA, January 11-14, 2013
- Omnet++ Workshop 2013, Cannes, France, March 5th, 2013
- Networked Systems 2013, Stuttgart, Germany, March 11-15, 2013

- IEEE Infocom International Workshop on Emerging Design Choices in Name-Oriented Networking (NOMEN 2013), Torino, Italy, April 14-19, 2013
- Energy Efficiency in Large Scale Distributed Systems, Vienna, Austria, April 22-24, 2013
- IEEE International Workshop on Hot Topics in Mesh Networking, Madrid, Spain, June 4, 2013
- IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, Madrid, Spain, June 4-7, 2013
- Wired/Wireless Internet Communications 2013, St Petersburg, Russia, June 5-7, 2013
- Conference on Future Internet Communications 2013, Coimbra, Portugal, May 15-16, 2013
- IEEE International Symposium on Quality of Service, Montreal, Canada, June 3-4, 2013

Desislava Dimitrova

- 5th International Workshop on Multiple Access Communications, Dublin, Ireland, November 19-20, 2012
- AIMS 2013 - PhD Workshop, Barcelona, Spain, June 25-28, 2013

Nikolaos Thomos

- IEEE QoSTREAM 2013 (in conjunction with ICC'13)

Denis Lima do Rosario

- TCP of Simposio Latinoamericano en Infraestructura, Hardware y Software

Ph.D. Jury Memberships

Torsten Braun

- Olof Rensfelt, Uppsala Universitet, October 12, 2012
- Peter Dely, Karlstads Universitet, December 14, 2012
- David Palma, Universidade de Coimbra, March 8, 2013
- Andrei Aurel Vancea, Universität Zürich, February 22, 2013

Project and Person Reviewing Activities

Torsten Braun

- European Coordinated Research on Long-term Challenges in Information and Communication Sciences & Technologies ERA-Net (EU CHIST-ERA)
- Committee member for faculty position at Uppsala Universitet
- Reviewer for Norwegian Core Competence and Value Creation in ICT (VERDIKT) program
- 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

- Elsevier Computer Communications
- IEEE Communications Magazine

Desislava Dimitrova

- IEEE Communications Letters
- IEEE Transactions on Mobile Computing
- Elsevier Computer Communications
- Elsevier Computer Networks
- Elsevier Performance Evaluation
- International Journal of Distributed Sensor Networks
- Journal on Wireless Communications and Networking

Almerima Jamakovic-Kapic

- Elsevier Transportation Research Part C Journal
- Elsevier Physica A: Statistical Mechanics and its Applications.
- Oxford Journal of Complex Networks

Denis Lima do Rosario

- British Journal of Mathematics & Computer Science
- IEEE Transactions on Wireless Communications

Invited Talks and Tutorials

Alexandru-Florian Antonescu

- SLA Driven Dynamic Orchestration and Composition for Distributed Cloud-Based Services, 7th Workshop on Cloud-based Service Platforms for the Future Internet, Winterthur, November 29, 2012

Torsten Braun

- Information-Centric Networking in Wireless/Mobile Networks, IFIP/ACM LANC 2012, 7th Latin America Networking Conference, October 5, 2012
- Die Evolution des Internet, 30 Jahre Freundeskreis Hans-Furler-Gymnasium Oberkirch (Germany), October 19, 2012
- Mathematik und Algorithmen für die drahtlose Internet-Kommunikation, Hans-Furler-Gymnasium Oberkirch (Germany), October 19, 2012
- Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 13, 2102
- UAVNet: A Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles, COST Action IC 0906 Meeting Dublin, November 20, 2012
- Software-Defined Networking for Mobile Network Services, Panel Presentation at 19th IEEE LANMAN Workshop, Brussels, Belgium, April 10-12, 2013
- Information-Centric Networking in Mobile Networks, Universität Zürich, February 22, 2013

- Easily Deployable A4 Wireless Mesh Networks (eA4-Mesh), eA4Mesh Final Dissemination Event, Neuchâtel, April 5, 2013
- Content-Centric Networking in Opportunistic and Mobile Networks, Alcatel-Lucent Bell Labs, Holmdel, NJ, USA, May 23, 2013

Desislava Dimitrova

- Active vs Passive Localisation Strategies, 2nd Joint ERCIM eMobility and MobiSense Workshop, St Petersburg, Russia, June 4, 2013

Almerima Jamakovic-Kapic

- A4 Wireless Mesh Networks, SWITCH - ICT Focus, Solothurn, October 22, 2012

Nikolaos Thomos

- Network Coding for Multimedia Communications, University of Glasgow, UK, April 2013
- Network Coding for Multimedia Communications, Alpen-Adria-Universität Klagenfurt & Lakeside Labs, Austria, May 2013
- Network Coding for Multimedia Communications, University of Essex, UK, May 2013

Andre Gomes

- Follow Me Cloud and Virtualization of (Multimedia) Services and Applications: Challenges and Possible Solutions, Future Network & Mobile Summit 2013, Lisbon, Portugal, July 3-5, 2013

Organized Events

- 2nd Joint ERCIM eMobility and MobiSense Workshop, co-located with the 11th International Conference on Wired/Wireless Internet Communications WWIC 2013, St Petersburg, Russia, June 4, 2013
- Workshop Mobile Cloud Networking and Services 2013, co-located with the IEEE International Conference on Communications 2013 (ICC 2013), Budapest, Hungary, June 13, 2013
- Computer Science Summer School seminar, organised together with the Dependable Systems and Networks group and Distributed Systems group of University Neuchâtel, Les Plans-sur-Bex, Switzerland, June 26-28, 2013.

3.8 Publications

Publications submitted in the academic year 2012/2013 and appearing in the following academic year are not listed.

Books

- Alex Galis and Anastasius Gavras (Eds.); Almerima Jamakovic, Thomas Michael Bohnert, Georgios Karagiannis: Future Internet Assembly 2013: Validated Results and New Horizons Series, Lecture Notes in Computer Science, Vol. 7858, May, 2013, ISBN 978-3-642-38081-5

Reviewed Journal and Conference Papers

- Zhongliang Zhao, Denis do Rosario, Torsten Braun, Eduardo Cerqueira, Hongli Xu, Liusheng Huang: Topology and Link Quality-aware Geographical Opportunistic Routing in Wireless Ad-hoc Networks, The 9th International Wireless Communications and Mobile Computing Conference (IWCMC 2013), Cagliari, Italy, July 1-5, 2013, IEEE Press, ISBN 978-1-4673-2478-6
- Matthias Thoma, Alexandru-Florian Antonescu, Theano Mintsu, Torsten Braun: Linked Services for M2M Communications, Proceedings of the 9th International Wireless Communications and Mobile Computing Conference (IWCMC 2013), Cagliari, Italy, July 1-5, 2013, IEEE Press, ISBN 978-1-4673-2478-6
- Gustavo Pessin, Fernando S. Osório, Jefferson R. Souza, Jó Ueyama, Fausto G. Costa, Denis F. Wolf, Desislava Dimitrova, Torsten Braun, Patrícia A. Vargas: Investigation on the Evolution of an Indoor Robotic Localization System Based on Wireless Networks, Applied Artificial Intelligence Journal, Vol. 27, Nr. 6, July, 2013, ISSN 0883-9514
- Alexandru-Florian Antonescu, Andre Gomes, Philip Robinson, Torsten Braun: SLA-Driven Predictive Orchestration for Distributed Cloud-Based Mobile Services, IEEE ICC'13 - 1st International Workshop on Mobile Cloud Networking and Services (MCN), pp. 748-753, Budapest, Hungary, June 9-12, 2013, IEEE Press, ISBN 978-1-4673-5753-1

- Alexandru-Florian Antonescu, Philip Robinson, Torsten Braun: Dynamic SLA Management with Forecasting using Multi-Objective Optimizations, IFIP/IEEE Integrated Network Management Symposium (IM 2013), pp. 457-463, Ghent, Belgium, May 27-31, 2013, IEEE Press, ISBN 978-1-4673-5229-1
- Markus Anwander, Torsten Braun: A Reliable, Traffic-adaptive and Energy-efficient Link Layer for Wireless Sensor Networks, IFIP Networking 2013, Brooklyn, New York, USA, May 22-24, 2013, ISBN 978-3-901882-55-5
- Dragan Milic, Torsten Braun: Guaranteed Greedy Routing in Overlay Networks, The Conference on Future Internet Communications (CFIC Coimbra 2013), Coimbra, Portugal, May 15-16, 2013, DOI 10.1109/CFIC.2013.6566327
- Denis do Rosario, Rodrigo Costa, Aldri Santos, Torsten Braun, Eduardo Cerqueira: QoE-aware Multiple Path Video Transmission for Wireless Multimedia Sensor Networks, 31th Brazilian Symposium on Computer Networks and Distributed Systems (SBRC), Brasilia, Brazil, May 6-10, 2013, ISSN: 2177-496X
- Almerima Jamakovic, Desislava Dimitrova, Markus Anwander, Teodor Macicas, Torsten Braun, Jan Schwanbeck, Thomas Staub, Benjamin Nyffenegger: Real-World Energy Measurements of a Wireless Mesh Network, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Torsten Braun, Tuan Anh Trinh: Energy Efficiency Issues in Information-Centric Networking, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Vitor Bernardo, Marilia Curado, Torsten Braun: Enhancing IEEE 802.11 Energy Efficiency for Continuous Media Applications, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Regina B. Araujo, Carlos H. C. Ribeiro, Damla Turgut, Jo Ueyama, Torsten Braun: Deploying Real-Life WSN Applications: Challenges, Solutions, and Future Directions, International Journal of Distributed Sensor Networks, Vol. 2013, Nr. 610892, April, 2013,

pp. 7-8, Hindawi Publishing Corporation Editorial Article, DOI 10.1155/2013/610892

- Torsten Braun, Andreas Mauthe, Vasilios Siris: Service-Centric Networking Extensions, The 28th ACM Symposium on Applied Computing, pp. 583-590, Coimbra, Portugal, March 18-22, 2013, DOI 10.1145/2480362.2480475
- Denis do Rosario, Zhongliang Zhao, Claudio Silva, Eduardo Cerqueira, Torsten Braun: An OMNeT++ Framework to Evaluate Video Transmission in Mobile Wireless Multimedia Sensor Networks, 6th International Workshop on OMNET++, Cannes, March 5, 2013, ISBN: 978-1-4503-2464-9
- Markus Anwander, Torsten Braun, Philipp Hurni, Thomas Staub, Gerald Wagenknecht: User and Machine Authentication and Authorization Infrastructure for Distributed Wireless Sensor Network Testbeds, Journal of Sensors and Actuator Networks, Vol. 2, Nr. 1, pp. 109-121, March, 2013, DOI 10.3390/jsan2010109
- Matthias Thoma, Alexandru-Florian Antonescu, Theano Mintsi, Torsten Braun: Linked Services for Enabling Interoperability in the Sensing Enterprise, International Conference on Enterprise Interoperability (IWEI 2013), Vol. 144, March, 2013, Lecture Notes in Business Information Processing, Springer, DOI 10.1007/978-3-642-36796-0_12
- Zan Li, Desislava Dimitrova, Torsten Braun: TDOA-Based Localization System with Narrow-band Signals, PhD forum in Conference on Networked Systems (NetSys), Stuttgart, Germany, March, 2013
- Denis do Rosario, Philipe Lima, Kássio Machado, Eduardo Cerqueira, Zhongliang Zhao, Torsten Braun: Demo Abstract - Disseminating WMSN Data by Using Social Network and Web, 10th European Conference on Wireless Sensor Networks, Ghent, Belgium, February 13, 2013
- Tamara Tomic, Nikolaos Thomos and Pascal Frossard: Distributed Sensor Failure Detection in Sensor Networks, Elsevier Signal Processing, Vol. 93, No. 2, pp. 399-410, February, 2013, DOI 10.1016/j.sigpro.2012.07.028

- Hyunggon Park, Nikolaos Thomos and Pascal Frossard: Approximate Decoding Approaches for Network Coded Correlated Data, *Elsevier Signal Processing*, Vol. 93, No. 1, pp. 109-123, January, 2013, DOI 10.1016/j.sigpro.2012.07.007
- Philipp Hurni: Traffic-Adaptive and Link-Quality-Aware Communication in Wireless Sensor Networks, *PIK - Praxis der Informationsverarbeitung und Kommunikation*, Vol. 36, Nr. 1, pp. 3-8, February, 2013, De Gruyter, DOI 10.1515/pik-2012-0138
- Kássio Machado, Denis do Rosario, Eduardo Cerqueira, Antonio A. F. Loureiro, Augusto Neto, José Neuman de Souza: A Routing Protocol Based on Energy and Link Quality for Internet of Things Applications, *Sensors (Basel)*, Vol. 13, pp. 1942-1964, January, 2013, DOI 10.3390/s130201942
- Simon Morgenthaler, Torsten Braun, Zhongliang Zhao, Thomas Staub, Markus Anwander: UAVNet - A Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles, 3rd International Workshop on Wireless Networking and Control for Unmanned Autonomous Vehicles, pp. 1603-1608, Anaheim, CA, USA, December 3-7, 2012, IEEE Press, DOI 10.1109/GLOCOMW.2012.6477825
- Alexandru-Florian Antonescu, Philip Robinson, Torsten Braun: Dynamic Topology Orchestration for Distributed Cloud-Based Applications, *IEEE International Symposium on Network and Cloud Computing and Applications (NCCA 2012)*, pp. 116-123, Imperial College, London, UK, December 3-4, 2012, CPS (Conference Publishing Services), DOI 10.1109/NCCA.2012.14
- Denis do Rosario, Rodrigo Costa, Helder Paraense, Kássio Machado, Eduardo Cerqueira, Torsten Braun, Zhongliang Zhao: A Hierarchical Multi-hop Multimedia Routing Protocol for Wireless Multimedia Sensor Networks, *Network Protocols and Algorithms - Special Issue on 2nd IEEE Smart Communication Protocols and Algorithms*, Vol. 4, Nr. 4, pp. 44-64, December, 2012, Macrothink Institute, DOI 10.5296/npa.v4i4.2121
- Matthias Thoma, Sonja Meyer, Klaus Sperner, Stefan Meissner, Torsten Braun: On IoT-services: Survey, Classification and Enterprise Integration, 2012 IEEE International Conference on

Green Computing and Communications (GreenCom), pp. 257-260, Besancon, France, November 20-23, 2012, IEEE Press, DOI 10.1109/GreenCom.2012.47

- Carlos Anastasiades, Arian Uruqi, Torsten Braun: Content Discovery in Opportunistic Content-Centric Networks, 5th International Workshop on Architectures, Services and Applications for the Next Generation Internet, pp. 1048-1056, Clearwater, FL, USA, October 22-25, 2012, IEEE Press, DOI 10.1109/LCNW.2012.6424042
- Zhongliang Zhao, Torsten Braun, Denis do Rosario, Eduardo Cerqueira, Roger Immich, Marilia Curado: QoE-aware FEC Mechanism for Intrusion Detection in Multi-tier Wireless Multimedia Sensor Networks, 1st International Workshop on Wireless Multimedia Sensor Networks (WMSN), pp. 689-696, Barcelona, Spain, October 8-10, 2012, IEEE Press, DOI 10.1109/WiMOB.2012.6379150
- Zhongliang Zhao, Björn Mosler, Torsten Braun: Performance Evaluation of Opportunistic Routing Protocols: A Framework-based Approach using OMNeT++, 7th Latin America Networking Conference, pp. 28-35, Medellín, Colombia, October 4-5, 2012, ACM, ISBN 978-1-4503-1750-4
- Gustavo Pessin, Fernando Osorio, Jefferson Souza, Fausto Costa, Jo Ueyama, Denis Wolf, Torsten Braun, Patricia Vargas: Evolving an Indoor Robotic Localization System Based on Wireless Networks, 13th International Conference on Engineering Applications of Neural Networks, pp. 61-70, London, UK, September 20-23, 2012, Springer, DOI 10.1007/978-3-642-32909-8_7
- Nikolaos Thomos and Pascal Frossard: Towards one Symbol Network Coding Vectors, IEEE Communications Letters, Vol. 16, No. 11, pp. 1860-1863, November, 2012, DOI 10.1109/LCOMM.2012.092812.121661
- David Hock, Vitor Bernardo, Thomas Zinner, Florian Wamser, Karin Hummel, Marilia Curado, Rastin Pries, Torsten Braun, Phuoc Tran-Gia: Evaluating the Trade-off Between Energy Efficiency and QoE in Wireless Mesh Networks, 4th International Conference on Communications and Electronics (ICCE), pp. 233-238, Royal city of Hue, Vietnam, August 1-3, 2012, DOI 10.1109/CCE.2012.6315904

Technical Reports

- Hugues Mercier, Torsten Braun, Pascal Felber, Peter Kropf, Pierre Kuonen: 2013 Doctoral Workshop on Distributed Systems, Technical Report IAM-13-002, Les Plans-sur-Bex, Switzerland, July 15, 2013
- Denis do Rosario, Zhongliang Zhao, Eduardo Cerqueira, Torsten Braun, Aldri Santos: A Link Quality and Geographical-aware Routing Protocol for Video Transmission in Mobile IoT, Technical Report IAM-13-001, March 28, 2013
- Eirina Bourtsoulatze, Nikolaos Thomos, Pascal Frossard: Distributed Rate Allocation in Inter-Session Network Coding, available at <http://arxiv.org/abs/1212.5032>, Dec. 2012
- Nikolaos Thomos, Rethnakaran Pulikkoonattu, Pascal Frossard: Intermediate Performance Analysis of Growth Codes, available at <http://arxiv.org/abs/1211.4014>, Nov. 2012
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