The intention of this report is to provide information about research and teaching activities of the Chair of Communication Networks (Lehrstuhl für Kommunikationsnetze – Informatik III, Institut für Informatik). The Chair of Communication Networks is one of the eight chairs of the Institute of Computer Science, which forms one of the two institutes of the Faculty of Mathematics and Computer Science at the University of Würzburg, Germany. During the reporting period, 2006–2010, the number of Scientists in our Chair has stabilized. The number of research assistants has slightly grown from fifteen 2006 to currently sixteen. The number of student helpers and tutors is around twenty three. Accordingly, the existing working relationships between our institute and other universities and research institutes have been further intensified and new relationships have been established. New research projects with German, European, and North-American companies have been initiated and existing ones have been strengthened. To facilitate the communication with all the partners, this report appears in English.

As described in this activity report, the research activities of the Chair of Communication Networks currently focus on the following areas:

(1) Next Generation Networks (NGN), (2) Wireless networks (Mobile Network Research Group, MNRG) and (3) Future Internet Applications & Overlays (FIA).

A number of research cooperations were established with national and international companies, e.g. Alcatel-Lucent Bell Labs (Stuttgart, Germany), Bosch (Stuttgart, Germany), BSI (Bonn, Germany), DATEV e.G. (Nuremberg, Germany), Siemens AG (Munich and Berlin, Germany), Siemens Enterprise Networks (Munich, Germany), France Telecom (France), T-Mobile International (Bonn, Germany), T-Labs (Berlin, Germany). During the reporting period we also received funding for research projects from the Deutsche Forschungsgemeinschaft (DFG), the Bundesministerium für Bildung und Forschung (BMBF) and the European Union (EU). From BMBF, the project G-Lab (German-Lab) working towards Future Internet has been awarded, for which I am serving as project coordinator.

I would like to express my thanks to all scientific friends and research project partners, who continuously motivate and provide us with interesting input and novel ideas emerging to fruitful projects and who support us with knowledge and financial funding. I also thank the research fellows, students, and visiting scientists who contribute to the working atmosphere where research and teaching activities can flourish in a friendly and natural way.

Würzburg, June 2010
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S. Oechsner, M. Hartmann, B. Staehle, T. Hoßfeld (from left to right)
The Faculty of Mathematics and Computer Science is one of the ten faculties of the Bayerische Julius-Maximilians-Universität Würzburg located at Würzburg, the capital of Lower Franconia in the north of Bavaria.

Within the faculty, there are two institutes: Mathematics and Computer Science. Eight autonomous chairs (in German ‘Lehrstühle’) constitute the Institute of Computer Science covering a broad spectrum of research in computer science:

- Efficient Algorithms and Knowledge-Based Systems
- Programming Languages and Programming Methodology
- Communication Networks
- Theoretical Computer Science
- Technical Computer Science
- Artificial Intelligence and Applied Informatics
- Robotics and Telematics
- Aerospace Information Technology

This activity report focuses on research and teaching activities of the Chair of Communication Networks (Lehrstuhl für Kommunikationsnetze, Informatik III) during the period 2006 – 2010.

### 1.2 Staff

**Chair:**
Prof. Dr. -Ing. Phuoc Tran-Gia

**Research Assistants:**
Dr. rer. nat. Andreas Binzenhöfer (15.02.03 – 13.02.08)
Dipl. Inform. Michael Duelli (since 01.04.07)
Dipl. Inform. Matthias Hartmann (since 15.05.08)
Dipl. Inform. Robert Henjes (since 01.05.04)
Dipl. Inform. Matthias Hirth (since 01.02.10)
Dipl. Inform. David Hock (since 01.05.09)
1.3
The Institute

On a floor space of 3,300 m², two lecture rooms named after A. Turing and K. Zuse with capacity of 250 persons each, two computer pools, seminar rooms, laboratories, and offices are located. The total building costs amounted to 14 Mio. €.

The new robotics building was finished in 2006, expanding the institute yet again to accommodate the newest chair, Robotics and Telematics (Informatik VII).
2. Research

The research activities of the chair focus on performance analysis, dimensioning, and optimization of telecommunication systems. We aim to apply methods in queuing theory, probability theory, simulation, and optimization theory to design, analyse, assess and improve the performance of telecommunication systems and networks. Current research activities can be grouped into the following major topics:

- Design and performance assessment of future communication networks
- Self-organization and content delivery systems and platforms
- Planning and analysis of mobile communication systems

2.1 Next Generation Networks (NGN)

Group leader: PD. Dr. habil. Michael Menth, Dr. Rastin Pries
Group members: Michael Duelli, Matthias Hartmann, Robert Henjes, David Hock, Michael Jarischel, Dominik Klein, Rüdiger Martin, Daniel Schlosser

The Vision of the Future Internet

The Internet in a wider sense is no longer the mere connection of wireline networks. It rather comprises numerous access and transport technologies like Modem, DSL, WiMaX, WLAN, ATM, MPLS, SONET/SDH, Gigabit-Ethernet, and optical WDM networks. New services like file sharing applications based on peer-to-peer (P2P) networks, voice-over-IP (VoIP), publish/subscribe services and many other middleware solutions extend the conventional portfolio of Email and World Wide Web (WWW). The convergence of wireless mobile networks and in particular wireless sensor networks with traditional wireline networks is a challenge for the Internet community. The communication infrastructure in a highly demanding business world needs more than the best effort data delivery available in today’s Internet: real-time applications like video conference, tele-operation, or tele-control require upper bounds on packet loss and delay, and most customers are not willing to renounce on the high reliability and availability of the old, inflexible, and rather homogenous
telephone network. Thus, heterogeneous technologies, mobility, quality of service (QoS), and resilience are major challenges for the future Internet when customers confront network providers with superior demands which are even explicitly stated in the service level agreements. In addition, scalability is getting more and more important as the Internet grows in terms of attached networks and participating users as well as flexibility of edge networks to do traffic engineering and easily change providers.

Technologies, Performance Aspects, and Methodologies

The NGN group focuses on the performance evaluation of new mechanisms for future communication networks. The following list briefly summarizes the studied technologies, the main performance aspects, and the applied methodologies for performance evaluation.

- Technologies: MPLS, IP, optical networks, OpenFlow, middleware
- Performance aspects: benchmarking, resource management, network resilience, routing scalability
- Methodologies: measurement, simulation, mathematical analysis, optimization using linear programs and heuristic approaches, Markov chains, queuing theory, testbed implementation

Within the last three years, the NGN working group concentrated on IP and MPLS networks including aspects from optical networks. It investigated the performance of different server platforms for the Java Messaging Service (JMS) that are recently often used as communication middleware in large software projects. Within the last four years the research of the NGN group provided quantitative studies regarding server benchmarking, resource management, and network resilience. Their numerical results were based on measurements, simulations, and mathematical analyses. Mechanisms for scheduling, buffer management, admission control, routing, network resilience, and scalability issues were improved by exploiting system knowledge and optimization techniques like linear programs and heuristic approaches. Recently, future Internet design also plays a major role which implies security issues and testbed implementations.

Research Areas

The research of the NGN group is manifold and spans multiple areas in communication. They have in common quantitative studies that help manufacturers and service providers to understand networking mechanisms, to configure them, and to make best use of limited and costly resources. The research is financed by several DFG and industry projects and led to many international publications and patents. The BMBF-funded G-Lab project allows major efforts in the area of future Internet routing.

Optical Multilayer Networks
M. Menth, M. Duelli

Optical networks guarantee an abundance of bandwidth for the future as fiber optic technology promises almost unlimited transmission capacity. However, so-called dark fiber requires significant and expensive hardware support to transmit bits and bytes over buried fiber. We consider the structure of optical networks including fiber topology, optical cross connects, transponders, muxponders, repeaters, protection switches and try to design least-cost networks. Communication networks consist of various layers such as the physical links, logical lightpaths of different bandwidths, and logical connections in the above packet-switched domain. We study routing, grooming, and resilience issues on different layers and design cost-optimal networks. Each of the layers can be optimized for itself, but there is a large potential in the optimization of the multilayer network and additional resilience requirements make it really challenging. Most of this work is done in the CELTIC project 100GET-E3-R3G.

Resilient Networks
M. Menth, M. Duelli, M. Hartmann, D. Hock, D. Klein, R. Martin

Today’s information society depends more and more on the reliability of the communication infrastructure. If transmission links or switching nodes fail, backup paths are required to maintain connectivity. Furthermore, backup paths must have sufficient capacity to survive transient failures without major service interruptions. This is important as fiber cuts or hardware failures are common and inevitable in network operation.

Our work targets at the evaluation and the optimization of resilient networks. On the one hand, we develop methods to quantify network resilience in terms of ingress-egress disconnection and overload probabilities. On the other hand, we study the path layout of various resilience mechanisms. This has an impact on the required primary and backup capacity. We look at intelligent usage of end-to-end protection like self-protecting multipaths (SPM), new standards such as MPLS fast reroute, we investigate work in progress such as IP fast reroute mechanisms currently proposed by the IETF,
and we consider alternative structures such as (relaxed) multiple routing configurations (MRCs). A major part of these activities is devoted to the optimization of the path layout using linear programs or heuristic methods. Most of this work is done for DFG, European projects, and industry projects such as GMPLSINT, IP-FRR, RESILIENT-IP, OMRAS, MOP, and Lightcomm.

Future Internet Routing
M. Menth, M. Hartmann, D. Klein

Routing in today’s Internet is separated into routing within autonomous systems (AS), the so-called intradomain routing, and routing between ASes, the so-called interdomain routing. Intradomain routing forwards traffic along least-cost paths whose costs are based on administrative link weights. In contrast, interdomain routing is mainly driven by policies and uses the path vector protocol BGP. As the Internet is large and steadily growing, the number of BGP messages increases and so do also the number of entries in the routing tables of the routers in the default-free zone (DFZ) where routing tables do not have a default entry for packets for whose destination no entry is available. The routing table sizes are already tremendous in the order of 250000 and seem to grow either polynomially or even exponentially. Traffic forwarding by routers becomes more demanding with larger routing table sizes. Therefore, the operation and further expansion of the Internet is at risk since it is not clear whether technological progress in router hardware can keep pace with the growth of the routing table sizes. As a consequence, router vendors and network operators work on new routing principles and try to standardize solutions which are more scalable. The locator/identifier split (Loc/ID) is an important concept on which the routing in the future Internet will be based. Currently, we study various proposals including IPv6 issues, evaluate pros and cons, and work on interworking methods between the new and the old Internet.

Future Internet Congestion Control
M. Menth

Congestion control in today’s Internet is based on TCP. TCP is simple, it cannot guarantee bandwidth, and it controls rather individual flows than the overall behavior of a user. For instance, a user can open many TCP connections to get a larger bandwidth share in case of congestion than another user operating only a single TCP connection. This lack of functionality in the current network architecture has been realized by vendors and operators and it is already discussed in IETF.

The congestion and pre-congestion notification (PCN) working group of the IETF designs simple mechanisms for admission control and flow termination which are based on packet markings. We contribute to this evolution with Internet drafts, classification of implementation options, and performance evaluation studies.

Re-feedback is a mechanism to encourage honest congestion notification to sending sources and to force them to back off if they contribute too much to congestion in the Internet. It is a completely new control paradigm including TCP and non-TCP traffic. We contribute to its design, formulation, and performance evaluation.

Most of this work is done within the DFG project GMPLSINT and the industry project Lightcomm.

Performance Evaluation of Services and Applications
M. Menth, R. Henjes

The user perceived quality of service does not only depend on the smooth operation of the physical, link, and network layer, but also on higher layer entities such as middleware and application servers. Therefore, sufficient server capacity is another crucial element of an effective communication infrastructure. Thus, another research area is the investigation of server performance. On the one hand, the download time of web pages are analyzed depending on web technologies and the structure of web pages. On the other hand, the maximum message throughput of various servers for the Java Messaging Service (JMS) is investigated. Publisher clients send messages to the JMS server which distributes them to so-called subscriber clients that may install filters for certain message types on the server. The JMS server performance varies by several orders of magnitude depending on the server type and the application scenario, and in particular, on the number of installed filters and on the average replication grade of the messages. The knowledge of this performance behaviour is crucial for the decision whether JMS technology is suitable to build the communication backbone of large-scale applications and it provides useful insights for the appropriate dimensioning of server clusters. Further activities focus on grid computing and voice over IP systems. The research in this area is funded by the industry project DiRC and further cooperative research exists with the computation centre of the University of Würzburg.
Traffic Engineering
M. Menth, R. Martin

Traffic engineering (TE) uses statistical techniques such as queuing theory to predict and engineer the behaviour of telecommunication networks such as telephone networks or the Internet.

There are various means to influence the packet flows in communication networks to improve quality of service (QoS) in terms of packet loss and delay.

- Buffer management decides which packets are stored in buffers during overload situations and which packets are discarded. Examples are the equal treatment of all packets regardless of their priority, threshold-based queuing, i.e., low priority packets are discarded if a certain buffer occupation is reached, or Random Early Detection (RED), i.e. packets are discarded with a certain probability that depends both on their priority and the current buffer occupation. Thus, buffer management has a high impact on the packet loss probability.

- Scheduling determines the transmission order of packets that are queued in the buffer during overload situations. Examples are the simple first-in-first-out (FIFO) strategy, weighted fair queuing (WFQ) that is approximated by weighted round robin (WRR), and earliest deadline first (EDF). Obviously, scheduling has an impact on the packet delay.

- Admission control (AC) grants priority transportation to a limited number of flows and rejects surplus flows to guarantee QoS for ongoing calls in the system. Admission control methods can be classified in link and network admission control (LAC, NAC). LAC uses queuing formulae and approximations thereof to decide whether an additional flow can be accepted without QoS violation of the ongoing flows. This decision addresses primarily a single resource, typically a single link. NAC considers AC for an entire network. It enables AC at the network border and takes into account the flow’s path through the network. In recent years, the NGN group developed and investigated new LAC and NAC methods. New LAC methods are, e.g., LAC algorithms for real-time traffic or experience-based admission control (EBAC). Existing NAC methods were classified for the first time and new ones were developed. Link failures are more often the reason for network congestion than increased user traffic. Therefore, “resilient NAC” has been designed and investigated for wireline networks and recently corresponding concepts for mobile ad hoc networks were proposed.

- Capacity overprovisioning assures that sufficient capacity is available to carry at least high priority traffic under any high load condition. On the one hand, these increased load conditions may result from a changed traffic matrix that is due to increased user activity, due to hot spots caused by popular contents at some server location, or due to interdomain rerouting. On the other hand, local congestion may occur because of intradomain rerouting due to link or node failures. Research issues are, e.g., the characterization of realistic overload conditions and the assessment of the required capacity that suffices to guarantee QoS under these conditions. Such analyses help network operators to dimension their networks safely and to avoid unnecessary investments.

- Load balancing algorithms are often applied in communication systems and the resource management usually relies on an exact enforcement of configured traffic distributions. However, this is only trivial when the traffic is balanced on a per packet basis, but per-packet load balancing is not a good option since it provokes packet reordering that is detrimental for higher layer transport protocols like TCP. As a consequence, load balancing is required on the flow level. Simple algorithms using hashes based on the flow identifiers of the packet header achieve that goal in a very simple and efficient way, but performance studies show that the accuracy of the load balancing result depends on the balanced traffic volume and that more sophisticated hash-based algorithms can improve this accuracy significantly.

The research in these areas was carried out in DFG and industry projects such as GMPLSINT, KING, and OMRAS.

Performance Evaluation Methods
M. Menth, R. Henjes

Queuing theory and simulation technique provide valuable tools for the assessment of technical systems which is the major focus of the NGN group. However, sometimes new methods are required and insufficient or computationally inefficient standard methods must be extended or approximated. In particular, the modelling and evaluation techniques for discrete time Markov chains are steadily improved since they are often applied for the performance evaluation of practical problems. In addition, a very simple, fast, and rather accurate approximation formula for M/G/1-∞ queuing systems has been proposed on the base of the Gamma distribution. Mathematical analysis is a fast means for performance evaluation on a high abstraction level while packet-based simulations model more details, but they are also more time-consuming. Fluid simulation is a hybrid approach. Extensions for fluid simulation regarding load balancing and multipath routing have recently been developed in cooperation with the Telecommunications Research Center Vienna (ftw).
Performance-Energy Saving Trade-Off
R. Pries, D. Klein

While the focus of previous research was on increasing the performance of distributed systems, energy aspects play now a major role. The performance increase of a system often does not scale linearly with the power consumption. Research aspects are, to look at the trade-off between performance and energy savings. This requires that not only one side of a distributed system is looked at, but the overall system has to be evaluated because an energy-related optimization on one side can lead to more energy consumption on another part of the distributed system. The research in this area is carried out in the COST project on energy efficiency in large scale distributed systems.

Network Monitoring and Analysis
R. Pries, D. Schlosser, M. Jarschel

Current simulations and analytical models of communication networks are using traffic models and application distributions which are older than 15 years. However, the fast emerging future Internet applications require continuous measurements to create realistic traffic models. We perform concurrent measurements together with a Germany-wide wireless Internet service provider. The analysis of the measured data is performed using a combination of real-time deep packet inspection and a later host behavior classification. These classifications are then used to illustrate the application distribution, packet size distribution, flow size distribution, and user behavior with which new traffic models are created.

Network Management and Control using OpenFlow
R. Pries, M. Jarschel, D. Schlosser

Intelligent network management and control mechanisms are required in all areas of today’s Internet. OpenFlow is a specification, which allows to easily perform network management and control experiments in a production network. The concept separates the control plane from the switching logic. This way, researchers are able to perform experiments based on actual production traffic. It provides flexibility to invent and test new protocols and mechanisms. In addition, OpenFlow can be used as catalyst for testbed evolution. The key elements are intelligent controller implementations that can be used for network monitoring, service mobility, multi-homing, etc. Scalability issues of the OpenFlow approach and research on service mobility are carried out in the industry project SOFA and the BMBF project COMCON.

2.2
Wireless Networks
(Mobile Network Research Group, MNRG)

Group leader: Dr. Dirk Staehle
Group members: Barbara Staehle, Andreas Mäder, Rastin Pries, Florian Warnser, Tuo Liu (guest PhD student from Univ. of Sydney), Alexander Klein (external PhD student at EADS), Alexey Vinel (guest PhD student from Saint-Petersburg State University of Information Technologies, Mechanics and Optics, Russia)

The recent years brought great changes in the landscape of mobile and wireless networks. The HSPA (High Speed Packet Access) extensions to the UMTS (Universal Mobile Telecommunication System) networks have been introduced in Germany and Europe and deliver comfortable high speed Internet access with up to several Mbps in downlink direction. In parallel, IEEE802.16 based Mobile WiMAX (Worldwide inter-operability for Microwave Access) networks became an alternative cellular technology with networks operated mostly in the US and Asia. Wireless LAN (WLAN) hotspots enjoy great popularity and are available in many places including most airports, train stations, etc. The great density of WLANs partly becomes a challenge due to overlapping coverage areas and an insufficient amount of non-overlapping channels.

The standard for next generation UMTS networks, Long Term Evolution (LTE), has been finalized in 2009 and the IEEE802.16m standard for the next generation of WiMAX networks is finalized in 2010. Both standards use OFDMA (Orthogonal Frequency Division Multiple Access) as transmission technology, LTE specifies a variant SC-FDMA (Single Carrier-Frequency Division Multiple Access) for the uplink. The next generation of wireless networks provides higher bandwidth and lower delays by using enhanced physical layer techniques and radio resource management mechanisms like channel aware and frequency-selective scheduling, inter-cell interference coordination, and multi-antenna systems used for beam-forming or single and multi user MIMO (multiple input multiple output). Additionally, self-organizing mesh networks and fixed relays will decrease the operational costs by introducing network nodes that relay traffic to/from other nodes without a direct connection to the Internet. The variety of different access technologies, e.g. WLAN, EDGE, UMTS, HSDPA integrated in a single device longs for an integrated operation of the respective networks in order to realize the “always best connected” paradigm. This implies the implementation of vertical handovers (VHO), i.e. seamless handovers between different network access technologies.
The Mobile Network Research Group applies methods for performance evaluation to mobile and wireless networks. These methods range from measurements over simulations to analytic methods. A key topics of the group is radio network planning where evaluating the quality of a planned or existing network is an essential part for initial network design or targeted network optimization and extension. In a long-term cooperation with T-Mobile we develop analytic methods for their UMTS radio network planning tool PegaPlan. In the context of radio network planning we also consider traffic characterization which includes traffic measurements, source traffic modeling, and spatial traffic distributions. Another key research fields is the design and optimization of protocols and radio resource management mechanisms. From the perspective of cellular network technology our main focus lies on UMTS/HSPA/LTE and WiMAX cellular networks. Sensor networks and mesh networks are emerging fields of research in our group. In particular for mesh networks, we established a testbed in order to develop and test prototypes of our resource management solutions. The following figure gives an overview of our research focus regarding methodology and network technology.

In the following we present the main research projects within the period addressed by this report:

**Analytical Methods in the Planning Process of WCDMA Networks**
A. Mäder and D. Staehle

The general target of radio network planning and optimization is to find a network configuration with minimal costs fulfilling the service specific network requirements in terms of coverage, capacity, and QoS. One substantial element is topology planning that selects appropriate NodeB sites and evaluates if the coverage and capacity requirements are met. The finding of optimal sites is an iterative process of subsequently optimizing the network configuration and evaluating the resulting quality. The latter task is commonly performed by quite time-consuming Monte Carlo simulations. In this research project we aim at developing analytic methods that evaluate the quality of a network more efficiently. The methods yield slightly less accurate results in a considerably shorter time. Consequently, they should be used at the beginning of the planning process for a fast selection of cell sites.

During the period covered by this report, the focus of our work was on the impact of HSDPA and Enhanced uplink on the UMTS radio network planning process. An inter-cell interference model was developed for both the Enhanced Uplink and the HSDPA. The difference in the modeling for HSPA in contrast to WCDMA using dedicated channels is that they typically carry best effort traffic and the resource management assigns only the capacity not required by dedicated channels to the HSPA users. Accordingly, the focus of the analytic models was to estimate the throughput for HSPA users under different radio resource management schemes.

The work on WCDMA radio network was conducted in cooperation with T-Mobile/T-Systems.

**Radio Resource Management and Scheduling in Cellular Networks**
A. Mäder, F. Wamser, D. Staehle

Radio Resource Management (RRM) is a critical task within cellular networks. The objective of RRM is to assign radio resources to users and connections such that their quality of experience (QoE) or quality of service (QoS) are fulfilled or optimized. RRM runs on several time scales and includes scheduling, resource allocation, inter-cell interferences coordination, and admission control etc.
Radio Resource Management for HSPA

Radio Resource Management (RRM) is a critical task for the HSDPA and Enhanced Uplink extensions of UMTS. One of the key components of RRM is to share the available resources in terms of transmit power share on the downlink and received power share on the uplink between users on dedicated channels (DCH) and the channels for HSDPA and Enhanced Uplink namely the HS-DSCH and the E-DCH. The HS-DSCH requires two types of resources, transmit power and channelization codes which are both limited. The allocation of both types of resources to the HS-DSCH can either be static or dynamic. Alternatively, a hybrid scheme is possible where some resources are statically reserved for the HSDPA and the remaining resources are dynamically shared between HS-DSCH and DCHs with strict priority for the DCH. The assignment strategies provide a trade-off between blocking probabilities for DCHs and throughput for the HSDPA that was investigated by means of simulation and also partly by analytic methods. The basis for these investigations was an extension of the well known orthogonality factor model that allows a simple estimation the throughput of an HSDPA user depending on the multi-path propagation model and the applied scheduling scheme which can be either channel-oblivious, i.e. round-robin or channel-aware utilizing multi-user diversity.

With the introduction of the Enhanced Uplink the assignment of power resources to the E-DCHs moves from the Radio Network Controller (RNC) to the NodeB which allows an allocation of resources on a much shorter time-scale. In particular, it allows a scheduling of users based on their current demand and also based on their channel quality though the scheduling is typically not fast enough to follow fast fading. The impact of different scheduling or resources assignment schemes on performance in terms of throughput and blocking probabilities for Enhanced uplink users have been investigated by means of analytic models and simulations.

The work on HSPA was partially conducted in cooperation with T-Mobile/T-Systems.

Radio Resource Management for OFDMA

The critical part in the design of an RRM mechanism in OFDMA networks is the flexibility of the system and hence the number of decisions to make. One of the key components of RRM is other-cell-interference coordination, another one is the scheduler that should optimally use the resources in order to fulfill the user’s requirements in terms of QoS or QoE.

In the project FunkOFDMA, we work on the interaction of scheduling and inter-cell interference coordination. Up to now, we have investigated how the selection of appropriate modulation and coding schemes can help improve the performance on fractional frequency reuse, a possible approach for interference coordination supported by the IEEE802.16m standard. Currently, we work on an approach how to schedule users in an IEEE802.16m network that supports fractional frequency reuse, frequency diverse scheduling and frequency selective scheduling. As a basic for this studies we develop a system level simulator for IEEE802.16m.

Performance Evaluation of IEEE 802.16 MAC layer
R. Pries, D. Staehle, A. Vinel

The IEEE 802.16 standard specifies the physical and MAC layer for WiMAX certified products. The MAC layer is strictly connection oriented and specifies the service of a connection by a set of parameters. In particular, the standard specifies a series of scheduling services which specify how a connection obtains resources for uplink data transmissions. The scheduling services reach from the Unsolicited Grant Service (UGS) which corresponds to a constant bit rate service to Best Effort (BE) which is a pure on-demand service where the subscribed stations requests for bandwidth according to the instantaneous buffer content using a contention mechanism or by piggybacking the request to an ongoing data transmission. The scheduling services in between UGS and BE partly rely on unicast requests which means that the base stations polls the subscriber stations by allocating enough bandwidth for the subscriber station to send a single request.

The focus of our investigations was the performance of different request mechanisms mainly for the best effort service. The performance evaluation was partly performed by an OPNET simulation; partly analytical models could be developed for different evolutions of the bandwidth request mechanism. The current focus is on the evaluation of the contention mechanism proposed for the IEEE802.16m standard.

The work on the IEEE 802.16 MAC layer is conducted together with the Saint-Petersburg State University of Information Technologies, Mechanics and Optics in Russia.
Heterogeneous Networks
R. Pries, A. Mäder, D. Staehle

The integration of different wireless access technologies like UMTS, WLAN, WiMAX, and meshed networks into a heterogeneous network is one major topic for the near future. Since every access technology has been designed from a different perspective regarding user behavior, supported applications, and QoS requirements, such a heterogeneous network has to take into account the strengths and weaknesses from every technology.

While there are already different approaches how to enable the handover between various technologies we focus on the development of strategies when to perform a handover. Here, we can follow two general strategies: the handovers can be performed reactive or proactive. A proactive strategy tries to balance the load among all networks while concurrently optimizing the performance of all users. A handover takes place whenever it improves the network situation considerably. A reactive strategy tries to perform a handover when the service quality of a user drops below or the load of a cell exceeds a certain threshold. Then, a handover to another technology is executed if this situation will remedy the observed performance problems.

The goal of our work is to develop methods for judging the performance for an existing network situation and to estimate the performance of a network/user after a handover has been triggered. We developed performance estimation functions for both a UMTS/HSPA network and a WLAN cell. An OPNET simulator is developed for evaluating the performance of different evaluation functions and handover triggers.

The work is performed together with the Telecommunications Networks Group at TU Berlin within the project POL4G funded by the German Research Council (DFG).

Mesh Networks
A. Klein, R. Pries, B. Staehle, F. Wamser, D. Staehle

Multi-hop broadband wireless access networks (BWA) are intended to provide broadband Internet access to user without a single radio link to a station with a direct connection to the Internet. Instead, the traffic of a remote station will be forwarded by one or more stations over radio links in order to reach the Internet. We distinguish two types of Multi-hop BWA networks: Relay Networks and mesh networks. Relay networks typically extend the coverage area of a single base station or access point by connecting relay stations in form of a tree. Relay networks are typically extensions of cellular networks as for the UMTS Long Term Evolution (LTE) or Mobile WiMAX. Mesh networks consist of nodes that are more strongly interconnected and may include multiple gateway points to the Internet. Mesh networks are mostly based on the IEEE 802.11 standard with the IEEE 802.11s working group developing a dedicated standard for mesh support.

Currently, the research on mesh networks consists of four projects:
- Performance models and network planning: This research project is performed in the project PlanMesh which is funded by the German Research Council (see also project PlanMesh).
- Routing mechanisms for mesh and sensor networks: The target is to develop a simple routing mechanism that is robust and efficient in spite of node mobility and highly variable traffic demands.
- QoS support in IEEE 802.11 based mesh networks: Current IEEE 802.11 networks do not sufficiently support QoS for real-time communication. The key idea is to perform the resource management in the mesh network based on the quality of experience (QoE) at application layer monitored either on the mesh nodes or at the mesh clients. Currently, the QoE of YouTube videos is monitored and if the video is about to stall, the YouTube stream is either switched to another gateway or if this is not possible, the interfering best-effort traffic is reduced. This project was first started in cooperation with T-Systems and is now continued within the G-Lab project.
- Intra-Mesh Congestion Control: The IEEE802.11s standard provides a mechanism called Intra-Mesh Congestion Control in order to avoid packet losses due to buffer overflows within the mesh network. The mechanism mainly provides a packet format for mesh nodes to signal an overload situation to its neighbors. We develop and investigate the benefits of intra-mesh control mechanisms compliant to the IEEE802.11s standard. This research project is performed within the G-Lab project.

Sensor Networks
A. Klein, B. Staehle, D. Staehle

Sensor networks are multi-hop wireless networks with the special characteristics that they are rather simplistic, send data only rarely, and have no independent power supply such that an energy efficient operation is crucial. The research in the area of sensor networks has two major projects:
- Energy Consumption Models: Different energy consumption models and the qualitative and quantitative difference when using certain energy models for evaluating the performance of sensor networks is investigated.
- Cross-Layer optimization: The MAC layer of sensor networks are specially designed for operating in an energy efficient way, i.e. they try to save energy by falling into the sleep mode as long as possible. A MAC layer oblivious routing layer that ignores sleep times when sending routing messages may lead to a bad network performance due to many route timeouts or badly chosen routes. The target of this project is to develop a combination of routing and MAC layer that tries to coordinate the sending of routing layer messages with MAC layer sleep times.

- Task based sensor network planning: The target of this project is to plan a sensor network using a task-based, coarse-grain simulator. The critical part of a sensor network typically is its energy consumption that depends on the tasks the sensor network has to fulfill and the capabilities of the nodes. Tasks could be simple sensing in certain intervals, transmitting the data to a gateway, aggregating data, answering to requests for data in the Internet, or also management tasks like route updates, etc. The simulator updates the energy state of the sensor nodes according to the energy these tasks consume and also updates the network due to extra-ordinary events like node failures, energy-harvesting, installation of new nodes or batteries etc. The target of the simulator is to compare the costs for different sensor network deployments which would be intractable for a more detailed simulator. This research project is done within the G-Lab project.

Measurements and Traffic Characterization
R. Pries, F. Wamser, D. Staehle

A profound understanding of the traffic characteristics are of fundamental importance to proper radio network planning. Different applications like web browsing, gaming, P2P file-sharing, or VoIP have completely different QoS requirements, consume different amounts of radio resources, and behave differently in the case of congestion. Source traffic modeling aims at developing models for application specific traffic sources to be used for generating traffic in simulations. The continuous evolution of the applications and their traffic characteristics requires a continuous enhancement of the respective traffic models. Furthermore, the introduction of new access technologies like HSDPA or WiMAX that typically offer a higher bandwidth to the user than the existing ones, leads to new services in the context of wireless networks.

In a current research project the shared Internet access over WLAN in student dormitories is measured in order to gain statistics on the currently used applications and to develop a source traffic model.

2.3 Future Internet Applications & Overlays (FIA)

Group leader: Dr. Tobias Hoßfeld
Group members: Matthias Hirth, Michael Jarschel, Frank Lehrieder, Simon Oechsner, Daniel Schlosser, Thomas Zinner

Applications in the Future Internet are expected to rely heavily on application intelligence being included in the clients and on the feedback and the participation of the end users. Apart from that, many applications include the provisioning of high-quality multimedia content to their users. For these reasons, the Quality of Experience of the end users as well as the mechanisms to deliver the content and to integrate the end users are of major importance for the success of the application. This has implications for the underlying networks and their management.

One of the currently most important technologies to distribute content in a scalable fashion is Peer-to-Peer (P2P) technology utilizing overlay networks for communication. It utilizes the resources of end users for the application, thus adding new resources with each new user. Peer-to-Peer (P2P) services and P2P content distribution applications have become very popular, as witnessed by the relentless spread of the file-sharing platforms like eDonkey and BitTorrent or video streaming systems like SopCast, PPLive or Zattoo. P2P services have even surpassed the World Wide Web in popularity, at least in terms of traffic volume. Backbone operators and Internet service providers consistently report P2P-type traffic volumes exceeding 50% of the total traffic load in their networks, sometimes up to 80%. These figures impressively reveal that P2P services have evolved to one of the most popular applications in today’s Internet and thus make P2P an important area of networking research.

Another currently developing field of research are online communities and social networks like Facebook, Xing or Twitter. Users connecting to each other and exchanging messages are forming a different kind of logical network, which is interesting to model in order to gain insight into information diffusion, communication behaviour of end users and relevance of messages in relation to their source.

Network management has to cope with the new demands and technologies introduced into applications. A new solution is network virtualization, where the physical resources of the network are abstracted from their usage. Thus, a server may be running in a virtual machine that can be moved freely from one physical node to another. Virtual links may be generated by the implementation of intelligent routers separating traffic in different virtual networks.
This enables the strict distinction of traffic classes and their easier management. Network providers can offer services created specifically for a given application by building a virtual network from virtual components.

Performance Evaluation of Future Internet Applications

The major focus of the FIA group is the performance evaluation of edge-based applications and services, which are based, e.g., on the P2P paradigm. The large portfolio of used P2P technologies comprises resource access control mechanisms, like cooperation strategies for distributing contents, as well as resource mediation mechanisms, like distributed hash tables for lookup of users and resources in a system. In this context, content distribution and real-time applications are considered, but also systems for network control and network management are within the scope.

For social networks, the focus is on the modelling of the user graph and its properties, as well as on creating models of the message flow between users. Finally, techniques to implement and manage virtual networks are created and evaluated.

In the last three years, new performance evaluation models were derived within the FIA group. Due to the fact, that the users or peers are providing resources in the system and the considered technical environments, the emerging user behaviour of such applications is changing, e.g. peers might behave selfish or altruistic. In addition, new influence factors like churn or pollution of systems have to be considered which do not exist in traditional centralized systems. Besides the theoretical studies, measurements in real-world systems or deployed test beds were done as a proof-of-concept of the newly designed mechanisms or to investigate the system behaviour in more complex environments. In this context, the quality of experience (QoE) of the users is of interest to investigate the performance as perceived by the end user and non-linear regression is applied to describe the basic relationships.

In summary, the following list shows the used methodologies within the P2P group: proof-of-concept implementation, measurement in real-world systems and deployed test-beds, user surveys for QoE, user and system modelling, simulation, mathematical analysis, non-linear regression, Markov chains, queueing theory.

Content Distribution
T. Hoßfeld, F. Lehrieder, S. Oechsner, D. Schlosser

P2P file sharing systems contribute to the majority of traffic volume that is currently being transported in the Internet. Applications like eDonkey or BitTorrent are used to share large volume content and alleviate the problem of overloaded servers by distributing the load among all sharing peers, which makes P2P systems highly scalable and resilient content distribution systems. Sophisticated cooperation strategies, such as the multi-source download and tit-for-tat principle, are the foundation of the extreme efficiency of P2P content distribution networks. Multi-source download means the simultaneous download of parts of a file, referred to as chunk, from several sources in parallel.

Content Distribution overlays are typically underlay-agnostic, i.e., they do not consider the Internet topology when establishing and using connections. Thus, network resources are used inefficiently and high costs are incurred for the Internet Service Providers (ISPs). We evaluate strategies that reduce this costly traffic while not reducing the application performance of the end users. This ensures that these strategies are accepted by the P2P community, in contrast to unilateral approaches of the past.

File Diffusion and User Impatience
T. Hoßfeld

In content distribution networks, a user is mainly interested in reliability and efficiency of the offered service and does not care about the underlying technology. The considered technology for realizing such a service can either be a traditional client/server (CS) architecture or a peer-to-peer (P2P) network. In CS, the capacity of the server is the bottleneck and has to be dimensioned in such a way that all requests can be accommodated at any time, while a P2P system does not burden a single server since the content is distributed in the network among sharing peers. However, corrupted or fake files may diminish the reliability of the P2P service due to downloading of useless contents. In both systems we assume that the user is willing to wait only for a limited time until the download completes. If the downloading process exceeds a patience threshold, the user will abort his attempt. We use these models to analyze the benefits and drawbacks of these architectural principles. We compare a CS system to P2P and evaluate the downloading time, success ratio, and fairness while considering
flash crowd arrivals and corrupted contents. We use a fluid model to derive analytical models taking into account time-dependent behavior and flash-crowd effects. The analysis model can be applied for example to eDonkey-like P2P file-sharing networks or the OnlineTVRecorder.com service. The later one is a video delivery service in Germany as an example. For describing the steady state behavior of this OnlineTVRecorder service, sophisticated Markovian queueing models are derived taking into account this user impatience.

The file diffusion process in P2P file-sharing networks can be compared to the spreading of a disease (e.g. avian influenza) in a finite population. Commonly, differential equation systems are used to describe the population dynamics, depending on the state the individuals are in. We use the well-known SIR (Susceptible-Infected-Recovered) model as basis for our model of how a file is disseminated in an eDonkey-like file-sharing network. Depending on the number of sharing users and the demand for a specific file, we can evaluate the rate of diffusion. Based on this mathematical model, our focus lies on the influence that malicious peers offering corrupt files have on the diffusion process which is called pollution.

**Mobile P2P and Multi-Homing**

*T. Hoßfeld, M. Duelli, D. Schlosser*

The performance of P2P content distribution in cellular networks depends highly on the cooperation and coordination of heterogeneous and often selfish mobile users. The major challenges are the identification of problems specifically arising in cellular mobile networks and the development of new cooperation strategies to overcome these problems. In this context, we investigate common cooperation strategies using multi-source downloads. We demonstrate the fundamental “last chunk” problem of typical strategies as used by eDonkey or BitTorrent. This is caused by the selfishness of users; however, an ordered chunk delivery evades this problem. In addition, the impact of mobility and vertical handover between different wireless access technologies is investigated. An abstract mobility model is required to allow the performance evaluation in feasible computational time. As a result, the performance in today’s and future cellular networks may be predicted and new approaches to master heterogeneity in cellular networks are derived.

Furthermore, we investigate how the P2P paradigm can be applied in general to wireless and mobile networks, in particular the mapping of P2P mechanisms to cellular networks without losing the advantages of the P2P technology. It discusses the impact of device mobility on mobile P2P services and the selection of mobility management mechanisms and cooperation strategies among peers for these systems. The aim of this project is the categorization and performance evaluation of P2P mechanisms in mobile environments. Necessary modifications of the basic P2P approaches in mobile networks are revealed in order to improve the system performance and to get dependable systems.

**Performance of Structured Overlay Networks**

*A. Binzenhöfer, T. Hoßfeld, S. Oechsner, R. Henjes, T. Zinner*

Overlay networks establish logical connections between users on top of the physical network. While randomly connected overlay networks provide only a best effort service, a new generation of structured overlay systems based on Distributed Hash Tables (DHTs) was proposed by the research community. However, there is still a lack of understanding the performance of such DHTs. Additionally, those architectures are highly distributed and therefore appear as a black box to the operator. Yet an operator does not want to lose control over his system and needs to be able to continuously observe and examine its current state at runtime.

In this field of work, both problems are addressed. We evaluate the performance of structured overlay networks under different aspects and thereby illuminate in how far such architectures are able to support carrier-grade applications. Second, to enable operators to monitor and understand their deployed system in more detail, we introduce both active as well as passive methods to gather information about the current state of the overlay network. Apart from this, we provide analytical methods to evaluate a specific but practically relevant form of a DHT, the so-called one-hop DHT.

**Quality of Experience**

*T. Hoßfeld, T. Zinner, D. Schlosser, B. Staehle*

The subjective service quality as perceived by the end-user is an important aspect which is often neglected in classic network monitoring. Yet it is the end-user who decides whether he will continue to use the service or not. Besides of objective end-to-end QoS parameters, QoE focuses on subjective valuations of service delivery by the end users. It addresses (a) service reliability comprising service availability, accessibility, access time and continuity, and (b) service comfort comprising session quality, ease of use and level of support. QoE is a subjective measure from the user perspective of the overall value of the provided service or application. The necessity of introducing QoE can be explained on the example of VoIP. A voice user is not
interested in knowing performance measures like packet loss or received throughput, but mainly in the experienced speech quality and timeliness of the connection.

The interest in how the user perceives usability, reliability, quality and price-worthiness as a means of competition is increasing. The provider or an application itself needs to be able to observe and react upon quality problems, at best before the customer perceives them. In order to provide the customer the best QoE, it has to be estimated, e.g. utilizing simple mapping function, and accordingly the provider or the application reacts with appropriate mechanisms. This is investigated on the example of P2P-based video-on-demand streaming with scalable / multi-description video codecs within the P2P group.

In this context, we consider strictly QoS demanding applications like VoIP or remote desktop applications. Currently, the H.264 video codec and its extension, Scalable Video Codec (SVC), are studied. Simple mapping functions between QoS and QoE are investigated and appropriate parameters derived for these mapping function. In particular, we consider easily measurable QoS parameters, like packet loss or jitter delay variations, and show their impact on the QoE, e.g. in terms of mean opinion scores. Therefore, test beds are used to control the network environment and the influence on the user-perceived quality on application level is captured.

**P2P-based Live TV and Video-on-Demand**  
T. Hoßfeld, S. Oechsner, T. Zinner

With increasing access bandwidth speeds for end users, the new Internet-based television (IPTV) has gained popularity as a means of delivering high-quality video content delivery networks. In general, IPTV architectures can be either client/server based, which can be modeled and analyzed using methods from queuing theory, or they can be based on (often proprietary) P2P topologies, referred to as P2PTV. Based also on the different types of offered media content (network-based video recorders, video-on-demand, or live TV streaming) the goal is to characterize the traffic of these networks and identify the factors impacting on the user-experienced quality. As a result of the found interdependency between traffic characteristics and QoE, the system adapts to the current network situation and tries to maintain a certain QoE. An example for such a dynamic QoE control mechanisms includes the usage and choice of scalable / multi-description video codecs and their setting during run-time.

**Online Social Networks and Crowdsourcing**  
T. Hoßfeld, M. Hirth, S. Oechsner

Recently the characteristics of online communities changed dramatically. In the past years there existed only small communities of people sharing the same interests and organizing themselves in web forums or chat rooms. Nowadays huge online social networks (OSNs) like Facebook, YouTube, or Twitter consist of thousands or millions of people from all over the world and various social and cultural backgrounds. These online communities gain an ever-increasing influence on real life, as to many people the information on the platforms seem to be very trustworthy because the content is created by their friends and acquaintances. As a result it becomes important to know how information spreads in OSNs, e.g., to track down the source of inappropriate material. Furthermore OSNs contain a huge workforce and a lot of knowledge, which is already exploited in projects like Wikipedia. A new approach to use this workforce and the wisdom of the crowd referred to as crowdsourcing. Crowdsourcing can be viewed as a further development of outsourcing. With outsourcing, entrepreneurs choose specialized subcontractors to accomplish certain parts of the development or production process. In contrast, “crowdsourcing is the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call” [Jeff Howe 2008 http://www.crowdsourcing.com]. According to Jeff Howe’s definition, the main differences to outsourcing are, that the entrepreneur does not know who accomplishes her task and that the workers form not an organized group like a firm but are members of a large anonymous crowd accessible via crowdsourcing platforms. In traditional work organization, the employer delegates work to the workers, but in the crowdsourcing approach, the worker chooses which tasks she wants to work for.

Crowdsourcing offers the possibility to get work done very quickly by accessing a large and relatively cheap workforce, but in order to use the full potential of crowdsourcing, techniques have to be developed to detect untrustworthy employers and workers. Further, the relations between the quality of the work and the given incentives have to be evaluated.
3. Courses

3.1 Overview

Bachelor
- Informationsteilung
- Hardwarepraktikum
- Seminar in Kommunikationssysteme
- Bachelor-Arbeit

Bachelor
- Transmission Theory
- Hardware Laboratories
- Computer and Communication Networks
- Seminars in Communication Systems
- Bachelor Thesis

Master
- Leistungsbewertung Verteiler Systeme
- Simulationsstechnik
- Ausgewählte Kapitel aus der Rechnernetzkommunikation
- Bachelor-Arbeit

Master
- Performance Evaluation of Distributed Systems
- Discrete Event Simulation
- Chosen Topics from Computer Communications
- Special Courses from the Industry
- Master Thesis

Bachelor
- Installation und Technik in der Mobilfunknetze
- Seminars in Mobile Communication Networks

Master
- Mobile Network Planning and Management
- Seminars in Broadband Networks

Bachelor
- Softwarewerkzeuge für Kommunikations netze

Master
- Design and Analysis of Wireless Systems
3.2 Lectures

Bachelor Courses

Transmission Theory
[Informationsübertragung]
communication theory, information theory, coding theory, components of communication networks

Hardware Laboratories
[Hardwarepraktikum]
communication networks, coding

Computer and Communication Networks
[Rechnernetze und Kommunikationssysteme]
features of computer and communication networks, architecture of computer networks, protocols, performance evaluation of computer networks, TCP/IP, routing in the Internet, switching systems, service integration, mobile communication systems, ATM and high-speed networks

Master Courses

Performance Evaluation of Distributed Systems
[Leistungsbewertung verteilter Systeme]
probability theory, stochastic processes, teletraffic, performance evaluation techniques, queuing theory

Discrete Event Simulation
[Simulationstechnik]
generation of random variables, discrete-event simulation technique, experimental design, rare-event simulation, in-stationary simulation

New Concepts and Technologies in Mobile Communications
[Neue Konzepte und Technologien in der Mobilkommunikation]
fundamentals of wireless networks, modern transmission techniques (turbo codes, hybrid ARQ, adaptive modulation and coding, channel-aware opportunistic scheduling, MIMO), mobility in IP networks, ad-hoc networks, vertical handover, TCP over wireless

Next Generation Networks
[Designaspekte zukünftiger Internetstrukturen]
group organization and control structures of the Internet, multicast protocols, multimedia communication, optical networks, resilient communication networks, peer-to-peer networks, ad-hoc networks

Planning and Management Methods for Computer Networks
[Planungs- und Managementmethoden in Telekommunikationsnetzen]
planning methods, management frameworks, IP management mechanisms, traffic and performance monitoring and assessment, event handling, network design, network simulation and analysis, management tools

Professional Project Management
[Professionelles Projektmanagement in der Praxis]
project setup, project goals, project structuring, solving projects in teams, resource planning, controlling, communication, project management tools

Industrial Engineering
[Industrial Engineering]
IT Methods in the Industrial Environment
3.3 Dissertations and Habilitations

Michael Menth (Habilitation)
Design and Performance Evaluation of Control Mechanisms for the Future Internet

Kurt Tutschku (Habilitation)
Peer-to-Peer Service Overlays – Capitalizing on P2P Technology for the Design of the Future Internet.

Rastin Pries
Performance Optimization of Wireless Infrastructure and Mesh Networks.

Tobias Hoßfeld
Performance Evaluation of Future Internet Applications and Emerging User Behavior.

Andreas Mäder

Rüdiger Martin
Resilience, Provisioning, and Control for the Network of the Future.

Andreas Binzenhöfer
Performance Analysis of Structured Overlay Networks.

Jens Milbrandt

Stefan Köhler
Interior Gateway Routing Optimization and Quality of Service – Algorithms and Performance Study.

David Mittelstädt
On the Capacity of the OFDMA Uplink with Dynamic Fractional Frequency Reuse. [Untersuchung der Uplink-Kapazität von OFDMA-Netzen mit dynamischem Fractional Frequency Reuse]

Melanie Brotzeller
Performance evaluation of a dependable overlay for supporting vertical handover. [Leistungsbewertung eines verlässlichen Overlays zur Unterstützung von Vertical Handover]

Michael Höfling

Michael-Jarschel
Classification and Characterization of Delay Sensitive Network Traffic. [Klassifizierung und Charakterisierung von verzögerungsempfindlichem Netzwerkverkehr]

Viktor Wendel

David Stezenbach
Implementing and Testing Seamless Gateway Handovers in Wireless Mesh Networks. [Aufbau und Untersuchung eines unterbrechungsfreien Gateway Wechsels in drahtlosen Netzwerken]

Markus Leimbach

Christian Schwartz

Xiaohua Qin

Desheng Fu
Intra-Mesh Congestion Control in IEEE802.11s Networks. [Intra-Mesh Congestion Control in IEEE802.11s Netzen]

Matthias Hirth
Monitoring Application Layer Performance in Wireless Mesh Networks. [Überwachung der Applikationsgüte in drahtlosen Mesh Netzwerken]

Jochen Prokopetz
User-perceived Quality of Scalable Video Coding in P2P Based VoD Systems. [Vom Nutzer wahrgenommene Qualität von Skalierbaren Video Codcs in P2P-basierten Video-on-Demand Systemen]

Florian Metzger

Florian Wamser
Traffic Measurement and Characterization of a Broadband Wireless Internet Access. [Verkehrsmessung und Charakterisierung eines drahtlosen Internet-Breitbandzugangs]

CPEX Models and Optimization for Multi-Layer Optical Networks. [CAPEX-Modell und Optimierung für mehrschichtige, optische Netzwerke]

Moritz Mohrman
Simulative Leistungsbewertung der deutschen IT-Frühwarninfrastruktur. [Simulative Leistungsbewertung der deutschen IT-Frühwarninfrastruktur]

Matthias Koller
Performance Evaluation of Failover Mechanisms for the ActiveMQ JMS Server. [Leistungsbewertung von Ausfallssicherungsmechanismen für den ActiveMQ JMS Server]

Dominik Klein
Future Internet Routing: Motivation, Design Options, and Early Proposals. [Routen für das Internet der Zukunft: Motivation, Gestaltungsmöglichkeiten und erste Vorschläge]

Christian Bergner
QoS Control of a P2P-based VoD System. [QoS Control für WiMAX Mesh Netze]

Marieta Stoykova

3.4 Diploma Theses (Diplomarbeiten)

David Stezenbach
Implementing and Testing Seamless Gateway Handovers in Wireless Mesh Networks. [Aufbau und Untersuchung eines unterbrechungsfreien Gateway Wechsels in drahtlosen Netzwerken]

Markus Leimbach

Christian Schwartz
Christopher Pluntke  
(Processing and Grooming in ausfallsicheren WDM-Mesh Netzwerken: Heuristiken und Leistungsbewertung)

Frank Lehrieder  
(Leistungsbewertung von Pre-Congestion Notification basierter Zugangskontrolle und Flussterminierung für das zukünftige Netz)

Matthias Hartmann  
(Leistungsbewertung und Optimierung von IP Fast Reroute Mechanismen)

Markus Weiß  
Measurement-based Evaluation of the Quality-of-Experience of Thin-Client Architectures.  
([Messassierte Evaluierung der Quality-of-Experience von Thin-Client Architekturen])

Stefan Mentz  
Measurement-Based Parameter Adaptation for WLAN Capacity Enhancement.  
([Messasserten basierende Parameteranpassung zur Erhöhung der WLAN Kapazität])

Matthias Kuhnert  
Performance Evaluation of non-beacon enabled ZigBee mesh networks.  
([Leistungsbewertung des Nicht-Beacon Modus in ZigBee basierten Sensornetzen])

Johannes Dölfel  
Cellular Network Assisted Car-to-Car Communication.  
(Handover-Szenarien in einer Mobilfunkverbindung)

Matthias Archut  
Resilient Admission Control for Ad-Hoc Networks.  
([Ausfallsichere Zugangskontrolle für Ad-Hoc Netze])

Thorsten Gutbrod  
Implementation of an Integrated WLAN/UMTS Simulation in OPNET.  
([Implementierung einer integrierten WLAN/UMTS Simulation in OPNET])

Stefan Möhlbeck  
Modeling and Leistungsbewertung von periodischem Echtzeitverkehr.  
(Modelling and Performance Evaluation of Periodic Realtime Traffic)

Christian Gößwein  
Simulation of the Performance of the WiMAX TDD Mode.  
([Simulative Leistungsbewertung des Enhanced Uplink in UMTS-Netzen])

Michael Duelli  
Modelling and Impact of Mobility on P2P Systems in Wireless Networks.  
([Modellierung und Auswirkungen von Mobilität auf P2P Systeme in Wireless-Netzen])

Christian Schmidt  
Implementierung eines netz-adaptiven Selbstorganisationsmechanismus für unstrukturierte P2P-Overlays in der PlanetLab Umgebung.  
([Implementierung eines netz-adaptiven Selbstorganisationsmechanismus für unstrukturierte P2P-Overlays in der PlanetLab Umgebung])

Frank Lohr  
Replikationsstrategien für zuverlässige Kerberos-S-Infrastrukturen.  
([Replikationsstrategien für zuverlässige Kerberos-S-Infrastrukturen])

Markus Spahn  
Analytical Leistungsspezifikation des High Speed Downlink Packet Access in UMTS.  
([Analytische Leistungsspezifikation des High Speed Downlink Packet Access in UMTS])

Valentin Himmler  
Performance Comparison of Popular JMS Servers in Different Application Scenarios.  
([Leistungsgesellschaft von gängigen JMS Servern in unterschiedlichen Anwendungsszenarien])

Markus Kienzen  
Simulation of WiMAX Mesh Networks.  
([Simulative Leistungsbewertung von WiMAX Mesh Netzten])

Korbinian Humm  
Preventing of Link Overhead in Case of Network Failures by Backup Path Layout Optimization.  
([Vermeidung von Linküberlast im Fehlerfall durch Optimierung explicit gelenkter Backup Pfade])

Marco Schuster  
Scheduling of VoD Data Streams for the UMTS High Speed Downlink Packet Access.  
([Scheduling von VoD Datenströmen für den UMTS High Speed Downlink Packet Access])

Thomas Zinner  
Supporting Vertical Handover Using a Structured P2P Overlay Network.  
([Unterstützung einer Technologie-übergreifenden Verbindungsübergabe durch ein strukturiertes P2P Overlay Netzwerk])

Uwe Seiler  
([Simulative Leistungsbewertung der Architekturparameter des BitTorrent-Protokolls])

Ulrich Spörlein  
Optimization of the Self-Protecting Multipath for Application in Practice.  
([Optimierung des Self-Protecting Multipath für den praktischen Einsatz])

Lasse Jansen  
Fluid-Simulators for Accelerated Performance Evaluation in Packet Networks.  
([Fluid-Simulatoren zur Beschleunigung von Leistungsbewertungen in Paketnetzen])

Matthias Wiesen  
Performance of the Network Layer Handover in Wireless LAN Environments.  
([Leistungsfähigkeit des Handovers auf Vermittlungsschicht in Wireless LAN Umgebungen])

Alexander Klein  
Performance Comparison of Different Configurations in WiMAX Networks.  
([Leistungsbewertung verschiedener Konfigurationen in WiMAX Netzwerken])

Christian Zepfel  
([Leistungsgesellschaft der JMS Server WebSphereMQ und SunMQ im Echtzeitkommunikationsumfeld])

Stefan Papke  
Verfahren zur Verwendung eines zweiten Scrambling Codes in einem UMTS Sektor.  
([Verfahren zur Verwendung eines zweiten Scrambling Codes in einem UMTS Sektor])

3.5 Bachelor Theses (Bachelorarbeiten)

Christian Sieber  
([Interoperabilität von IPv4 und IPv6 Netzwerken durch Protokollübersetzung])

Sebastian Deschner  
YouTube Video Streaming over TCP: Predicting the Quality for Mesh Backhaul Links.  
([YouTube Video Streaming über TCP: Vorhersage der Qualität für Mesh Backhaul Links])
4. Scientific Contacts

4.1 Scientific Cooperations

The chair maintains scientific contacts to the institutions involved in the following projects. Most of the activities are organized in the framework of research contracts.

EU Projects

**Euro-NGI, Euro-FGI, Euro-NF – Design and Engineering of the Next Generation Internet**

The mission of the Euro-NGI network and its successors Euro-FGI and Euro-NF is to create and maintain the most prominent European Network of Excellence (NoE) in Next Generation Internet design and engineering. The NoE is acting as a “Collective Intelligence Think Tank”, representing a major support for the European Information Society industry and leading towards a European leadership in this domain. The recent technological advances will lead to exploitable innovative services once the integration of these technologies through innovative architectures is achieved. The Future Internet will offer multi-service/multimedia, mobility, convergence (services and fixed-mobile), Quality-of-Service and variable connectivity as the norm. On one hand, future high-speed wire-line and wireless access technologies provide instant high bandwidth connectivity, which makes difficult to forecast traffic and thus to apply existing traffic engineering methods. On the other hand, the technology diversity explodes and mastering such a heterogeneous environment becomes essential to the network designer. This requires investigation into new multi-technology architectures. It is understood today that new design, planning, dimensioning and management principles are needed. In this context, the main topics addressed by the NoE are:

- Mastering the technology diversity (vertical and horizontal integration) for the design of efficient and flexible NGI architectures.
- Providing required innovative traffic engineering architectures adapted to the new requirements and developing the corresponding appropriate quantitative methods.

The NoE brings together the competencies of networking experts from 56 research institutions and involves more than 300 researchers and Ph.D students. The Chair of Communication Networks was involved in a leading role during the creation of the NoE. Today, it is a lead participant and is coordinating the integration work in the NoE.

**Euro-NGI-Redlarf**

BitTorrent introduced an extremely efficient peer-to-peer networking technique for distributing a very large file (say, gigabytes) to a very large number of recipients (scalability should extend to millions) by splitting it into relatively small chunks (say, thousand chunks) in such a way that the recipients forward their downloaded chunks to further recipients. This project studies fully distributed analogues on BitTorrent from several points of view: algorithm design, testing and analysis.

**Main objectives:**

1. Design and study, using analytical models, different mediation algorithms applicable in a file distribution system based on chunk transfer along random encounters. The objective is to maximize the file distribution performance in terms like throughput, delay and reliability.

2. Implement and test these algorithms in a working, experimental peer-to-peer content distribution system. Tests and performance measurements are made using partners’ capabilities and, in particular, in the world-wide PlanetLab environment.

3. Analyse and test the reliability and stability performance of various overlay network alternatives of the system.

**Euro-NF-Virtual Network Resource Embedding Algorithms (VNREAL)**

The Virtual Network Resource Embedding Algorithms (VNREAL) project is funded by the Euro-NF Network of Excellence. The partners are University of Passau and the Universitat Politecnica de Catalunya. It considers the virtualization of networks, which is a recent trend that promises significant advantages in terms of flexibility and sustainability of communication networks. In order to achieve efficient operation of such virtualized networks, it is paramount to develop algorithms that will compute an optimal distribution of physical resources. The aim of the VNREAL project is the design and creation of a software tool that will enable computation of an optimal mapping of virtual resources onto physical resources.

**Euro-NF-QoEWeb – Quality of Experience and User Behaviour Modelling for Web Traffic**

In this project, user perceived quality and user behaviour for web traffic is modeled. This allows providers to judge end user QoE based on QoS parameters like loss rate or throughput, and to act in time to prevent users from getting dissatisfied. The main objectives are a quantification of QoE for web traffic, based on passive measurements (observations) within an operator’s network and active measurements in a test laboratory, and a description of an appropriate model for the (timely) behaviour of web user satisfaction / impatience which builds upon feedback of the user-perceived quality, based on the measurements. The derived user model is used to identify the impact of QoE on system performance in business environments like wireless networks with shared capacity. Finally, reputation management applying the derived model is quantified in order to allow provider/operator to react before the user-related reputation gets critical.

**Euro-NF-ISPeer: ISP-friendly Peer-assisted Content Distribution**

In the context of this project we will consider the problem of ISP managed peer-assisted content distribution systems for video-on-demand streaming. The aim of the project is the development of a cooperation strategy using the example of a peer-assisted content distribution overlay for video streaming. Since the ISP offers this system, a cooperative interaction between the overlay and the ISP is possible.

The main objectives are to identify requirements for ISP-friendly content distribution and the network-related information that should be interchanged between the ISP and the overlay. The project will develop a cooperation framework which takes into account useful information from the ISP for topology forming and the resource management in the overlay, and determines and evaluates the gain obtained by using the proposed solution.

**Euro-NF-MultiNext: Measuring Concurrent Multipath Transmissions in an Experimental Facility**

The use of concurrent multipath (CMP) transmissions will bring exceptional advantages to networks, such as higher throughput and increased resilience. However, CMP will introduce additional complexity which has to be understood. First, CMP transmission will inevitably introduce out-of-order packets due to different stochastic packet delay characteristics on the paths. The re-ordering can be compensated by buffering at the destination, possibly leading to increased end-to-end delay but still being transparent to the transport protocol. Second, the different stochastic delay processes on the paths can amplify each other in their negative effects on out-of order packets. Third, the strength and occurrences of such combination effects are highly non-intuitive.
The main objective of the project is to provide a deep understanding of multipath transmissions. For that, an exemplary mechanism based on the SEATTLE architecture is implemented and deployed within the PLE experimental facilities. The project investigates how measurements of the outlined mechanism can be conducted within the PLE, performs measurements of the multipath mechanism and links the results to theoretical mathematical models.

European STREP IST Project – SmoothIT

The Internet traffic stemming from overlay-based applications, e.g., Peer-to-Peer applications, increases rapidly with the increase of available bandwidth of end-nodes. For today’s Telecommunication Service Providers and Internet Service Providers the issue arising is: how to control and manage network traffic stemming from overlay-based applications. As the structure of overlays determines the traffic flows in ISP networks, it is highly efficient for an ISP to influence overlay configuration based on information on their structure. Overlays have to be managed to maximize the benefit for multiple operators/ISPs involved, and to increase the capability to withstand faults, and balance the network load. Additionally, better QoS for overlay based applications across ISP domains is required which leads to an improved media consumption experience for the end-users called Quality of Experience (QoE). SmoothIT (Simple Economic Management Approaches of Overlay Traffic in Heterogeneous Internet Topologies) is an international STREP project funded by the European Commission with nine European partners running from 2007–2010. The main objective is to optimize the overlay structure for minimizing the ISP’s costs, while increasing the user’s quality of experience, using incentive-based economic traffic management.

European COST-IC0804 Project

The chair is an active member and the official representative of Germany in the European COST-IC0804 Project, which is entitled “Energy Efficiency in Large Scale Distributed Systems”. The goal of the project is to propose realistic energy-efficient alternate solutions to share IT distributed resources. Thereby, several aspects of energy-efficiency in distributed systems are analyzed ranging from energy efficiency inside a server over energy-efficient data centers to end-to-end energy-efficient optimization. The focus in Würzburg is the trade-off between energy-saving and performance aspects. An energy-related optimization on one side can lead to more energy consumption on another part of the distributed system. This trade-off is evaluated by means of analytical optimization models, simulation models, and programs.

European COST-290 Project

The chair is an active member and the official representative of Germany in the European COST-290 Project, which is entitled “Traffic and QoS management in wireless multimedia networks (Wi-QOST)”. The main objective of the Action is to increase the knowledge on future advanced Multiservice Wireless Networks (MWNs) and specifically on traffic nature and behaviour and its impact on network architecture, performance and planning. Special attention must be given to Quality of Service and related aspects in both access networks and core networks in the presence of mixed multimedia traffic. To accomplish this, new analytical tools, software implementations and prototypes have to be developed and validated. For achieving these objectives the action is subdivided into four working groups: traffic engineering, QoS provisioning for multimedia traffic in wireless environment, network planning and dimensioning, and service aspects.

European COST-IC0906 Project

The chair is an active member and the official representative of Germany in the European COST Action IC0906, which is entitled “WiNeMO – Wireless Networking for Moving Objects”. The project focuses on autonomous wireless objects which will in great numbers be incorporated in the Internet of the Future. These objects move around with diverse patterns and speeds while communicating via several radio interfaces. Examples of such objects may include humans, cars or unmanned aerial vehicles, with every object acting as a networking device generating, relaying and/or absorbing data.
Achieving the Internet of the Future, will require global interoperability amongst objects/devices, not typically common place due to inherent features of today’s Internet. To overcome the 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.

**BMBF Projects**

**G-Lab**

The project G-Lab consists of a Germany-wide research and experimental facility which is used to investigate the interplay between new technologies and the requirements of emerging applications. 32 partners are involved in the project which is led by Prof. Phuoc Tran-Gia. The project currently contains two different phases and the chair is involved in both phases, focusing on several different aspects.

Entwicklung und Leistungsanalyse innovativer Algorithmen und Strukturen für das zukünftige Internet (ELIAS) (Phase 1)

The wireless networking group focuses on congestion control and QoE-based radio resource management in wireless networks. The contention-based access of WLAN requires an efficient congestion control mechanism to ensure fairness between the various traffic flows and to provide QoS guarantees. Although this is already complex in one-hop environments, this is even more difficult in wireless mesh networks where the flows traverse several hops. The chair focuses on several different solutions. Firstly, the congestion control can be performed on the WLAN MAC layer by blocking surrounding stations of a congested station. Secondly, application layer monitoring can be used to monitor QoS demanding applications and to either throttle best effort traffic or to reroute real-time traffic over other gateways when a certain quality cannot be guaranteed anymore.

The aim of another work package is to develop new mechanisms which satisfy the users’ requirements for high application quality, resilience, and security. For that, the work package focuses on decentralized and distributed approaches. A secure and available communication is hereby the basis for a further optimization of the service with respect to the user perceive quality, the quality of experience. In addition, quality of service guarantees can be provided by new mechanisms for congestion detection and congestion repair.

We classify and analyze the trade-off between efficiency, overhead, robustness, and quality of service. Based on this, the different mechanisms are evaluated with respect to scalability, resilience, and user perceived QoE.

Another focus of the project is on future Internet routing. The current routing system of the Internet suffers from a scalability problem. Due to the high dynamics of customer networks joining and changing their attachment points to the relatively stable core of provider networks and due to their multi-homed connection, the number of entries in the routing tables recently grows at tremendous rate. Solutions are needed to make future Internet routing more scalable. They should also bring additional benefits to provider and customer networks to give incentives for their adoption. The locator/identifier split is a widely discussed principle to improve the routing scalability of the Internet.

We look at different implementations and study mapping systems that are needed for their support. New concepts are developed, simulated, and implemented in the experimental facility for demonstration purposes.

**Control and Management of Coexisting Networks (COMCON) (Phase 2)**

Control and Management of COexisting Networks (COMCON) is a project funded by Federal Ministry of Education and Research (BMBF) together with Nokia Siemens Networks, DOCOMO Communication Laboratories Munich, IKR University of Stuttgart and Infosim. The objective of COMCON Project is to design novel control and management mechanisms that support the coexistence of networks in a future Internet scenario and illustrate the economic advantages. The main targets are the use of virtualization techniques to support and introduce new services and new transport networks. Towards that goal, interfaces between business roles in coexisting networks realized by network virtualization are specified. A provider and operator-grade management and control function of coexisting virtual networks is built. It comprises of intelligent isolation, dynamic reassignment of resources, and efficient and effective monitoring of virtual network slices.
Data communication demands for more and more capacity. DSL access of 16 Mbit/s is common in Germany, 100 Mbit/s is already offered by some providers. Fiber access is state of the art in many countries of South-East Asia and tremendous traffic volumes are exchanged over fiber lines. This trend will continue over the next decade. The market is competitive such that Internet service providers (ISPs) need to provide high-quality services (high throughput, little delay, little jitter, high reliability) at low cost.

The CELTIC initiative brings together university researchers and business partners to jointly face this challenge. ADVA, Alcatel-Lucent, Ericsson, and Nokia-Siemens Networks are the main drivers each of them heading a group of university and small or medium enterprise partners. The Chair of Communication Networks of the University of Würzburg is part of the subproject „100GET-E3: End-to-End Carrier-Grade Ethernet“ led by Nokia-Siemens Networks and receives funding under the name „R3G: Routing, Grooming, Resilience, and Resource Management for MultiLayer Networks“.

The objective of the project 100GET is to provide a low-cost high-capacity solution for the network of the future. Two main objectives are addressed: the transmission of 100 Gbit/s and the provision of high-quality services at low cost. The project R3G focuses on the second aspect.

One of the main cost factors for ISPs are network components and among them IP routers are most expensive. Therefore, ISPs look for alternatives that are cheaper with respect to investment and operation cost. Enhanced Ethernet technology - the so-called Carrier Ethernet - seems to be a candidate to replace many IP routers within networks of ISPs. Therefore, international standardization bodies like IEEE or IETF push forward T-MPLS, VLAN XC, and PBB-TE/PBT.

The research of the University of Würzburg targets at the following issues. Cost savings can be obtained by keeping traffic in the optical domain as long as possible, using packet-switching capabilities of Carrier Ethernet nodes inside the network only when needed, and banning IP routers from the core. This is achieved by intelligent traffic grooming and routing that should make best use of the network resources. In addition, the reliability of the network is improved by cost-efficient protection switching and restoration mechanisms. To that end, optimization methods for the design and configuration of a future communication architecture are developed.

### DFG Projects

#### MobileP2P
Peer-to-Peer (P2P) computing is a networking and distributed computing paradigm which has become highly popular in the wired Internet. It permits users or entities to share their resources, e.g. bandwidth, files or CPU cycles. P2P services are end-user applications, like file-sharing and P2P-based networking fundamentals, like network control or network management. These services form overlay on application level, representing logical relationships among peers.

With the advances in wireless data communication technology, the increasing number of mobile users and their desire for ubiquitous communication, P2P has drawn attention to be applied in wireless and mobile networks. Mobile P2P services are aiming to transfer the advantages of P2P services (server-less operation, edge services, self-organization …) into the wireless domain. However, the special characteristics of mobile environments such as limited throughput, lossy channel, diversity of network architectures, and in particular the user mobility, are expected to have significant impact on the functioning and performance of these services.

In this project we investigate how the P2P paradigm can be applied to wireless and mobile networks, in particular the mapping of P2P mechanisms to cellular networks without losing the advantages of the P2P technology. It discusses the impact of device mobility on mobile P2P services and the selection of mobility management mechanisms and cooperation strategies among peers for these systems. The aim of this project is the categorization and performance evaluation of P2P mechanisms in mobile environments. Necessary modifications of the basic P2P approaches in mobile networks are revealed in order to improve the system performance and to get dependable systems.

#### Pol4G – Handover strategies for an improved performance of 4G networks
The integration of different wireless access technologies like UMTS, WLAN, WiMAX, and meshed networks into a heterogeneous network is one major topic for the near future. Since every access technology has been designed from a different perspective regarding user behavior, supported applications, and QoS requirements, such a heterogeneous network has to take into account the strengths and weaknesses from every technology.
This project between the Technical University Berlin and the University of Würzburg is funded by the Deutsche Forschungsgemeinschaft (German Research Foundation). The goal of this project is to integrate WLAN and UMTS into one system and to design policies for the handover between these technologies. This work is based on two well-known architectures to couple these technologies: tight as well as loose coupling. Secondly we develop a combined handover and admission control for both technologies which can be either centralized or of distributed manner. This includes either one or several network entities which store the current situation of the network. In order to enable a comparison of both access technologies, an equivalent bandwidth metric has been designed for UMTS as well as WLAN.

This allows fine-grained handover policies which are far beyond simple best-connect strategies. Due to the evaluation of the current situation in every access technology, our framework enables policies which consider the key strengths and weaknesses of every technology in different situations.

**PlanMesh - Performance Evaluation and Planning of Wireless Multihop Broadband Access Networks**

The target of this project was to develop planning algorithms for wireless mesh networks. The planning problem is to select locations for mesh routers and mesh gateways together with the hardware to install which means mainly the number of radio interfaces and the backhaul capacity for gateways. The challenge in the planning of mesh networks lies in planning a self-organized network i.e. routing and gateway selection, channel and radio selection, and scheduling and rate selection should actually be self-organizing without too much manual interaction. However, such a network is hard to plan so the solution was to perform the mesh network planning for an optimized resource management. The optimal resource management was derived in two steps. First, an algorithm was developed to determine max-min fair throughputs for a mesh networks with predefined routing and channel allocations. In a second step, the optimal routing and channel allocation were found using a genetic algorithm that used the max-min fair rate allocation as evaluation function. Finally, the network planning problem was solved by extending the genetic algorithm to the selection of gateways and routers. The evaluation function was extended to the operating and installation costs of the required mesh routers and gateways.

**FunkOFDMA – Performance Evaluation of Radio Resource Management Mechanisms in Cellular OFDMA Networks**

OFDMA is the multiple access technology used in the next generation mobile LTE or WiMAX networks. The performance of these systems strongly depends on intelligent radio resource management mechanisms. These should on the one hand utilize the theoretical radio capacity as far as possible but on the other hand also consider both the system and network architecture and the user- and application behavior in an adequate way. The target of this project is to develop and evaluate radio resource management mechanisms that are usable in future OFDMA networks. The focus is on the relation of frequency-selective scheduling and interference coordination taking realistic traffic models into account.

**Simulation and Analytical Performance Evaluation of a GMPLS-Oriented Internet Architecture (GMPLSINT)**

Generalized Multiprotocol Label Switching (GMPLS) is the newest of a series of frameworks developed by the Internet Engineering Task Force (IETF) to provide traffic engineering (TE) and network control mechanisms in today’s Internet. It basically extends the present MPLS standard to optical networks and is capable to deal with heterogeneous networking technologies. These different technologies may be packet- or circuit-switched and based, e.g., on either copper or fiber. TE plays an important role in the GMPLS framework. While TE issues have already been well studied in connection with conventional MPLS, new TE mechanisms for the GMPLS technology represent a great challenge that is due to the complex structure of GMPLS and the numerous network resources (packet labels, time slots, wavelengths, fibers) that have to be managed in heterogeneous networks. In principle, the application of MPLS-based TE mechanisms to improve load balancing and resource utilization is costly with regard to a heavy administrative effort. These administrative burdens result in scalability problems which have partially been solved by introducing the Label Switched Path (LSP) hierarchy which enables traffic aggregation and reduces signalling costs. GMPLS also uses this concept to construct a virtual and hierarchical network structure based on which it distributes the traffic load and reduces the required TE information.

The project investigates the GMPLS framework as a means for TE in the Next Generation Internet (NGI). A simulative and analytical study provides insight into different aspects of the GMPLS technology. Research issues are the behavior and the usability of GMPLS in complex real-world network scenarios and its potential for optimization regarding a scalable resource management and a high resource efficiency under resilience requirements.
IP networks have the self-healing property. Their routing re-converges after a network failure by exchanging link state advertisements (LSAs) such that all but the failed nodes can be reached after a while if a working path still exists. This self-healing property was the main motivation for the DARPA (Defense Advanced Research Projects Agency) when designing the Internet and made the Internet an enormous success over the last 30 years. IP re-convergence is a very simple and robust mechanism. However, the disadvantage of such a method is obvious: it is slow. In particular, the interval to exchange the LSA updates cannot be reduced to arbitrarily small values for stability reasons and the computation of the shortest paths that are needed to construct the routing tables based on the new LSAs requires a substantial amount of time. This time overhead is tolerable for elastic traffic but not for real-time or even high-precision telematic or tele-surgery applications. Currently, standardization organizations like the IETF discuss IP Fast Reroute (IP-FRR) mechanisms to overcome the problems involved in long routing re-convergence while not abandoning the IP routing concept. These mechanisms make dimensioning of new networks and configuration of existing networks more complex and raise the following research issues:

• How much capacity is required in the network to survive a given set of network element failures the network should be protected against without traffic loss (dimensioning)?

• How much traffic can be carried over a given network without traffic loss for a given set of network failures (configuration)?

• How severe is the impact of unprotected network element failures?

Obviously, the answers to these questions depend on the specific rerouting approach. In this project, we analyze IP-FRR algorithms currently under discussion in the international research community with respect to these issues. As stability is a crucial aspect of such algorithms, stability aspects are our main focus. We suggest extensions or improvements where possible and we plan to develop new methods if required.

Industry Projects

Siemens AG - Performance Evaluation of Architectures for Distributed Real-Time Communication (DiRC)

In this project, we focus on architectures for distributed real-time communication. In particular, we study eventing systems that are implemented, e.g., according to the publish/subscribe paradigm. They may be used as middleware in distributed applications.

Both information providers – so-called publishers – and information consumers – so-called subscribers – register at the server. The publishers send messages to the server that forwards them to all subscribers. Optionally, subscribers can install filters on the server that select only a certain subset of messages for them. Currently we study the following problems:

• There are no or only insufficient performance evaluation studies about the capacity of JMS servers. We tested several types from different vendors and assessed their capacity in different application scenarios, in particular with and without filters. Our measurement results showed that the capacity of the servers ranges over several orders of magnitude depending on the server type and the application scenario.

• Eventing systems in large distributed applications must handle an enormous message rate. The applications often have real-time or quasi-real-time requirements, i.e., the delay observed by the messages at the JMS server must be small. As mentioned above, the service time for messages ranges over several orders of magnitude. We considered different application scenarios to assess a reasonable upper bound on the variation of the service time and derived the waiting time distribution for the messages. The results showed that the waiting time is short even at a high server load of 90% if the server capacity is sufficiently large.

• The capacity of a single server may not suffice to forward the traffic of a large-scale application. Therefore, we look at the performance of server clusters.
In the future of our information society, business people as well as private citizens will depend more and more on telecommunication. At present, we can think of video conferences based on a simple PC but new concepts for network services and applications will open up completely new experiences like tele-presence and virtual reality.

The current telephone infrastructure and the Integrated Services Digital Network (ISDN) are not flexible enough to satisfy the demands of this evolution and the present Internet is not capable to carry mission critical data in an adequate way. A new, reliable, and secure broadband-network for real-time communication must be able to transport high bitrates with appropriate quality of service (QoS). After the success and the vast expansion of the Internet Protocol (IP) in the past years, this protocol suite will be the base for continuous end-to-end communication in the "Next Generation Internet" (NGI). In contrast to the approaches that are currently discussed in the Internet community, the future communication infrastructure must be scalable and easy to manage. Its operation must be economical while providing good QoS to the customer, even in the case of network failures. The KING project takes care of these requirements. Its main focus thereby lies on the network spanning control and operation mechanisms which should be as simple as possible since the complexity of already existing solutions in this domain causes high costs for introduction and further maintenance. Network and system concepts are developed and implemented in corresponding system components which will be subsequently demonstrated and verified in an appropriate network environment. In addition to a demonstration network, a trial in a real network environment is intended that comprises users, network and service providers.

Siemens AG – Multiple Location Execution (MAX) and Principles of Distributed Frontend Machines (Prima)

In B3G core networks, applications such as the Call Session Control Functions (CSCF), frequently need to access user data. However, the data sets are distributed over several database servers, necessitating a lookup system that locates queried data.

The aim of this project is to develop and evaluate a P2P-based architecture to provide these specific lookup functions for subscriber data in B3G core networks. The envisioned system needs to cope with the given performance constraints while offering additional advantages over the state-of-the-art solution. The scope of the performance evaluation varies from small-scale systems to large providers.

In an extension, a prototype of the architecture was built and the viability of the concept shown.

Deutsche Telekom – System Analysis of an OpenFlow Architecture (SOFA)

The idea of OpenFlow is to separate the data path from the control path. This means that simple forwarding still resides on the switch, whereas high-level routing decisions are done on a separate controller. This split of the switching and controlling logic enables the creation of vendor-independent intelligent control mechanisms.

The goal of the project is to evaluate the potentials of OpenFlow for the future Internet. Various fields of application for OpenFlow are evaluated and compared to already existing approaches such as MPLS. Furthermore, different OpenFlow architectures are analyzed in terms of scalability, meaning how many flows can be handled dynamically and how to organize the switch-controller mapping. Therefore, measurement studies are performed to gather performance-relevant parameters and the interaction of the switch and the controller is evaluated.

T-Mobile - Algorithms for UMTS Radio Network Planning

The general focus of the project was the development of algorithms for the UMTS radio network planning software PegaPlan. In the period covered by this report the following sub-projects have been conducted:
Interference Prediction for the Enhanced Uplink

The purpose of the project is the inclusion of the Enhanced Uplink (or E-DCH, HSUPA) in the UMTS planning process. This requires the calculation of the interference densities in the cell coverage area under consideration of the new features of the E-DCH. These features comprise amongst others a reduced transport time interval of 2ms, hybrid ARQ and fast NodeB controlled rate scheduling which is performed by scheduling grants for the allowed uplink transmit power.

Dimensioning of hardware components for HSDPA and Enhanced Uplink

This project aims at extending the hardware dimensioning algorithm developed for dedicated channels to the HSDPA and Enhanced Uplink. The hardware pool at a NodeB is shared among all users served by this NodeB including different sectors, uplink and downlink connections, and DCH, HSDPA, E-DCH users. The aim of this project is to develop an algorithm that provides the cheapest hardware configuration at a NodeB that provides desired service quality for all types of users which in particular means that the hardware shall not restrict the service quality below the one provided by the radio capacity.

Nortel Networks – Lightweight Support for Real-Time Communication in the Future Internet (LightComm)

The objective of this project is to design and develop lightweight support for real-time communication in the Internet. The work is embedded into the efforts of the IETF working group on Congestion and Pre-Congestion Notification (PCN). It aims at the standardization of admission control and flow termination on pre-congestion notification.

A link is „pre-congested” with regard to a certain rate threshold if its traffic rate is above that threshold within some tolerance. This can be effectively controlled by virtual queue or token bucket based algorithms. Packets may be marked in case of pre-congestion such that this marking information notifies egress nodes that rate thresholds have been exceeded somewhere in the network.

PCN-based admission control and flow termination associates an admissible rate and a supportable rate with each link in the network. If the admissible rate is exceeded, all packets are marked with „admission-stop” and if the supportable rate is exceeded, the packets exceeding this rate are marked with „excess traffic”. The egress node monitors the markings of its received packets. If the majority of the packets of a specific ingress-egress-aggregate is marked with „admission-stop”, the corresponding ingress node stops the admission of further flows. If the egress node receives packets with „excess-traffic” marks from a specific ingress-egress-aggregate, the ingress node is notified to terminate flows to reduce the traffic load in the network. This is only the basic idea, but many variants thereof are proposed.

The advantages of that approach are

- Interior nodes can be unaware of any reservations, they just perform traffic metering and marking.
- If a link or node failure occurs, traffic is rerouted and possibly causes congestion on backup paths. However, this concept allows to set the admissible rates low enough such that the admitted traffic can still be carried by the network after a protected failure. This is called resilient admission control.
- If a major network outage happens and severe overload occurs inspite of careful capacity overprovisioning, the flow termination function guarantees that the network can be brought back to a state without congestion.

The purpose of this project is to work out suitable PCN mechanisms and to conduct performance studies for discussion in IETF to support the standardization process.

DATEV – TrendScout Project

TrendScout is a project conducted by the Chair of Communication Networks (University of Würzburg) and the DATEV e.G., Nuremberg. The main goal is to present new IT technologies and to evaluate their usability in practice. The topics are not completely determined in advance. Arising, interesting topics can be suggested by the different groups involved in the cooperation. Momentarily, two universities are involved in the project permanently (University of Würzburg, University of Trier). Experts from other universities join on invitation by the Chair of Communication Networks (University of Würzburg) on special occasions. Thematically, the focus is laid upon current and future hard- and software trends (.NET framework, Grid Computing, …) and performance evaluation and simulation (Website Performance Analysis, …). Furthermore, evolving network technology (autonomic networking), security aspects to control physical access to high-security buildings (biometrics) and system security to control access to software and sever systems are vitally discussed.
DATEVasp

Current applications can be deployed using a Thin-client architecture, i.e., the software is not running on the user’s computer but on a server. Since user commands and their visualization are transmitted via a network, the Quality of Experience (QoE) of the user depends on the characteristics of that network.

The DATEVasp projects aims to quantify this dependency by measurements in a testbed. The software and architecture used is provided by Datev e.G., and is used also in a real-world environment.

Alcatel-Lucent – Future Internet Routing – Overview, Concepts and Simulation (FIROCS)

The project goals are to explore routing and traffic management issues for the „network of the future” as they are discussed in IRTF/IETF and the Future Internet cluster of EU FP7 research projects. Scalability, resilience, multipath routing, mobility, and advanced traffic engineering as well as their control architectures and protocols play a major role. Various existing routing approaches are revisited, discussed and assessed in the new context. Appropriate routing paradigms for virtualized networks are identified, analyzed, and evaluated in particular with regard to performance and viability.

Federal Office for Information Security (Bundesamt für Sicherheit in der Informationstechnik – BSI) – Design of IT Early-Warning Systems

Due to its open structure the use and the operation of today’s Internet faces again and again unprecedented dangers. Maleficent attacks may lead to a restricted availability or even to an entire breakdown of network components. In order to protect the national German Internet from these and other threats, an Internet-Early-Warning-System is developed during the course of this project. Due to the big number of different malware, this system has to be built on a multitude of components which have to work together. For instance, different probe types have to be deployed in the Internet in order to gain measurements. These measurements have to be correlated and processed in order to use them in an IT Early-Warning System. In this project we investigate the architecture and the operation of such a system. Key aspects are the scalability of the system, security issues, as well as efficiency and robustness.

BOSCH MAMS

Application identification is getting more and more complex nowadays. On the one hand there are much more new applications, which want to communicate, than unused port numbers. Thus collisions are inescapable. On the other hand applications might use port numbers, which are well known as used by other appliances in order to bypass firewalls and enable services, which the network operator does not want to support. The trend to encrypt and camouflage the data transmitted makes the situation even worse. Therefore, this project aims to analyze methods, which try to reveal application information based on network data, evaluate their performance, and improve the rate of successful application recognition.

4.2

Workshops, Seminars and Conferences

4.2a

Workshops hosted by the chair

Würzburger Workshops on IP: “Visions of Future Generation Networks” (EuroView)

The objective of the seminar series is to address research issues at the intersection of traffic management and traffic engineering. The series was started in 2000 and has since been held yearly. The 2002 event was part of the international ITC Specialist Seminar series.

Since 2006 workshop is organized by the University of Würzburg and the German Informatics Society (ITG) on behalf of the Euro-NGI/FGI/NF Network of Excellence and focuses on Visions of Future Generation Networks. More information on the program and seminar registration can be found on the workshop web-pages:

http://www3.informatik.uni-wuerzburg.de/ITG/
Euro-NGI Integration Workshop on New Trends in Network Architectures and Services

The Chair of Communication Networks hosted the Euro-NGI (see project description) workshop on New Trends in Network Architectures and Services in 2006. The main objective of the workshop was to share the knowledge on the various technologies among the 59 partners of the Euro-NGI community and to collaborate on the design of the required innovative architectures.

The main topics covered by the workshop were:
- Horizontal and Vertical integration of Fixed and Mobile Networks
- Core Networks Evolution
- IP Networking Evolution
- New Services: Infrastructure and Management
- New trends in Network Management

Third Euro-NGI Plenary Meeting

Additionally to the Euro-NGI workshop, the 3rd Euro-NGI plenary meeting was hosted in Würzburg with over 150 international participants.

Workshop: „Simulation of P2P Networks and Applications“

The algorithms and methods of the Peer-to-Peer (P2P) technology are often applied to networks and services with a demand for scalability. In order to evaluate quantitatively and qualitatively such P2P services and their corresponding networks, different possibilities like analytical approaches or simulative techniques can be used to improve the implementation of a simulation in general. This task is even more important for large scale P2P networks due to the number of peers, the state space of the P2P network, and the interactions and relationships between peers and states. The goal of this workshop is to show how large scale P2P networks can be efficiently evaluated and methods are demonstrated how to avoid problems occurring in simulations of P2P services.

More Information on the program can be found on the seminar web-pages:
http://www3.informatik.uni-wuerzburg.de/conferences/

19th VDE/ITG Section 5.2.4 Meeting on „VoIP over Wireless“

The objective of this workshop was to take a closer look on the research development in the field of Voice over IP (VoIP) connection in wireless networks. The workshop was jointly organized by the Chair of Communication Networks and the ITG Working Group 5.2.4. The ITG 5.2.4 working group on mobility in wireless networks started in June 2001. The working group addresses architectures, protocols, and mechanisms of present and future mobile communication. It is a national group with around 30 active participants.

4.2b Co-organized Seminars and Conferences

Workshops on Future Internet Design (FID) collocated with ECOC in 2007 and 2008

This workshop brings together researchers in the area of future Internet design including in particular „Clean Slate Design“ and researchers in the area of optical communications, to raise mutual awareness, explore areas of joint interests, and stimulate discussion on the directions of future network research. Both communities will need to closely cooperate to overcome a number of fundamental issues to make the future Internet happen. This workshop series started in 2007 collocated with ECOC in Berlin and in 2008 the workshop is again collocated with ECOC in Brussels.

More information on the program and seminar registration can be found on the workshop web-pages:
http://www3.informatik.uni-wuerzburg.de/FID/

4th Euro-NGI Conference on Next Generation Internet Networks

NGI 2008 conference is the continuation of the series of successful events held in Rome, Valencia and Trondheim. It has provided an international forum for the presentation of high quality, peer-reviewed papers covering various aspects of future networking, including the future Internet architecture and quality of service. It is organized by the Network of Excellence (NoE) Euro-FGI (former Euro-NGI) that was initiated by the European Commission during the 6th framework program and will be continued in the next funding period as Network of Excellence Euro-NF. The conference is a key event contributing to reach the EU targets of integrating the European research effort in the Next
Generation Internet domain and to strengthen the collaboration with non-European researchers and institutions. The conference was held April 28 – 30 2008, at the AGH University of Science and Technology in the city of Kraków, Poland.

http://www.kt.agh.edu.pl/ngi2008/

21st International Teletraffic Congress (ITC 21)

The International Teletraffic Congress (ITC) was created in 1955 to initially cater to the emerging need to understand and model traffic in telephone networks using stochastic methodologies, and to bring together researchers with these considerations as a common theme. Over the years, it has broadened its scope to address a wide spectrum ranging from the mathematical theory of traffic processes, stochastic system modelling and analysis, traffic and performance measurements, network management, traffic engineering to network capacity planning and cost optimization, including network economics and reliability for various types of networks. The 21st edition of the conference was held on September 15-17 2009 in Paris, France. One third of the submissions were accepted and 59 technical papers were presented together with 5 keynotes. One general best paper award and one best student paper award were given. The 1st Workshop on Data Center Converged and Virtual Ethernet Switching (DC CAVES) was collocated with the conference.

http://www.i-teletraffic.org/itc21/

20th ITC Specialist Seminar on Network Virtualization

Concept and Performance Aspects

A major objective of this ITC Specialist Seminar was to identify early and future performance issues and to provide methodologies and mechanisms to address the various aspects of performance in network virtualization. The seminar was intended as a forum for scientists and engineers in academia and industry to exchange and discuss their latest experiences, and research results. It addressed techniques, architectures, performance models, and performance engineering methods leading to real world network virtualization solutions that provide users with efficient techniques for creating and operating their own high performance virtual network. The 20th ITC Specialist Seminar was held from May 18th to May 20th in Hoi An, Vietnam.

http://www.itcspecialiste-seminar.com/

4.3 Visiting Scientists

During the last years the chair hosted the following scientists from national and international organizations:

Visitors from national organizations:
- Adam Wolisz, Technische Universität Berlin
- Christian Hoehne, Universität Tübingen
- Hans Barth, T-Mobile AG, Bonn
- Bernhard Liesenfeld, T-Mobile AG, Bonn
- Bernd Schröder, brown-iposs, Bonn
- Klaus Heck, Hotzone, Würzburg
- Timo Kosch, BMW Group Research and Technology, München
- Stefan Köhler, infosim, Würzburg
- Marius Heuler, infosim, Würzburg
- Klaus Olszowi, infosim, Würzburg
- Sven Engelhardt, Tiscali International, Dreieich
- Oliver Schwarz, Tiscali International, Dreieich
- Klaus Schertler, EADS Deutschland, München
- Frank-Uwe Andersen, Siemens AG, Berlin
- Norbert Vicari, Siemens AG, München
- Hermann de Meer, University of Passau
- Cornelia Kappler, Siemens AG, Berlin
- Wolfgang Scheidel, Siemens AG, München

Visitors from international organizations:
- Luca Cavaglione, University of Genova, Italy
- Franco Davoli, University of Genova, Italy
- Tuo Liu, University of Sydney, Australia
- Krysztof Pawlikowski, University of Canterbury, New Zealand
- Andre Broido, Cooperative Association for Internet Data Analysis (CAIDA)
- Marie-Ange Remiche, Free University of Brussels, Belgium
- Ivan Gojmerac, Telecommunications Research Center Vienna, Austria
- Peter Reichl, Telecommunications Research Center Vienna, Austria
- Betrand Morin, France Telecom, France
- Kalyan Basu, University of Arlington, TX, USA
- Ilkka Norros, VTT, Finland
- Vesa Pehkonen, VTT, Finland
- Markus Fiedler, Technical University of Blekinge, Sweden
- Stefan Cheuv, Technical University of Blekinge, Sweden
- Marco Mellia, Technical University of Turin, Italy
- Kenji Leibnitz, University of Osaka, Japan
- David Rosse, France Telecom, France
- Michael Frater, University College Australian Defence Force Academy, Australia
- Anna Sfairopoulou, Universitat Pompeu Fabra, Spain
4.4 External Activities and Committees

P. Tran-Gia serves as
- Head of Administration board of G-Lab
- Director and founding coordinator of the “Center of Optimization of Communication Networks” (Interdisciplinary Research Center, Universities Würzburg, Aachen, Trier; sponsored by Nortel External Research)
- Chairman of the management committee, European Union project COST 257 “Impact of New Services on the Architecture and Performance of Broadband Networks”
- Vice-Chairman of the management committee, European Union project COST 279 “Analysis and Design of Advanced Multiservice Networks supporting Mobility, Multimedia, and Internetworking”
- Member of the German Communications Society (ITG: Informationstechnische Gesellschaft)
- Member of the German Computer Science Society (GI: Gesellschaft für Informatik)
- Member of the Institute of Electrical and Electronics Engineers (IEEE)
- Member of the Traffic Engineering Committee of the German Communications Society (NTG)
- Member of IFIP 7.3 (Computer Performance)
- Member of IFIP 6.3 (Computer Network Performance)
- Member of GI/ITG working group 1.2.1 “Queuing Theory”
- Member of the board of GI/ITG working group “Measuring, Modelling, and Performance Evaluation of Computing Systems”

M. Menth serves as
- Leader of the workgroup “routing and addressing” in G-Lab
- Leader of the special interest group on “routing” in G-Lab
- Co-organizer of the local PhD student colloquium
- TPC Co-Chair of the 4th Conference on Next Generation Internet (NGI), 2008
- TPC Co-Chair of the 21st International Teletraffic Congress (ITC 21), 2009
- Guest Co-Editor of the Special Issue on “Traffic and Performance Issues in Networks of the Future” in the Annals of Telecommunications

D. Staehle serves as
- Chairman of the “Traffic Engineering” working group in the COST 290 action
- Coordinator of the ITG Working Group 5.2.4 “Mobility in IP-based Networks”
- TPC Chair of the IEEE Broadband Wireless Access Workshop (www.bwaws.org)
- TPC Chair of the 7th International Conference on Wired / Wireless Internet (WWIC) 2009
- Workshop chair of 15th International Conference on Telecommunications (ICT) 2008

R. Pries serves as
- Working group chairman of COST IC0804 (http://www.cost804.org)
- Assistant of the BMBF project G-Lab (http://www.german-lab.de)

T. Hoßfeld serves as
- Co-Chair of the EuroView Workshops since 2008
- Co-Chair of the ATNAC 2010 Internet Technology track
- Co-Chair of the 3rd Workshop on Economic Traffic Management (ETM) 2010

Furthermore, the chair participated in the Paper Committees or in the reviewing process of the following journals:

- ACM Multimedia Systems Journal (MMS)
- Computer Networks
- Computer Communications
- Computers and Operations Research
- European Journal of Operations Research
- European Transactions on Telecommunications (ETT)
- IEEE Journal of Selected Areas in Communications (JSAC)
- IEEE Wireless Communication Magazine (WCM)
- IEEE Communication Letters
- IEEE Communications Surveys and Tutorials
- IEEE/ACM Transactions on Networking
- IEEE Transactions on Multimedia
- IEEE Transactions on Network and Service Management (TNSM)
- IEEE Transactions on Wireless Communications
- IEEE Transactions on Mobile Computing
- Informatik Spektrum
- International Journal of Communication Systems
- International Journal of Electronics and Communications (AEU)
- International Journal of Communication Networks and Distributed Systems (IJCNDS)
- International Journal on Advances in Internet Technology
- International Journal on Advances in Telecommunications
- Journal of Circuits, Systems, and Computers
- Journal of Communications Software and Systems
- Journal of Communications Software and Systems
- Journal of Systems Architecture
- Performance Evaluation
- Performance Evaluation and conferences (selection)
- International Teletraffic Congress (ITC)
- ITC Specialist Seminar
- Euro-NGI Conference on Next Generation Internet Networks (NGI)
- Kommunikation in Verteilten Systemen (KIVS)
- Polish-German Teletraffic Symposium (PGTS)
- IEEE Symposium on Computers and Communications (ISCC)
- IEEE Informetrics
- IEEE ICC
- IEEE Globecom
- IFIP/IEEE International Symposium on Integrated Network Management (IM)
- IEEE/IFIP Network Operations and Management Symposium (NOMS)
- IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS)
- IEEE Consumer Communications & Networking Conference (CCNC)
- IFIP-TC6 Networking Conference (Networking)
- IFIP International Conference on Personal Wireless Communications (PWC)
- International Conference on Networking Communities (TridentCom)
- Development of Networks and Research Infrastructures for the Future Internet (FITraMEn)
- International Workshop on Traffic Engineering and Optimization of Peer-to-peer Environments (SAPIR)
- Service Assurance with Partial and Intermittent Resources (SAPIR)
- International Conference on Self-Organizing Systems (IWSS)
- Towards the QoS Internet
- International Workshop on Bandwidth on Demand
- Bioinformatics
- Workshop on Autonomic Networking (Anet)
- American Control Conference (ACC)
- Euro-NGI Workshop on Wireless and Mobility
- Euromicro International Conference on Parallel, Distributed and Network-Based Computing
- International Conference on Advances in Mesh Networks (MESH)
- International Conferences on Access Networks, Services and Technologies (ACCESS)
- Advanced International Conference on Telecommunications (AICT)
- International Conference on Communication Theory, Reliability, and Quality of Service (CTQR 2010)
- Wireless Days
- ACM International Symposium on Mobile Ad Hoc Networking and Computing (IMC)
- Workshop on Data Center Converged and Virtual Ethernet Switching (DC CAVES)
- Conference on Energy-Efficient Computing and Networking (e-Energy)
- International Conference on Computer Communication Networks (ICCCN)
- Future Internet Assembly (FIA)
- International Workshop on Modeling, Simulation, and Optimization of Peer-to-peer Environments (MSPP2P)
- International Workshop on Traffic Management and Traffic Engineering for the Future Internet (FiTraMEn)
- International Workshop on Reliable Networks Design and Modelling (RNDM)
- International Workshop on the Design of Reliable Communication Networks (DRCN)

- IEEE Vehicular Technology Conference (VTC)
- IEEE Local Computer Networks (LCN)
- IEEE International Conference on Peer-to-Peer Computing (P2P)
- IEEE International Conference on Advanced Information Networking and Applications (AINA)
- IFIP Wireless and Mobile Networking Conference (WMC)
- IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)
- IEEE International Workshop on Mobile Peer-to-Peer Computing (MP2P)
- ACM Sigmetrics
- International Conference on Wired/Wireless Internet Communications (WWiC)
- International Workshop on Quality of Service (IWQoS)
- International Workshop on Communications Quality & Reliability (COR)
- International Workshop on Modeling, Simulation, and Optimization of Peer-to-peer Environments (MSOP2P)
- International Peer-to-Peer for Handheld Devices Workshop
- International Workshop on Distributed Cooperative Laboratories: Instrumenting the Grid (INGRID)
- International Telecommunication Networking
- Broadband Wireless Access Workshop
- International Workshop on Peer to Peer Networks (PPN)
- Australasian Telecommunication Networks and Applications Conference (ATNAC)
- Southern African Telecommunications Networks and Applications Conference (SATNAC)
- International Conference on Analytical and Stochastic Modelling Techniques and Applications (ASMTA)
- International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom)
- International Conference on Networking and Services (ICNS)
- IPv6 - Deploying the Future Infrastructure (IPv6DFI)
- Internet Packet Dynamics (IPDy)
- International Conference on Communications and Electronics (ICCE)
- International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN)
- International Conference on Telecommunications and Multimedia (TEMU)
- Service Assurance with Partial and Intermittent Resources (SAPIR)
- Teletraffic Modeling and Management (TELET)
- Workshop on Advanced EXPERimental Activities ON WIRELESS Networks and Systems (EXPONGWIRELESS)
- EUNICE Open European Summer School
- IASTED International Conferences on Wireless and Optical Communications (WOC)
- International Conference on Digital Communications (ICDT)
- Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTCS)
- International Workshop on QoS in Multiservice IP Networks (QoS-IP-
  - Architectures for Quality of Service in the Internet (Art-QoS)
  - Performance Modelling and Evaluation of Heterogeneous Networks
  - European Personal Mobile Communications Conference
  - International Telecommunications Network Strategy and Planning Symposium (Networks)
  - Performance Modelling and Evaluation of Heterogeneous Networks (METNET)
  - International Conference on Software, Telecommunications and Computer Networks (SoftCOM)
  - International Workshop on QoS in Multiservice IP Networks (QoS-IP-
  - European Wireless Conference
  - Workshop on Resource Allocation in Wireless NETworks (RAWNET)
  - Euromicro Conference on Software Engineering and Advanced Applications (SEAA)
  - Workshop on Mobile Ad-Hoc Networks (WMAN)
  - International Conference on Late Advances in Networks (ICLAN)
  - International Workshop on Self-Organizing Systems (IWSS)
  - Towards the QoS Internet
  - International Workshop on Bandwidth on Demand
  - Bioinformatics
  - Workshop on Autonomic Networking (Anet)
  - American Control Conference (ACC)
  - Euro-NGI Workshop on Wireless and Mobility
  - Euromicro International Conference on Parallel, Distributed and Network-Based Computing
  - International Conference on Advances in Mesh Networks (MESH)
  - International Conferences on Access Networks, Services and Technologies (ACCESS)
  - Advanced International Conference on Telecommunications (AICT)
  - International Conference on Communication Theory, Reliability, and Quality of Service (CTQR 2010)
  - Wireless Days
  - ACM International Symposium on Mobile Ad Hoc Networking and Computing (IMC)
  - Workshop on Data Center Converged and Virtual Ethernet Switching (DC CAVES)
  - Conference on Energy-Efficient Computing and Networking (e-Energy)
  - International Conference on Computer Communication Networks (ICCCN)
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  - International Workshop on Modeling, Simulation, and Optimization of Peer-to-peer Environments (MSPP2P)
  - International Workshop on Traffic Management and Traffic Engineering for the Future Internet (FiTraMEn)
  - International Workshop on Reliable Networks Design and Modelling (RNDM)
  - International Workshop on the Design of Reliable Communication Networks (DRCN)
5.1 Dissertations & Habilitations

Rastin Pries

Michael Menth (Habilitation)

Tobias Hößfeld

Andreas Mäder

Rüdiger Martin

Kurt Tutschku (Habilitation)

Andreas Binzenhöfer

Jens Milbrandt

Stefan Köhler

5.2 Books

Y. Koucheryavy, G. Giambene, D. Staehle, F. Barcelo-Arroyo, T. Braun, V. Siris (Editors)

Alexander Klein
*Performance Comparison of Different Wimax Configurations – Impact of Scheduling and Contention Resolution on Quality of Service in Wimax Networks.* Saarbrücken, Germany, June 2008.

Jens Milbrandt

Andrzej Jajszczyk, Piotr Cholda, Michael Menth
*Proceedings of the 4th EURO-NGI Conference on Next Generation Internet Networks (NGI).* April 2008.

Phuoc Tran-Gia
5.3 Book Chapters

Tobias Hoßfeld, Daniel Schlosser, Kurt Tutschku, Phuoc Tran-Gia

Tobias Hoßfeld, Michael Duelli, Dirk Staehle, Phuoc Tran-Gia

Kurt Tutschku, Andreas Beri, Tobias Hoßfeld, Hermann de Meer

5.4 Journal Articles

Rastin Pries, David Hock, Dirk Staehle

Michael Menth, Ruediger Martin, Matthias Hartmann, Ulrich Spoerlein

Michael Menth, Matthias Hartmann, Rüdiger Martin, Tarik Cicic, Amund Kvalben

Markus Fiedler, Tobias Hoßfeld, Phuoc Tran-Gia
A Generic Quantitative Relationship between Quality of Experience and Quality of Service. IEEE Network Special Issue on Improving QoE for Network Services, 2010.

Florian Warnser, Rastin Pries, Dirk Staehle, Klaus Heck, Phuoc Tran-Gia

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Michael Menth, Frank Lehrieder, Bob Briscoe, Philip Eardley, Toby Moncaster, Jozef Babiarz, Anna Charny, Xinyang (Joy) Zhang, Tom Taylor, Kwok-Ho Chan, Daisuke Satoh, Ruediger Geib, Georgios Karagiannis

Rastin Pries, Dirk Staehle, Barbara Staehle, Phuoc Tran-Gia

Andreas Mäder and Dirk Staehle

Michael Menth, Andreas Binzenhöfer, Stefan Mühleck

Daniel Schlosser and Tobias Hoßfeld

Michael Menth, Michael Duelli, Rüdiger Martin, Jens Milbrandt

Andreas Mäder, Dirk Staehle

Alexey Vinel, Qiang Ni, Dirk Staehle, Andrej Turlikov
5.5 Conference Papers

Thomas Zinner, Kurt Tutschku, Akihiro Nakao, Phuoc Tran-Gia

Kurt Tutschku
P2P-based Network and Service Operation for the Emerging Future Internet.

Andreas Binzenhöfer, Gerald Kunzmann, Robert Henjes
Design and Analysis of a Scalable Algorithm to Distinguish Chord-based P2P Systems at Runtime.

Andreas Binzenhöfer, Holger Schnabel, Phuoc Tran-Gia
Methods for Performance Improvement of Kademia-based Overlay Networks.

Robert Henjes, Michael Menth, Valentim Himmler
Throughput Performance of the BEA WebLogic JMS Server.

Peter Racz, Simon Oechsner, Frank Lehrieder
BGP-based Locality Promotion for P2P Applications.

displayed text
Frank Lehrieder, Simon Oechsner, Tobias Hößfeld, Zoran Despotovic, Wolfgang Kreller, Maximilian Michel

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Controlled vs. Uncontrolled Degradations of QoE – The Provisioning-Delivery Hysteresis in Case of Voice.
New Dimensions in the Assessment and Support of Quality of Experience (QoE) for Multimedia Applications, Tampere, June 2010.

Barbara Staehle, Matthias Hirsh, Rastin Pries, Florian Warnser, Dirk Staehle

Thomas Zinner, Oliver Hößfeld, Osama Abboud, Tobias Hößfeld

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Dirk Staehle, Barbara Staehle, Rastin Pries
Max-Min Fair Throughput in Multi-Gateway Multi-Rate Mesh Networks. IEEE VTC Spring 10, Taipei, Taiwan, May 2010.

Florian Warnser, David Mittelstädt, Dirk Staehle

Michael Duelli, Anke Endler, Michael Menth
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Osama Abboud, Thomas Zinner, Eduardo Lidanski, Konstantin Pusseu, Ralf Steinmetz

D. Schlosser, M. Hoffmann, T. Hößfeld, M. Jarschel, A. Kriestadter, W. Kreller, S. Köhler
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Matthias Hirth, Barbara Staehle, Florian Warnser, Rastin Pries, Dirk Staehle

Daniel Schlosser, Barbara Staehle, Andreas Binzenhöfer, Björn Boder
Improving the QoE of Citrix Thin Client Users. IEEE International Conference on Communications (ICC 2010), Cape Town, South Africa, May 2010.

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Supporting Scalable Video CODECs in a P2P Video-on-Demand Streaming System. 21th ITC Specialist Seminar on Multimedia Applications - Traffic, Performance and QoE, Miyazaki, Japan, March 2010.

Thomas Zinner, Osama Abboud, Oliver Hößfeld, Tobias Hößfeld, Phuc Tran-Gia

Barbara Staehle, Dirk Staehle, Rastin Pries
Effects of Link Rate Assignment in IEEE 802.11 Mesh Networks. 16th European Wireless Conference, Lucca, Italy, April 2010.

David Hock, Matthias Hartmann, Christian Schwartz, Michael Menth

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Tobias Hößfeld, Kenji Leibnitz, Akhiro Nakao

Matthias Hartmann, David Hock, Michael Menth, Christian Schwartz

Andreas Berl, Hermann de Meer, Tobias Hößfeld

Barbara Staehle, Dirk Staehle, Rastin Pries, Matthias Hirsh, Andreas Kassler, Peter Dely

Dirk Staehle and Rastin Pries and Alexey Vinel and Andreas Mäder

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Rastin Pries, Dirk Staehle, Simon Oechsner, Michael Menth, Stefan Menth, Phuoc Tran-Gia
On the Unfair Channel Access Phenomenon in Wireless LANs.

Simon Oechsner, Frank Lehrieder, Tobias Hoßfeld, Florian Metzger, Konstantin Pussepp, Dirk Staehle
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Thomas Michaelis, Michael Duelli, Mohit Chamania, Bernhard Lichtinger, Franz Rambach, Stefan Türk

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Frank Lehrieder and Michael Menth
PCN-Based Flow Termination with Multiple Bottleneck Links.
IEEE International Conference on Communications (ICC), Dresden, Germany, June 2009.

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Marking Conversion for Pre-Congestion Notification.
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Tomasz Ciszkowski, Wojciech Mazurczyk, Zbigniew Kotulski, Tobias Hoßfeld, Markus Fiedler and Denis Collange
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Barbara Staehle
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A Generic Algorithm for CAPEX-Aware Multi-Layer Network Design.

Simon Oechsner, Tobias Hoßfeld, Phuoc Tran-Gia
Performance Evaluation of a Distributed Lookup System for a Virtual Database Server.

Thomas Zinner, Kurt Tutschku, Akihiro Nakao, Phuoc Tran-Gia

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Thomas Zinner, Tobias Hoßfeld, Simon Oechsner, Phuoc Tran-Gia

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Andreas Mäder and Dirk Staehle
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Schemes on the System Performance of
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zation over HSDPA-Enabled Multi-cell UMTS
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Tuo Liu, Andreas Mäder, Dirk Staehle,
David Everitt
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in Multi-Cell Environments with Volume-Based
Best-Effort Traffic.

Andreas Mäder and Dirk Staehle and
Christian Gößwein
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UMTS Enhanced Uplink.
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Performance Analysis of the Polling Scheme in
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tions, Moscow, Russia, September 2007.

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Energy Consumption Framework for Wireless
Sensor Networks.
OPNETWORK 2007, Washington D.C., August
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Barbara Emmert, Andreas Binzenhöfer, Daniel
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If you are interested in obtaining one of the mentioned publications please contact:

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Some of the papers and reports are also available as electronic versions via Internet:

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