Department of Communications and Networking

Comnet: Annual Report 2012

Sassan Iraji (Editor)

Comnet: Annual Report 2012

Sassan Iraji (Editor)

DEPARTMENT OF COMMUNICATIONS AND NETWORKING
SCHOOL OF ELECTRICAL ENGINEERING
AALTO UNIVERSITY

ANNUAL REPORT 2012

CONTENTS

INTRODUCTION

COMNET IN BRIEF

The Department of Communications and Networking (Comnet) is a multi-disciplinary unit of research and higher education covering communications and networking technology, networking business, and human aspects of communication and communications technology. In its area, Comnet is the largest unit in Finland. Comnet develops communications, information and teletraffic theory and conducts fundamental and applied experimental research in communications and networking technology. In shaping the Internet technology, Comnet is a significant force internationally.

REVIEW OF 2012

DEPARTMENT HEAD'S REPORT

Year 2012 was characterized by mixed messages from the ICT sector in Finland. Nokia closed down its last mobile phone factory in Salo and reduced its R&D head count significantly. Also some of the operators have been reducing their head counts. At the same time NSN has increased its market share, Ericsson opened new site in Oulu and has been expanding also in Jorvas. Also Huawei opened new R&D center in Helsinki and Samsung announced that it will also set up a site here in Otaniemi. The number of employees in the ICT sector has still been growing, but the growth has shifted from ICT equipment manufacturing to software and services and from large companies to SMEs.

What is alarming from the Finnish economy point of view is that the terms of trade is shrinking. In April 2012, Minister of Economic Affairs, Jyri Häkämies set up the ICT 2015 working group to prepare a strategy to reforming the ICT industry in order to boost the competitiveness of Finland. ICT is sector itself has the potential to grow, but at the same time clever use of ICT can increase the productivity in many other sectors.

Regardless of the economic turmoil, our graduates have been able to find their place in the job market. Our department has been rapidly growing during the last seven years. Now it seems that the time of rapid growth is over and we are reaching a steady state. Although the external research funding did not grow during 2012, we were still able to improve the quality and quantity of our research output. The number of publications grew from 2011 by 10%. We have been increasingly successful in obtaining funding from highly competitive sources such as from the Academy of Finland. The department has also managed to increase its visibility in the international research community: We hosted the SIGCOM 2012 conference.

To better meet the needs of society, our bachelor program in Communications Engineering was completely reformed. The new "Automation and Information Technology" program is more generic focusing on "cyber" – the meeting point of physical world and information technology.

June 12, 2013   Riku Jäntti

ADMINISTRATION

PERSONNEL
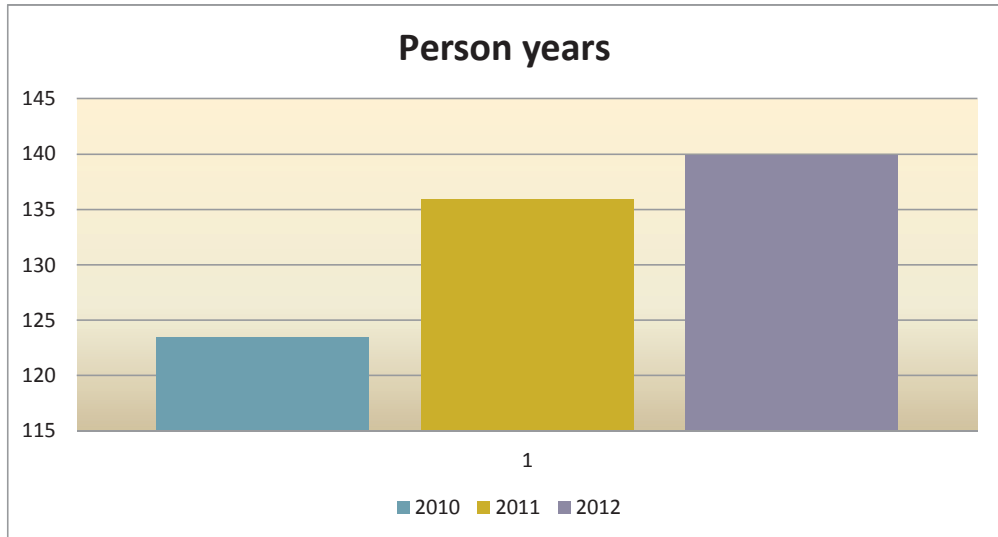
Figure 1: Development of the person years

Table 1: Personnel structure

Year	2010	2011	2012
Professors	9	9	9
Postdocs	8	10	8
Researchers with doctoral degree	5	8	7
Doctoral students	51	62	60
Research assistants	40	34	41
Teaching personnel (incl. part-time)	3,5	4	4
Technical services	3	5	3
Administration	4	4,5	5,5
Total	123,5	136,5	140

PROFESSORS

Riku Jäntti, Head of Department

Patric Östergård, Deputy Head of Department

Samuli Aalto

Heikki Hämmäinen

Jyri Hämäläinen

Raimo Kantola

Jukka Manner

Jörg Ott

Peter Reichl

Olav Tirkkonen

Professors Emeriti

Sven-Gustav Häggman

Kauko Rahko

Jorma Virtamo

IT SERVICES AND MEASUREMENT PLATFORMS

The ICT infrastructure of a department must support a variety of demands set by research and teaching. They create high competence requirements for the support staff and high expectations for the environment compared to a typical office. The needs of research and teaching cannot be met without dedicated and skillful staff that is also able to give good support for normal office computing needs. Having a touch for the "normal" environment is important to keep connection with the reality of ICT organizations and demands set by those environments.

It was seen that department must maintain its high quality day-to-day operations in ICT support to provide the service the research groups need. A good situation in the first half of 2012 turned worse by early 2013 when we had 1½ persons less in support team and new hires were not possible because of Aalto HR policy. School-level workload sharing does not yet provide any help for workload as for many cases deep understanding of research task is needed.

Research activities in the department require in part significant processing power; some require large amounts of memory while some handle large data sets. To provide for these needs, a computational clusters as well as large storage capacity exceeding 90 TB is available for the researchers. Networking research and teaching needs also a large number of routers and other networking hardware as well as testing equipment. These devices are acquired in part directly by projects, partly from the common budget, and some are also received as donations from equipment vendors and network operators.

Besides IT support, the infrastructure of the department also includes measurement platforms for practical experiments. The focus is mostly on wireless communications, but we also need the capability for measuring coaxial cables and optical components. These resources were continuously upgraded also in 2012.

Our platform for RF measurements currently includes a wideband radio channel simulator, spectrum/signal analyzers, vector signal generators, vector analyzers, a time-domain reflectometer, and multi-channel oscilloscopes. This platform supports measurements with bandwidth up to 80 MHz, in frequency range up to 6 GHz. A software-defined radio platform (a cognitive radio system) is available to implement specialized wireless applications, including MIMO algorithms and protocols.

The two new research facilities: a radio communication research laboratory and a test data center have been in very active usage proving their usefulness. Research of modern radio communication systems and equipment needs also possibility of over-the-air measurements without unwanted interference from other radios. Thus, a sufficiently large RF-shielded and RF-anechoic environment is needed. An existing RF-shielded room has been modified for this purpose.

The constructing of another test facility, the test data center, moved forward in late 2011 when the public bidding for an advanced cooling system including heat recovery and re-use was completed. The data center cooling was completed and operational in May 2012. This project is motivated by practical needs for larger test facilities but also as a platform of studying energy efficient data centers in co-operation with the departments of Electrical Engineering and Civil and Structural Engineering.

The RF research facility and data center are connected with 24-pair fiber optic cable making it possible to run computational servers at data center for RF signal generation, reception and analysis. Also there is a similar optical network connection to rooftop providing close proximity to antennas. Data center has also good optical network connectivity to other research and student laboratory spaces within department. Those can be utilized if normal 10Gbit/s campus networking is not enough or dedicated layer-1 connectivity is needed. Comnet has a direct research network connection to FUNET. This has proven valuable in developing co-operation with other research institutes and experimenting with new technologies without endangering the integrity and security of the Aalto campus network.

As the research network increases in size, a large part of it is also used for teaching. A large network provides a real-world like environment for students to develop their skills and apply the knowledge they have acquired on lecture courses. Disciplines within the department are continuously integrated to provide full-scale learning environments for students and researchers.
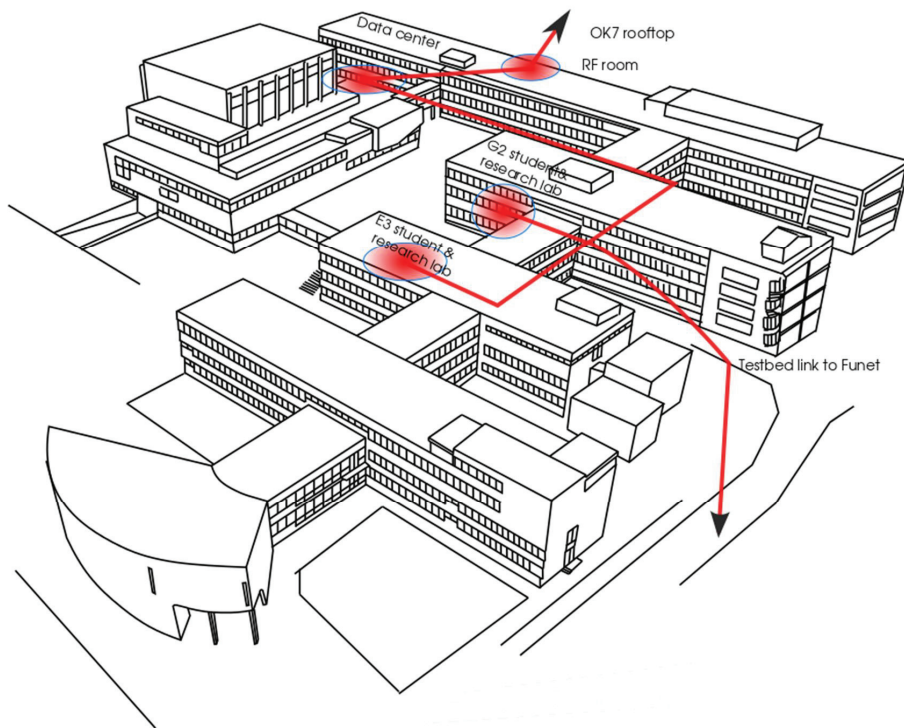
Figure 2: Department research and teaching facilities and fiber optic connections

FINANCIAL ISSUES

COSTS AND SOURCES OF FUNDING

Table 2: Development of expenses 2010-2012 (€)

Expenses	2010	2011	2012
Personnel	5 580 000	6 087 658	6 637 047
Equipment	234 000	395 085	531 178
Rents	550 000	553 689	587 507
Other	910 000	930 711	656 464
Total	7 274 000	7 967 143	8 412 196

Table 3: Development of funding 2010-2012 (€)

Source of funding	2010	2011	2012
Aalto funding	2 495 525	3 667 758	3 565 750
Academy of Finland	525 000	596 180	820 931
Tekes	2 443 000	2 060 502	2 465 909
Finnish companies	751 000	1 973 330	1 951 686
EU funding	401 000	654 016	496 866
Other funding	1 959 000	548 997	418 507
Internal funding (e.g. MIDE)		289 079	308 996
Total	8 574 525	9 789 862	10 028 645

Figure 3: Sources of funding in 2012
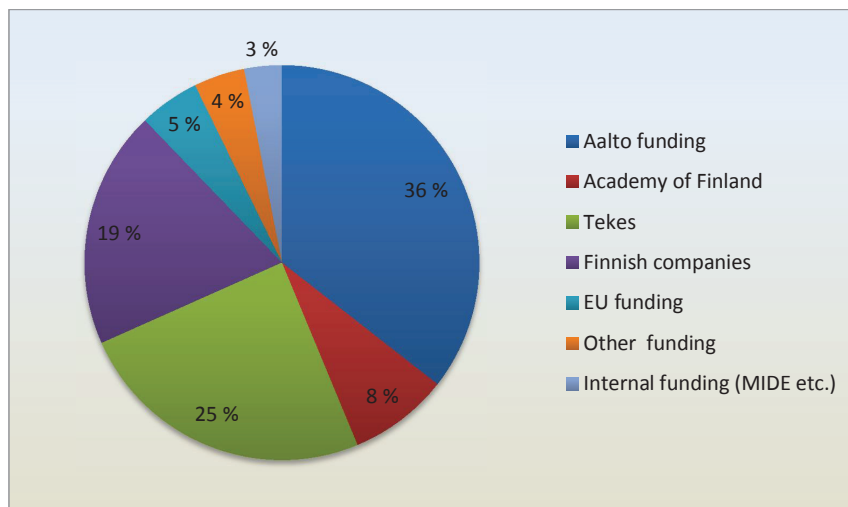
SOCIAL IMPACT

Information and Communications Technology is an important exports industry for Finland. ICT is penetrating deeper and deeper all areas of economics and all types of services in the society. Advancement in the growth of productivity in the economy is largely attributed to the use of ICT. This makes the education we give highly relevant for the Finnish economy. The proportion of communications engineering sector among the 100 largest R&D companies in Finland was 77% in 2010. Even if Nokia's share is removed from the figures, the proportion is still 10%. The recruitment of ICT experts in the industry has grown annually about 2% but the growth has shifted from large companies to small and medium size companies.

The social impact can be measured in terms of competence and new knowledge that is produced and used by the economy. Practical measures are how well our graduates are employed and where and with whom we partner in research, as well as the volume of the collaborative research that we conduct.

The high societal impact was recognized as the strongest feature of Comnet in the Research Assessment Exercise by the international review board in 2009. We were graded 5/5 on this measure by the board.

Figure 4 shows that a number of our graduates are employed by the big ICT companies in Finland. At the same time it shows that the graduates spread out widely into the Finnish economy.

We collaborate with tens of Finnish and some foreign companies and organizations in Research projects some of which are organized as collaborative research and some are directly funded by the companies or organizations. We also have important role in helping governmental organizations to develop their networking infrastructure.

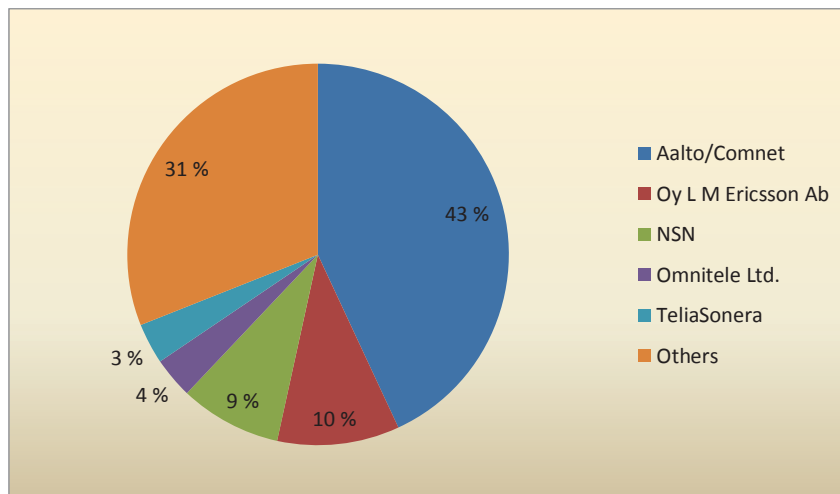In Figure 5 we show the distribution of our research project partners.

Figure 4: Employers of Master´s thesis students in 2012

Legend:
- Universities
- Companies & Industrial partners
- Institutes & Foundations
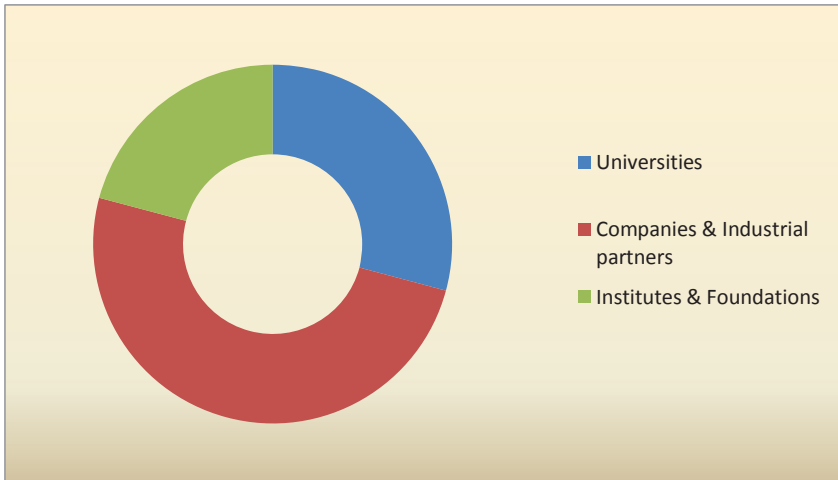
Figure 5: The cooperation – Comnet's partners in projects

A RESEARCH COMMUNITY HIGHLIGHT

ACM SIGCOMM, the flagship annual conference of the ACM Special Interest Group on Data Communication (SIGCOMM) on the applications, technologies, architectures, and protocols for computer communication, which is the most scientifically significant academic conference on communication and networking research, was organized for the first time in Finland on 13–17 August 2012. The conference was hosted by Aalto University and Nokia, with Aalto Comnet being instrumental to its success.

The conference program offered a number of presentations, papers, workshops and demos on new technologies, applications and Internet sector news. Scientific results related to such subjects as cloud services, information networks, wireless networks, server centres and Internet data security were showcased.   ACM SICGOMM is an annual event in which new technologies are often released for the first time. In earlier years, the conference served as the backdrop for the introduction of such novelties as WiFi, or wireless local network technology, and Internet domain name system DNS that translates domain names into IP addresses.

Because of the high esteem it enjoys, the event regularly attracts leading experts from around the world. In 2012, more than 600 participants from academia, businesses and state government attended the main conference, complemented by eight workshops and four tutorials. The entire event was a huge success

For the program and further details see http://conferences.sigcomm.org/sigcomm/2012/
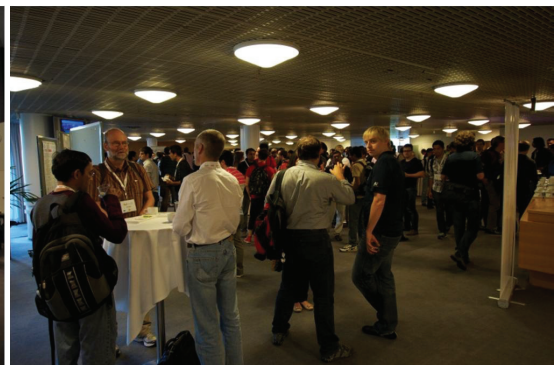
TEACHING

Comnet provides mainly master's and doctoral level education, but also has the responsibility for the courses related to communications and networks (ICT) in the bachelor's level Degree Programme in Communications Engineering for native students. Having started internationalization of the master's level education in 1999, Comnet is still providing a competitive International Master's Programme in Communications, which is attracting talented students from numerous countries.

In 2012, Prof. Olav Tirkkonen was appointed as the Coordinator of the Degree Programme in Communications Engineering, succeeding Prof. Jyri Hämäläinen. The Deputy Head of Department, Prof. Patric Östergård, is responsible for teaching at Comnet. More generally, department-level administration of teaching is becoming clearer through well-defined job descriptions and the introduction of a teachers' track at the university. Indeed, the processes for appointing the first teachers in these new tracks started in 2012. Yet another major organisational change that took place was the implementation of the university-level decision that teaching in the future will be a part of the job description of research personnel on all levels.

TEACHING DEVELOPMENT

The Teaching Evaluation Exercise (TEE), the aim of which was to promote new education culture, took place at Aalto University in 2011. The final external evaluation report was received in August 2011, and provided a fundamental base for the development work that took place in Comnet throughout 2012. TEE coincided with the start of the reform of the bachelor's level curriculum, which will be discussed later.

The annual teaching development day, open to all Comnet employees, took place in August. Various topical themes were handled and particular emphasis was put on the forthcoming reform of the master's level curriculum and its courses (to take place after the reform of the bachelor's level curriculum). The event was well attended and led to various concrete actions.

Recurrent basic issues related to teaching include (course) feedback, teaching and assessment methods, and reduction of the number of courses.

Feedback is an utmost important tool in the development of teaching and courses, and various tools for collecting feedback are available. Unfortunately, privacy and legal issues are making it more and more difficult to implement and utilize practical feedback systems effectively.

There is an urge for developing teaching and assessment methods, and teachers are encouraged to implement other methods than traditional lectures and exams. The university provides support in this process, on all levels up to the extended Aalto University Pedagogical Training Programme. Dr. Markku Liinaharja was among the first participants of that programme.

The dean of the school has emphasized that the number of courses in the school is far above the number in top universities, and she would like to see a change. This issue will be related to the reform of the master's level curriculum, but can and should to some extent be addressed already now. Indeed, the number of

courses in the department is constantly decreasing. This action has numerous gains: the employees' teaching load is decreased and the students are guaranteed to get core courses in the field delivered in well-designed packages.

CURRICULUM DEVELOPMENT

The reform of the bachelor's level curriculum started in 2011 and intensive development work took place in 2012 as the first students will arrive in fall 2013. In the first phase of this reform, the bachelor's level curricula in Aalto will be rebuilt and the number of education areas will be decreased. By 2013, there will be one bachelor's level degree programme in ELEC that contains three education areas, namely:

- Electrical Engineering
- Automation and Information Technology
- Bioinformation Technology

Comnet is one of the departments responsible for the Automation and Information Technology programme. The goal is to make the structure of the bachelor's level curriculum simpler, emphasize quality in learning and teaching, and promote student mobility in Aalto. In the future, the bachelor's level courses will be lectured in Finnish and the master's level courses in English.

INTERNATIONAL PROGRAMMES

Comnet has two international master's programmes. The Master's Programme in Communications Engineering is the oldest international master's level degree programme at Aalto (formerly, TKK) and has been running since 1999, while the International Master's Programme in Communications Ecosystem, launched in fall 2010, is one of the newest. The number of applicants (and enrolments) to these degree programmes have, with small fluctuations, always been on a high level and the students are very good.

International graduations constitute a significant portion of the total number of graduations in Comnet, and many research assistants and doctoral students in Comnet come from the international master's programmes. Currently the intake of native and international students is almost equal, while the number of international applicants to master's level programmes annually clearly surpasses the number of native applicants to the full 5-year degree programme. There is a constant increase in the proportion of international graduates at the master's level.

The department has also been active in launching dual-degree programmes with international partner universities of Aalto. The following dual-degree programmes are currently active:

- Dual degree in networks and services, with Telecom & Management SudParis, France
- Dual degree in wireless communications, with Royal Institute of Technology (KTH), Sweden
- Dual degree in communications engineering, with networking or radio focus with Instituto Superior Técnico (IST), Portugal
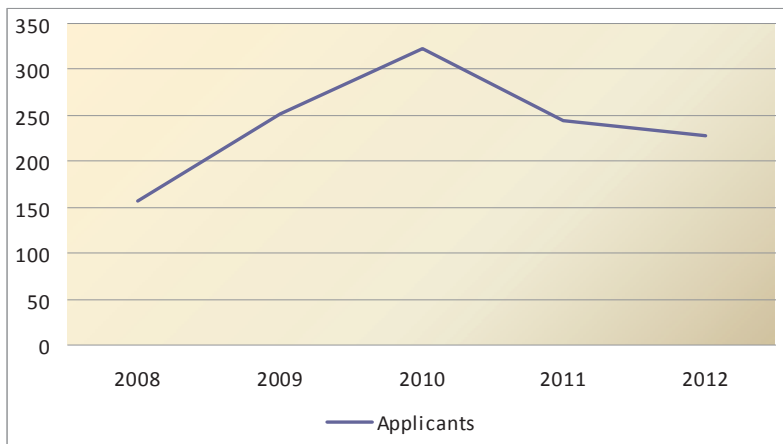
Figure 6: The number of first-choice applicants into International Master´s Programmes on Communication Engineering & Communications Ecosystem
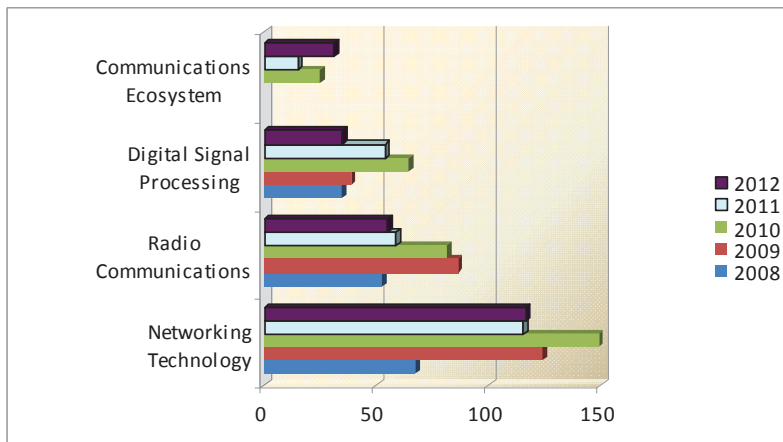
Figure 7: The number of first-choice applicants into international programmes per major

COURSES IN 2012

S-38.1105   Principles in Communication Engineering (Tietoliikennetekniikan perusteet)
S-38.1146   Introduction to Performance Analysis
S-38.1203   Networking Technology, project course (Tietoverkkotekniikan projektityö)
S-38.2121   Routing in Communication Networks
S-38.2131   Networking Technology, laboratory course A (Tietoverkkotekniikan laboratoriokurssi A)
S-38.2188   Communication Networks
S-38.3001   Telecommunications Forum P
S-38.3041   Operator Business P

S-38.3042	Seminar on Networking Business P
S-38.3046	Value Network Design for Internet
S-38.3061	Communications Ecosystem Analysis P
S-38.3062	Modelling Human Behaviour P
S-38.3115	Signalling Protocols
S-38.3120	Seminar on Communications and Networking
S-38.3133	Networking Technology, laboratory course B (Tietoverkkotekniikan laboratoriokurssi B)
S-38.3134	Networking Technology, laboratory course C (Tietoverkkotekniikan laboratoriokurssi C)
S-38.3138	Networking Technology, special assignment (Tietoverkkotekniikan erikoistyö)
S-38.3141	Teletraffic Theory P
S-38.3143	Queueing Theory P
S-38.3148	Simulation of Data Networks
S-38.3152	Networked Multimedia Protocols and Services (NMPS)
S-38.3153	Security of Communication Protocols (Tietoliikenteen tietoturva)
S-38.3156	Delay-tolerant Networking (DTN)
S-38.3159	Protocol Design P
S-38.3165	Switching Technology
S-38.3184	Network Traffic Measurements and Analysis P
S-38.3191	Network Service Provisioning P
S-38.3194	Wireless Networks
S-38.3195	Exercise Course for Network Service Provisioning P (Verkkopalvelujen tuotannon harjoituskurssi L)
S-38.3205	Individual Course on Networking Technology (Tietoverkkotekniikan yksilöllinen kurssi)
S-38.3215	Special Course on Networking Technology P (Tietoverkkotekniikan erikoiskurssi L)
S-38.3310	Thesis Seminar on Networking Technology (Tietoverkkotekniikan diplomityöseminaari)
S-38.3455	Challenged Networks P
S-38.3600	UNIX Application Programming
S-38.3610	Network Programming
S-38.4043	Postgraduate Seminar in Network Economics P
S-38.4050	Postgraduate Seminar in Communications and Networking Technology P
S-72.1010	Orientation Course for Studies in Communications Engineering (Johdatus tietoliikennetekniikan opiskeluun)
S-72.1110	Signals and Systems (Signaalit ja järjestelmät)
S-72.1110	Signals and Systems (Summer course 2012) (Signaalit ja järjestelmät)
S-72.1130	Telecommunication Systems
S-72.1140	Transmission Methods in Communication Systems
S-72.2205	Digital Transmission Methods
S-72.2211	Mobile Communication Systems and Services
S-72.2311	Laboratory Course in Communications Engineering 1
S-72.2410	Information Theory P
S-72.2510	User-Oriented Design of Telecommunications Services
S-72.3110	Individual Studies in Communications P (Yksilöllinen tietoliikennetekniikan kurssi L)
S-72.3120	Special Project in Communications
S-72.3216	Radio Communication Systems I
S-72.3226	Radio Communication Systems II
S-72.3235	Network Access P
S-72.3251	Laboratory Course in Communications Engineering 2
S-72.3260	Radio Resource Management Methods P
S-72.3281	Advanced Transmission Methods P
S-72.3295	Broadcasting and Distribution
S-72.3310	Communication Transmission Lines
S-72.3410	Coding Methods P
S-72.3510	Product Development of Telecommunication Systems

DEGREES IN 2012

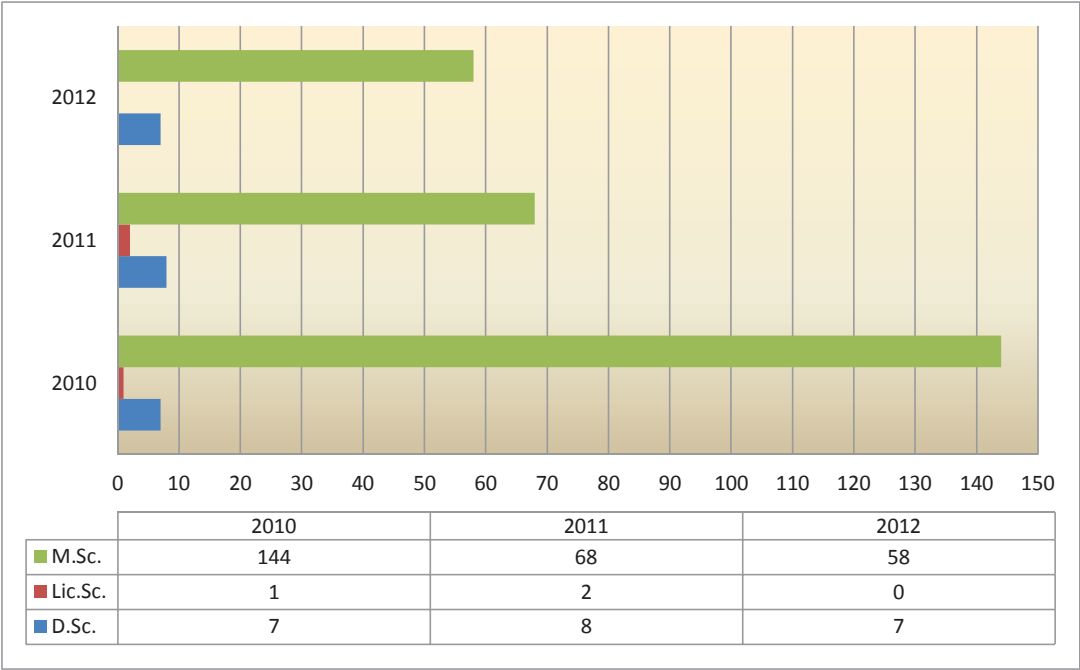|	2010	2011	2012
M.Sc.	144	68	58
Lic.Sc.	1	2	0
D.Sc.	7	8	7

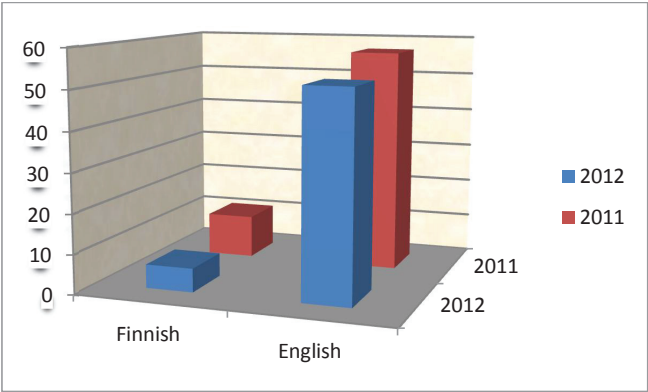**Figure 8: Number of degrees at Comnet in 2010-2012**

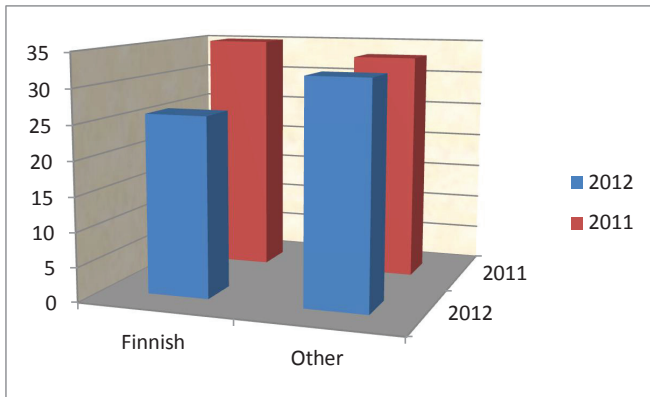**Figure 9: Languages of Master's theses 2011-2012**

Figure 10: Finnish vs. international M.Sc. graduates 2011-2012

RESEARCH

INTRODUCTION (TO RESEARCH)

Comnet carries out comprehensive research in the areas of communications and networking, two areas that have proven inseparable when tackling information exchange at any scale. Its expertise encompasses virtually all aspects of today's and future communication systems and networks.

- The *Communication* part of Comnet addresses research at the "lower layers" of communication systems, enabling and enhancing (primarily wireless) information exchange.

- The *Networking* part of Comnet focuses on creating (global) networks, embracing wireless and core infrastructure networks, and offering suitable communication services and applications on top to satisfy user demands ("higher layers").

These two parts represent the research theme of *Future Networking Paradigms*: architecting future communications and interactions from the transmission of individual bits to networked user applications spanning the globe (and even extending into space). Three *cross-cutting themes* span both parts and provide the fundamental tools to understand and develop these fields:

- *Network economics* captures needs/demands, behavior, and economics of users, operators, and other players in the marketplace.

- *Performance analysis and modeling* investigates characteristics of communications networks by means of traffic measurements and mathematical modeling and develops fundamental algorithms for

- *Information and communications theory:* Communications theory is the bridge between information theory and communications engineering. While information theory provides fundamental capacity limits for the link capacity, it does not provide guidelines on how these capacity bounds could be approached through using real systems that imposes various additional constraints and impairments.

With 9 professors and these complementary research fields, Comnet is well-positioned to approach research in communication and networking in a *holistic fashion*.

The fundamental research themes pursued by Comnet and the specific focus areas described above provide the foundation for strategic research missions following *grand research challenges*. Comnet has identified three such grand challenges we are pursuing in our research as long-term visions:

- *Carbon-neutral networking*: Connecting the remaining global users—2 billion to mobile networks and 5 billion to the Internet—creates, among many others, an enormous challenge in energy efficiency to be able to power wired and wireless network infrastructure, the backend and data center infrastructure, network access equipment, and all the end user devices. We believe that only holistic rethinking of network, protocol, and system architectures can enable this expansion in a carbon-neutral way.

- *Instant wireless Internet*: Internet access anytime, anywhere via wireless networks is becoming increasingly commonplace—provided that users are willing to put up with waiting for their desired content or their interactions to complete, leading to mostly inadequate *Quality of Experience*.

We pursue a comprehensive approach to future wireless access from the radio technologies to network operation to applications to reduce waiting time to delays below human perception.

- *Scaling the Internet to a thousand devices per user*: Not just the number of Internet users is growing, similarly is the number of their personal devices (for leisure, business, convenience, and medicine) and the number of shared devices penetrating private and public life.

  This will ultimately shift the scale of networking by several orders of magnitude as these devices want to be networked, accessed, managed, and controlled.

Yet another rising theme that will affect our research in the coming years is *cyber and network security*.

ADVANCED RADIO SYSTEMS PROGRAM

VISION AND MISSION

Future wireless systems will allow people to communicate with anyone, anywhere, and at any time using a range of devises and services. Wireless communication will enable self-configuring intelligent home and office systems that can interact with each other and with the Internet. Also widespread wireless sensor and actuator networks are important parts of the development towards all-wireless future and Internet of Things. Our general mission is to carry out world-class research and technology development in wireless communication technologies. Our efforts range from basic research in communications theory to applied research on practical engineering problems.

RESEARCH CHALLENGES

There is a wide span of technical challenges that we must overcome in order to make our vision possible. On our way to future we focus on the following research areas:

- **Flexible spectrum use.** Spectrum sharing is seen as one potential method to improve the efficiency of the spectrum utilization. Many regulators across the world are working towards opening TV bands for secondary spectrum access. The most potential applications of that band are M2M, rural broadband and wireless local area networking. The cellular industry is interested in co-primary sharing and licensed shard access. In secondary sharing case, the incumbent system needs to be protected from the aggregate interference caused by the secondary users. In co-primary case, both systems need to be protected against harmful interference. Interference modeling and control is essential in both cases. Our research focuses on modeling the interference between the systems sharing the spectrum and developing methods for interference control and co-existence. Especially, we focus on impact of very dense deployments and adjacent channel interference effects due to transmission chain nonlinearities.
- **Wireless broadband and system optimization.** The mobile system architecture will undergo a paradigm shift from a centralized, controlled and pre-planned hierarchical system towards self-organizing, self-optimizing ad hoc operation. The driver for this development is the drastically increasing number of cells resulting from the ever increasing capacity need due to wide scale deployment of mobile Internet. Introduction of relays and small cells, such as pico and femto cells, will lead to challenging interference problems that can be tackled by local interference coordination and system optimization. Another important research challenge in future wireless broadband systems is the energy consumption. The increasing data rates and operation bandwidths are pushing up the energy needs in the network. Yet, the energy consumption can be decreased by proper system design, optimization of network operations and dynamic control of cell availability.
- **Wireless sensor systems.** We believe that wireless sensor networks are application dependent and their protocols should be jointly developed with the sensor information processing schemes. Hence, we focus on co-design of wireless sensor networking protocols, sensor data signal processing methods, data fusion methods, and in case of control applications also the control algorithms. That is, our focus is on wireless sensor systems -- not just networking. In many real-life sensing and control applications accurate timing of the sampling and control actions is essential. Also the reliability of the sensor system is a critical factor. Typically, there are trade-offs between energy consumption, accurate timing, reliability, and application performance (such as estimation accuracy, control performance etc). Hence we seek to find the right balance for each application.

We focus on time and mission critical applications such as wireless automation, structural health and conditioning monitoring and situation awareness.

- **Basic research.** According to our mission we carry out both applied and basic research. The former is executed in subcontracting projects and partly in TEKES funded projects. The latter is carried out in projects funded by the Academy of Finland and TEKES, and as internal strategic research that is conducted by professors and experienced researchers.

MOST IMPORTANT PROJECTS

End-to-end Cognitive Radio Tesbed (EECRT): This is a TEKES project jointly with Nokia, Fairspectrum, DNA and Ministry of traffic and Communications. The goal of the project is to create a living lab cognitive testbed in Otaniemi, operating on TV white space frequencies, and offering end-to-end cognitive connectivity for test persons. Building and experimenting with the testbed will create new scientific and engineering understanding on the interplay of the technical and economic boundary constraints on the design and regulation of future cognitive radio systems operating on new bands, primarily in the present TV-spectrum. The targeted understanding is of value for regulating authorities, operators, infrastructure vendors, device and hardware manufacturers, with all of these players getting a better understanding of their possible role in a cognitive radio ecosystem. The project is led by Prof. Tirkkonen. Other participants include Prof. Riku Jäntti, Prof. Jukka Manner, and Prof. Heikki Hämmäinen.

Heterogeneous and dynamic wireless access networks (HEWINETS): This is a TEKES project together with Ericsson and Cassidian. The project focuses on radio resource management, interference coordination, and performance analysis of heterogeneous wireless networks consisted of macro, pico, and femtocells as well as nomadic relays. The work is divided into three work packages: WP1 Moving and fixed relays (Prof. Hämäläinen and Prof. Aalto), WP2 Dynamic TDD (Prof. Jäntti and Prof. Tirkkonen), and WP3 Heterogeneous network interference coordination (Prof. Tirkkonen and Prof. Aalto).

Home Base Station: An Emerging Network Paradigm (HOMESNET): This project is part of European CELTIC HOMESNET consortium (15 organizations) and funded in Finland by TEKES, Nokia Siemens Networks and European Communications Engineering. Finnish consortium is led by Aalto University (Professor Jyri Hämäläinen) and second Finnish research organization is VTT. Project focuses on femto base station systems that are characterized by very low costs, plug-and-play installation, low transmission power, use of existing fixed broadband (typically, digital subscriber lines) backhaul and limits access to a closed user group, such as, household members. Mass adoption HBSs will strongly influence the local area evolution.

Energy and cost efficiency for wireless access (ECEWA): This strategic TEKES Sino-Finnish collaboration project develops new cost and energy efficient solutions to future radio access networks. The use of emerging features such as femto cells, relays, and coordinated multipoint will require changes to the ways radio access networks are planned. Energy consumption of the network equipment has become increasingly important. The industry is looking ways to reduce the carbon dioxide emissions by improving the energy efficiency of the base station equipment. Energy efficiency of the networks will also impact on the way networks should be planned and operated. Saving energy also saves costs. Hence it is natural to study the cost and energy efficiency jointly. The Finnish partners of the project are Aalto University, Tampere University of Technology, Ericsson, Efore, and European Communications. The project is led by Aalto University (Professor Riku Jäntti).

Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society (METIS): This is a large integrating project funded by the European Union FP7. Participants are from major European mobile network infrastructure and user equipment vendors, operators and universities. The main objective of METIS is to lay the foundation for a European consensus on the future global mobile and wireless fifth generation communications system. METIS will provide valuable and timely contributions to pre-standardization and regulation processes, and ensure European leadership in mobile and wireless communications. METIS will provide fundamentally new solutions which fit the needs beyond 2020. Comnet role in METIS is to develop methods for flexible spectrum access, coexistence and robustness in multi-band and shared spectrum environments. Especially, we focus on control of aggregate inter-system interference, dynamic spectrum sharing, and spectrum access concepts for device-to-device (D2D) operation.

Spectrum Management for Future Wireless Systems (SMAS): The objective of this three-year project, funded by Academy of Finland, is threefold. First aim is to produce solid world class results to serve as a fundament of a theory of spectrum sharing. In particular, theoretical limits for the efficiency of spectrum utilization are studied. Second objective is to design general rules for spectrum sharing based on incentives of individual systems and to develop intelligent decision making methods for spectrum sharing. The third objective is to numerically determine the capacity of a network utilizing spectrum sharing. For this purpose, properties of the communication channel are modeled on the network level. The project partners are Aalto University, University of Turku and VTT. The project is led by Aalto University.

Networks 2020 (NETS2020): This project started in 2009 and is funded by TEKES, Nokia, Ericsson, Nokia Siemens Networks, Nethawk and Elektrobit. Research organizations are Aalto University (Professors Olav Tirkkonen and Jyri Hämäläinen) and Centre for Wireless Communications (University of Oulu). The research focus is in the future development and evolution of cellular communication systems including IMT-Advanced (IMT-A), its further evolution and its integration with other communication and data networks. The main emphasis is on evolving wireless network topologies, like relay based connections and femtocells. One of the key goals is to develop distributed algorithms performing automated network management tasks. The research is carried out in close cooperation with the best relevant universities and research institutes in China.

Distributed Resource Allocation and Interference Management for Dense Heterogeneous Wireless Networks: This is a joint project with Comnet and University of California and it is funded by Academy of Finland and National Science Foundation. The international research team will address critical deployment issues that arise in Heterogeneous Networks (HetNet) by focusing on the development of distributed and effective mechanisms for resource allocation and interference management in order to facilitate low complexity and decentralized network operation in heterogeneous environments. The project results will facilitate novel technological directions that transcend multiple networks and multiple network layers. In particular, the results will assist the near term deployment of wireless HetNet, including the broad use of femtocell deployment.

Feedback Optimization for Network-level Communication Strategies (FONCS): This is a project at Aalto funded by the Academy of Finland. In the project, optimization of network-level feedback for wireless communication is addressed. The main goals are to construct a closed form analysis framework for optimizing feedback use in the physical (spatial MIMO and power control) and MAC (Channel Quality and Hybrid ARQ) layers. The framework is applied to design efficient and near-optimal feedback schemes for network-level transmission strategies. Practical and implementable feedback designs with direct relevance to the design of future spectrum-efficient wireless communication systems will be constructed. In

particular, optimum feedback strategies for multiuser-MIMO (MU-MIMO), Collaborative Multipoint Transmission (CoMP) and Interference Alignment (IA) will be investigated. All of these strategies are particularly vulnerable to non-idealities in feedback, especially in the spatial domain

Robust and Secure Cognitive Radio Networks (Rosecorn): This is a project funded by the Academy of Finland. The main topic investigated is coexistence of secondary users in cognitive radio networks. Secondary users may be associated with different cognitive networks and seek to operate in the same frequency bands. Effective Radio Resource Management as well as security and privacy issues for cognitive networks are addressed. The project partners in Finland are Aalto University and the University of Oulu, in collaboration with Northwestern University and University of Maryland in the context of the Wireless Finland-US collaboration program.

Reliable and Real-Time Wireless Automation: This is a TEKES project jointly with the Department of Automation and Systems Technology, VTT, University of Vaasa, Konecranes, Metso Automaton, Wapice, Mervento, Vacon, and TK-Engineering. The RIWA project deals with reliable and real-time wireless communication and control systems for industrial wireless automation applications. Applying wireless technologies in industry enables flexible and cost effective automation systems. The primary goal of the project is to develop robust hardware and software components and design tools for industrial applications. The emphasis is on industrial pilots, where the research results of the projects are tested and evaluated. The pilots ensure both a tight cooperation between the research institutes and the industry partners and a guideline for researching and solving the right issues.

Interference Management for Wireless Networks beyond Present Horizon (IMANET): The project aims at providing relevant scientific information on general interference management between network nodes that have limited capability to exchange control information with each other. The focus in this project is to optimize the use of radio resources for a multi-antenna cellular system with varying level of coordination between the network elements. In addition, principles and methods for statistical interference management of future heterogeneous networks will be developed, analyzed and tested. Theoretical limits and guidelines for coordinated beamforming and resource allocation across different cells, relays, antennas, frequency, and time dimensions with different system optimization objectives are provided. Project is joint effort between Centre for Wireless Communications (Oulu) and Aalto University.

OTHER PROJECTS

- Quantitative Assessment of Secondary Spectrum Access (QUASAR), EU FP7, 2010-2012
- Wireless Indoor Situation Modeling II (WISM-II), TEKES project, 2010-2012
- TIEVA-II, Finnish Defense Forces, 2010-2012
- LTE Investigations in MIMO and Other topics (LIMO), Renesas Mobile Europe
- Machine-to-machine Self-organizing Networks, Renesas Mobile Europe
- InterMediate Cognitive Systems (IMCOS), Nokia
- Mobile Media Service Laboratory / Cognitive Connectivity, EIT
- ICT&E, Aalto ELEC energy efficiency program, 2012-2013

PEOPLE

Professors:

D.Sc. Riku Jäntti

D.Sc. Olav Tirkkonen

D.Sc. Jyri Hämäläinen

Senior Researcher:

PhD Natalia Ermolova (Communication theory)

Visiting scholar:

PhD Ülo Parts (Quantum communication)

Postdocs:

D.Sc. Edward Mutafungwa (Public Safety Communication, Femtocells)

D.Sc Alexis Dowhuszko (Wireless Communications)

D.Sc. Sassan Iraji (Wireless communications)

D.Sc. Kalle Ruttik (Flexible spectrum use, testbed development)

Ph.D. Jussi Poikonen (Memristors, cognitive radio)

Ph.D. Prathapasinghe Dharmawansa (Communication theory)

Ph.D. Minhua Ding (Communication theory)

Researchers:

M.Sc Konstantinos Koufos (Flexible spectrum use)

M.Sc Jussi Kerttula (Flexible spectrum use)

M.Sc. Byene Yihenew (Flexible spectrum use)

M.Sc. Byunqjin Cho (Flexible spectrum use)

M.Sc Mirza Alam (Energy and cost efficiency)

M.Sc. Aftab Hossain (Network energy efficiency)

M.Sc. Aamir Mahmood (Wireless sensor systems)

M.Sc. Zheng Yu (Wireless sensor systems)

M.Sc. Aleksi Marttinen (Public safety and military communications)

M.Sc. Mika Nupponen (Field measurements)

M.Sc. Zhong Zheng (GETA, Small cells, performance analysis)

M.Sc. Turo Halinen (Cooperative communication and small cells)

M.Sc. Beneyam Berehanu (Cooperative communication)

M.Sc. Maliha Jada (Network energy efficiency)

M.Sc. Osman Yilmaz (GETA, Self-organizing networks)

M. Sc. Inam Ullah (decode and forward relays)

M. Sc. Furqan Ahmed (Self-organization)

M. Sc. Shahrukh Bin Ali (LTE-A Radio Resource Management)

M. Sc. Parth Amin (Inter-Cell Interference Coordination, Self-organization)

M.Sc. Felipe Del Carpio Vega (Inter-Cell Interference Coordination)

M. Sc. Sergio Lembo (Inter-Cell Interference Coordination, feedback optimization)

M. Sc. Helka-Liina Määttänen (multi-user MIMO)

M. Sc. Udesh Oruthota (IQ-imbalance mitigation)

M. Sc. Renaud-Alexandre Pitaval (MIMO precoding)

M. Sc. Athul Prasad (Heterogeneous Network mobility)

M. Sc Lu Wei (Multivariate analysis of communications)

M. Sc Chia-Hao Yu (IMT-A RRM & self-organization)

M. Sc. Liang Zhou (Cognitive radio)

Alumni:

D.Sc. Iiro Jantunen (University of Eastern Finland)

D.Sc. Helka-Liina Määttänen (Renesas Mobile Europe)

D.Sc. Chia-Hao Yu (MediaTek Inc.)

D.Sc. Jari Nieminen (Nokia)

NETWORKING RESEARCH

Professors: Raimo Kantola, Jukka Manner, and Jörg Ott

The area is addressed by three collaborating groups led by each of the professors. The aim is to do world class research into new networking protocols, architectures and solutions arising from broader deployment of wireless technologies, new types of applications delivered over the Internet, the scalability and energy consumption problems and other challenge that are present in the current Internet and the technology push for scaling up the transmission speeds in the Internet.

The Networking Technology Group led by Professor Raimo Kantola has concentrated on routing, switching and measurements and trust management for the Internet. A particular effort has gone into developing a new Internet architecture based on the idea of raising trust to the position of a cornerstone of the architecture. This work has two areas: (1) protecting the interests of the receiver on the level of the basic interaction between communicating parties and (2) collecting evidence of misbehavior and using that to encourage cooperative behavior of the hosts. The first requirement is implemented by Customer Edge Switching and the second by Trust management. Put together we are trying to bring the kinds of methods people and other living organisms use to promote and maintain cooperation in a community to the Internet environment. We present our ongoing work on the architecture on the site: www.re2ee.org.

The Group for Networking Protocols, Software and Architectures led by Professor Jörg Ott pursues the goal of investigating short-term and long-term architectural changes to networked systems and protocols with a focus on transport and application layer aspects. The current two core research themes are: 1) Delay-tolerant networking -inspired architectures and protocols to enable and sustain communications in challenged networking environments and their implications for future Internet design. Instances of such architectures are information-centric networking and mobile opportunistic networking, 2) Adaptive real-time communications for fixed and wireless content distribution and conversational multimedia. Essential elements in research besides modeling and simulations are prototyping applications and experimentation in test beds and the real world. Both themes rely on growing network measurement efforts to understand the evolving Internet traffic patterns, understand deployment options for future protocols, infer (trends in) user demand and user behavior, assess user-perceived quality of experience, and derive mechanisms for improving performance.

The Networking and Transport Group of Jukka Manner has developed a number of technologies to enhance data transport and network connectivity of end hosts, both mobile and fixed. The group has five research themes: 1) evolution of data transport protocols and algorithms, and multipath and multilink data transfer for both fixed and mobile nodes, 2) energy-efficiency of data centers and wireless communications with a specific focus on extending the lifetime of smart phones, 3) Ethernet-based networking extending the IETF-driven TRILL technology (also called Routing Bridges), 4) network and cyber security with a focus on Ethernet-based networks and industrial systems and 5) a new kind of messaging platform for governmental use cases that can connect together old analog communication systems from the 80's with modern digital high-speed and wireless technologies and provide personal, group and geographical message delivery, a kind of DTN-like system. The key test bed and experimental platform is Netradar, available on all major smart phones and the Internet at www.netradar.org .

RESEARCH CHALLENGES

Wireless

Modeling Human-Based Networking and Communications

The is aim to further networking in which humans and their mobile devices constitute the network infrastructure – augmenting, substituting, or bypassing mobile operator infrastructure – to provide additional communication facilities. The key challenges are in human behavior: understanding human mobility as well as patterns for sharing/accessing content and human interactions – and their interrelations. These are needed to devise suitable mobility and traffic models to for evaluating (not just) DTN protocols, but also the overall performance of wireless applications.

DTN Routing, Transport, and Application Protocol Design

Delay-tolerant networks may feature a number of limitations and require rethinking protocols at all layers. Most notably, such limitations include large communication latencies and intermittent or non-existing instant end-to-end paths. While quite a few applications could, in principle, still operate in such environments, their protocol design needs to change: from avoiding frequent end-to-end interactions to novel schemes for pacing traffic (congestion control) and achieving reliability to new security concepts. Routing, transport, and application functionality may require closer interaction, yet maintaining independence as much as possible.

One goal of our work is supporting networking for mobile users without wireless networking infrastructure and in cases when infrastructure access is intermittent or otherwise unreliable. In particular, this means exchanging and sharing information directly between users and their devices, without the costly detour via network infrastructure and cloud services: *opportunistic networking and computing*. We investigate the theoretical foundations, explore novel mobile service and programming paradigms, and build systems for real-world deployment. One key feature of localizing communication is that avoiding relying on infrastructure prevents authorities and service providers from censoring and profiling/tracking users.

Protocols for Lossy Environments

The goal is to develop protocols, algorithms and methods that support communication in challenged environments. These environments include the ISM band where systems and networks are built and operated without proper planning and interference control, environments for sensor networks and special radio networks like PLM. The aim is to create co-operative cross layer mechanisms that suit for particular protocol stacks and to communication middleware.

Power Consumption

Mobile network and device vendors like to advocate constantly higher speeds and the network operators seek to enhance their coverage of the country. Thus, today the consumer is in theory living great times. However, the promises the industry is making are mostly available to e.g. laptop users and devices with high processing power, and large batteries. People carrying smart phones, the most basic and common user of mobile networks, are having problems because the new higher speed offers also consume much more energy than the previous generation. New battery technologies, and e.g. fuel cells, do not necessarily help because higher energy consumption also produces heat, which is undesirable in mobile devices being held

in peoples' hands. Thus, one research area within Comnet is the design and implementation of more power efficient mobile communication, with an emphasis on the network protocols and middleware. A related ongoing topic is the energy efficiency of the other end of the data transport connection, the data centers. With the huge increase of digital services and increasing network traffic, the energy consumption of data centers and in particular the cooling and heat reuse technologies have become very interesting topics.

Core Networks

Research is focused on measuring and analyzing the use of networks, developing and analyzing mechanisms and architectures that are needed in networks for addressing, identification, routing, information delivery.

Ethernet Networking

The background of our work is the ongoing move from synchronous bit stream oriented transmission using PDH and SDH to asynchronous packet based transport in worldwide public networks. This move is taking place due to the tremendous growth of data traffic that overtook voice traffic in volumes soon after year 2000 and due to the lower cost of asynchronous transport. Ethernet is also a popular technology to connect thousands of servers within data centers.

The aims are 1) to develop Carrier Grade Ethernet technology for the use of Ethernet in public services packet networks and 2) to enhance the classical Ethernet technology for broader use in the Internet. Further aims are investigate the security (or lack thereof) of Ethernet and enhance Ethernetworking technology for the purpose of solving the scalability and other problems that are present in the current Internet. Achieving this aim would lead to gradual replacement of IP as the key networking protocol in the Internet.

The footprint of Ethernet is growing. A new technology is 100Gbit/s Ethernet and the use scenarios that emerge with the growing footprint. One new way to leverage Ethernet into new use cases is link aggregation. This is pursued for both access and more generic use cases.

Network Measurements Studies

Network measurements pursue the goals of understanding the characteristics and usage of both existing and future networks and evaluating performance starting from network devices and ending with large-scale networks under different conditions. The challenge in studying existing network traffic is the delicate balance between needs of in-depth information and user's right to privacy. Careful anonymization and strict security procedures are the keys in protecting user's data while keeping information useful for research. Evaluating network device performance is a basic building block for reliable, high-performance networks. Finding scalability related problems in equipment and protocols require full-scale testing either in simulated or in a real network. Scalability of measurement infrastructure is ever important with the increase of link speeds.   Finally, infrastructure-based measurements at certain points in the topology yield only limited insight into network operation and performance as experience by the users. Those need to be complemented by large scale measurements based upon end user equipment (for fixed and wireless/mobile networks).

A new service launched by Comnet is called Netradar. It is a crowd sourced mobile network measurement platform with smart phone apps available for Android, iOS, Windows Phone, Meego and Symbian. The

system is distributed in the cloud with presence in EU, US and Asia. Various statistics and maps are presented at www.netradar.org .

Routing Algorithms

The aim is to develop algorithms for computing data structures (e.g. trees) that facilitate routing of packets with minimal cost, so that given constraints are satisfied. We seek to combine basic research on graph theory, algorithms, and computational complexity with practical heuristics and realistic requirements coming from the industry.

End-to-End Transport

Adaptive Real-Time Transport

The communication characteristics of the Internet and wireless (cellular) networks vary over time, calling for adaptive transport and application protocols. As loss patterns and congestion signals vary, different sensing and adaptation mechanisms are needed in protocol design for the respective environments, posing particular challenges as mixed networks become commonplace and (mobile) endpoints can no longer make assumptions about their operating environment. We investigate error and rate control mechanisms for both streaming and conversational multimedia, with a focus on leveraging and enhancing the Real-time Transport Protocol (RTP). This is particularly important with multimedia communication endpoints becoming web browser-based (real-time communication in web browsers, RTCweb), a recent development in the Internet driven by the industry that will lead to an ever faster growth of multimedia traffic.

Large-Scale Multimedia Content Distribution

Moving entertainment services such as TV to the Internet (IPTV) requires the capability of large-scale content distribution – which can be either achieved by ISP-supported native IP multicast or by means of peer-to-peer overlays. Both are conceptually similar one-to-many multicast dissemination of real-time streams, requiring mechanisms for error repair and overall quality monitoring, among others. We investigate network architectures to scale to millions of receivers by applying RTP in these environments and enhancing its feedback, monitoring, and adaptive repair capabilities as needed. We also study the suitability of multi-source and multi-path communication for RTP-based media.

Multipath transport

Until very recently, most of the work on Internet transport has focused on optimizing a single path between the sender and receiver. With the increase in multi-interface mobile devices and a wealth of competing technologies to connect almost any end host and access network, we need to look much more into data transport happening in parallel over multiple paths and links. Our network research has taken a number of focus points in multipath transport, for example, efficient connectivity for multi-interface mobile devices, multipath real-time streaming, multipath TCP, and new ways to provide affordable multihoming to small and medium businesses. We have already a number of prototypes on these topics, and focus on this area is increasing year to year.

Flow and congestion control algorithms

A topic very much related to the development of the networked world is how well the transport protocols do and their algorithms work with mobile users and their devices. For example, the power consumption of

a smart phone is tied to the time the radio equipment is on, not the amount of bytes transmitted. Thus, the faster we can transmit the data, the more we save energy on the mobile device. Moreover, research so far has presented a number of competing congestion control algorithms for communication over wireless links, but there is little work to make e.g. TCP-based transfer adaptive on finer scale and potentially change the used algorithms after each ACK-packet. The overall goal is to design the ultimate congestion and flow control algorithms for mobile devices typically sending small flows over a multitude of wireless technologies.

Networking Applications

Customer Edge Networking

We have studied and prototyped the principle of best effort communication where the network does its best not only for the sender like in the classical Internet but also for the receiver. Customer edge switching puts powerful policy controlled tools into the hands of the receiver and its edge device to block all unwanted traffic. A multi-homed edge tunnels all traffic through the core network to the other edge where the inbound node can enforce its requirements on the service flow admission. We can view these edge nodes as collaborative firewalls. Customer networks can place their nodes into private address realms. The edge node offers also legacy interworking for unchanged Internet hosts. On a higher networking layer, we are modeling the concept of Internet wide trust. During 2012 we completed several master theses on Customer Edge Switching and pulled all the results together into one integrated prototype/demonstrator that we have made available to the research community on the site: re2ee.org.

Content-Based Networking

A significant portion of Internet traffic is about publishing, sharing and accessing – public and private – content. The present host-centric model of the Internet insufficiently reflects this trend, and caches and overlay architectures have been designed to improve content distribution. We investigate elements of a future content-based (or: information-centric) networking architecture, in which any router may offer generic application support functions such as caching. We have devised optimizations at the edges for content access and sharing (opportunistic cooperation between mobile nodes) and are investigating applying similar concepts to elements of the core network.

Generic Messaging

Governmental, including military, communications typically employ hardware and software that has been designed and deployed for a particular purpose. Often this hardware is rather old, and outdated in terms the current state of the art on communications. Yet, the government organizations still have to use the old hardware for years to come, while looking into upgrading the network with more up to date hardware. There is thus a tremendous need to build whole messaging systems, where new and old hardware can coexist and work together. IP is not an option in this unification because the physical connectivity and hardware are so different, and there is no unified addressing scheme that could be used end-to-end. One major research and development effort in Comnet is building a messaging platform that can merge together any communication technology available currently, or designed in the future, while making sure old legacy hardware can still be used up to its end of life. The high level concept is similar to DTNs in that an end-to-end stable path is not expected, but communication is rather based on messages that are delivered hop-by-hop.

EXAMPLE PROJECTS

Future Internet Research Programme (ICT SHOK)

The Internet connectivity offered to end users, e.g., SMEs is somewhat two-fold: we have commodity class connectivity, e.g., home ADSL, without very high SLA guarantees, and then we have Internet access with SLA guarantees, e.g., 99,99% uptime, but with a high cost. One work item at Comnet is to design a scheme that would enable bundling multiple unguaranteed commodity class connections to form a high-speed connection with an SLA guarantee. Along the technical design, we are also investigating the business models for a virtual ISP and deployment of the technology.

Other important lines of work have concentrated on extending the lifetime of mobile phones by making efficient and intelligent use of the application protocols and wireless connectivity, and on the development of data transfer algorithms and protocols.

100GET

The Celtic 100GET project investigates future core network running at 100 Gbit/s links, and where the network is built over IEEE 802.3 Ethernet, or an evolution of the technology. In Finland, the subproject was composed of industry and research institutes. The focus of our work was on two topics, (1) understanding the scalability of legacy Ethernet and the recent IETF-driven Transparent Interconnection of Lots of Links (TRILL), and (2) extending the standard TRILL framework. This latter topic studies issues such as limiting the amount of broadcast Ethernet frames that is by nature an integral part of the technology, and making the whole network distributed, removing single points of failure and enabling efficient use of multiple routes between ingress and egress Ethernet switches across the core. Future work items in this area include suitable security models for a large Ethernet-based domain, and OAM for Ethernet networks. Recently 100GET was awarded the CELTIC Plus Innovation Award of 2013. In May 2013 the project was awarded the EUREKA Innovation Award in Brussels.

MEVICO

MEVICO was an international Celtic+ project that developed technology and solutions for the future releases of 3GPP, particularly in Rel11-Rel13. We worked on both Ethernet based transport for the access and core networks and for applying the concept of customer edge switching into mobile networks in MEVICO. More broadly, MEVICO covered relevant topics in network architecture, mobility & routing, packet transport, traffic management, network management & engineering and techno-economic aspects. The project included both conceptual research and demo/trial system implementations. The goal was to contribute to the technical drive and leadership of the EPC network (3GPP), and thus support the European industry to maintain and extend its strong technical and market position in the mobile networks market. A demonstrator of Customer Edge Switching was presented at the CELTIC event in Budapest at the end of MEVICO. MEVICO was awarded a CELTIC Plus Award of Innovation in Silver in that event.

PURSUIT

The Internet communication has become dominantly information-oriented, where users are more interested about "what" information they are consuming, instead of "who" delivers it. The PURSUIT project designed and implemented a novel, secure publish/subscribe information-centric communication architecture for the future Internet, based on the initial work done in PSIRP project. The project

investigated various problem areas related to publish/subscribe networking, such as mobility, security and routing. Topics of particular Comnet involvement were, for example: 1) how to design functions that have traditionally been part of the transport layer (such as congestion control) in information-centric publish/subscribe architecture; 2) how naming and content identification should be done in such network, so that an authentic content can be addressed securely; 3) designing strategies for packet-level caching and replication of content, considering the constraints from network resource management and congestion control. PURSUIT was an EU FP7 STREP project of 8 partners, running since September 2010.

SCAMPI

SCAMPI is a project in the field of opportunistic and mobile communications. The main goal of the project is to enable a rich variety of services to be composed from the diverse resources in the mobile users' environment. The project tackles opportunistic service composition both from the theoretical and systems perspectives. This includes building a middleware platform for developing and distributing opportunistic services and applications. The platform and applications are distributed in the Google Play Store and used as a basis for the SIGCOMM 2012 conference application. The project also produces a significant number of publications, including multiple best paper awards and a text book. SCAMPI is an EU 7th Framework Programme project running for three years starting from October 2010 and including eight partners from academia and the industry.

NETRADAR

Netradar is a crowd sourced mobile network measurement service. It has mobile applications for all major platform, such as Android, iOS, Windows Phone and Symbian Belle, and also e.g. for Meego. It was launched in Finland in summer 2012, and globally in March 2013. There are over a million measurements from mobile networks around the world, both cellular and WiFi. Aalto researchers use the data base for various scientific projects related to mobile communication and devices. The web site is at www.netradar.org.

EIT ICT Labs SDN Activity

We participated in the EIT ICT Labs innovation activity on Software Defined Networking (SDN). The activity provides complementary funding for work that is done in Carrier Projects such as MEVICO and others. The purpose is to promote research results to practical adoption through exploration, joint experiments and other actions helping the deployments of the innovations.

CORE GROUP:

Professors:

Professor Raimo Kantola

Professor Jukka Manner

Professor Jörg Ott

Senior Researcher

Docent, D.Sc. Zheng Yan

D.Sc. Nicklas Beijar

D.Sc. Jose Costa Requena

D.Sc. Esa Hyytiä

D.Sc. Pasi Sarolahti

Postdocs:

D.Sc. Mikko Pitkänen

D.Sc. Jani Lakkakorpi

D.Sc. Mikko Särelä

Researchers:

L.Tech. Marko Luoma

M.Sc. Visa Holopainen

M.Sc. Timo-Pekka Heikkinen

M.Sc. Saba Ahsan

M.Sc. Somaya Arianfar

M.Sc. Philip Ginzboorg

Teemu Kärkkäinen

M.Sc. Fida Khattak

M.Sc. Arseny Kurnikov

M.Sc. Marcin Nagy

M.Sc. Varun Singh

Michael Solomon

Jesus Llorente

Shen Yue

Maryam Pahlavan

M.Sc. Timo Kiravuo

M.Sc. Sebastian Sonntag

M.Sc. Le Wang

M.Sc. Gautam Moktam

M.Sc. Nuutti Varis

M.Sc. Lennart Schulte

M.Sc. Riku Luostarinen

M.Sc. Risto Järvinen

M.Sc. Juho Määttä

M.Sc. Antti Mäkelä

NETWORK ECONOMICS

The goal of the network economics group is to improve understanding of (mobile) technology acceptance by measuring and analyzing user behavior, by studying alternative technical and industry architectures, and by evaluating the techno-economic performance of new technologies.

RESEARCH CHALLENGES

Quantitative analysis of mobile user behavior

The always-on and multipurpose nature of personal mobile devices has enabled accurate quantitative analysis of mobile user behavior. We are challenging the boundaries of complex data mining and privacy by collecting and analyzing e.g. transaction data (from mobile devices), traffic data (from routers) and demographics data (from service providers and user questionnaires). The aim is to better understand user behavior in contexts (e.g. by location and activity), social networks (virtual vs. real world) and service adoption/diffusion.

Optimal industry and technical architecture for flexible radio access

Wireless Internet access technologies are gradually enabling more flexible use of spectrum (e.g. cognitive radio) and potentially higher utilization levels of scarce spectrum. This flexibility is emerging via two separate evolution paths: licensed and unlicensed. Our challenge is to better understand the technical, regulatory and economic rules needed to optimize the use of the bottleneck radio spectrum.

Techno-economic bottlenecks of Internet scalability

The Internet architecture and protocols need to scale up radically in the coming years. Anticipation of the key architectural bottlenecks early enough is of importance. Some of these bottlenecks are techno-economic by nature and cannot be easily solved without understanding of the related economics. Our challenge is to identify these techno-economic bottlenecks and to help solving them either by designing techno-economic solutions or by cooperating with relevant technology experts

EXAMPLE PROJECTS

MoMIE (Modeling of Mobile Internet Ecosystem)

MoMIE (2011-2012) is a national project involving the key actors of the Finnish mobile market. Mobile usage data has been collected and analyzed in a bottom-up manner to identify the trends and patterns in the Finnish market. Theories, models and hypotheses are created in a top-down manner and linked back to the experimental usage data. The resulting increased visibility to service adoption and diffusion may help market actors in business planning.

EECRT (End-to-end Cognitive Radio Testbed)

EECRT (2011-2013) includes our techno-economic analysis part to support alignment of technical architectures with market architectures. We have used system dynamics for the top-down modeling of the radio access evolution and agent-based modeling for the bottom-up analysis of potential TV white space

exploitation scenarios. One major observation is that local area application of white space looks more attractive.

SAIL (Scalable and Adaptive Internet Solutions)

SAIL (2011-2013) is a large EU FP7 project where our role is the techno-economic analysis of information-centric networking architectures and protocols. We have used scenario planning, diffusion theory, two-sided markets, and game theory to analyze the feasibility of architectures. Single-actor deployment of protocols (standard or proprietary), e.g. the current content delivery networks, seems successful because of simplicity and status-quo between actors.

CORE GROUP:

Professor Heikki Hämmäinen

Docent, Chief Research Scientist Kalevi Kilkki

Lic.Tech Pekka Kekolahti

D.Sc. Timo Smura

D.Sc. Mikko Heikkinen

M.Sc. Thomas Casey

M.Sc. Tapio Levä

M.Sc. Juuso Karikoski

M.Sc. Benjamin Finley

M.Sc. Antti Riikonen

M.Sc Henna Suomi

M.Sc Nan Zhang

M.Sc. Michail Katsigiannis

M.Sc. Tapio Soikkeli

M.Sc. Arturo Basaure

INFORMATION THEORY

Professors: Patric Östergård

The goal of the information theory group is to solve problems in discrete mathematics that arise in coding and information theory. A variety of computational methods are used, enhanced by algebraic and combinatorial techniques. The research is mainly funded by the Academy of Finland and led by Professor Patric Östergård.

COMPUTATIONAL METHODS IN DISCRETE MATHEMATICS AND INFORMATION THEORY

The aim of the research is the study of existence and classification problems in discrete mathematics and information theory using computational methods, enhanced by algebraic and combinatorial techniques. The methods are developed in a general framework, and have been applied to numerous types of discrete structures, such as codes, designs, and graphs, just to mention a few.

One major breakthrough is the discovery of nontrivial q-analogs of Steiner systems. Several famous people have studied this problem during the last four decades, with no success, and it was then thought that maybe such structures do not exist. The interest in the problem was further increased when it turned out the such structures have applications in network coding. Joint work with teams from Germany, Israel, and USA led to the discovery of q-Steiner triple systems of order 13 in the end of 2012.

The research team has further studied and published results on difference matrices and several types of generalized Hadamard matrices; unrestricted and constant weight error-correcting codes; Hamiltonian cycles and paths in graphs; Euclidean packing and covering problems; and coloring and domination problems for graphs. Just to mention one specific result, a new record (40) for the smallest possible order of a planar hypohamiltonian graph has been obtained. All these problems concern fundamental mathematical structures or properties motivated by applications in telecommunications or more generally in engineering.

The work on classifying and enumerating discrete structures has formed a continuation of earlier work that is described in the monograph [P. Kaski and P.R.J. Östergård, Classification Algorithms for Codes and Designs, Springer, Berlin, 2006]. Along this line, we have achieved several groundbreaking results in the recent years, including a classification of the perfect binary one-error-correcting codes of length 15 and an enumeration of the Latin squares of order 11.

Switching is a general technique for transforming a discrete structure into another with the same main parameters. There are many applications for switching, for example, switching can be used to obtain new (nonisomorphic/inequivalent/...) structures from known ones. One result of the research carried out in the team is that the multitude of certain discrete structures can be explained by the fact that they are all (or almost all) connected via a sequence of switches.

Many of the computational results obtained have required very CPU-intensive computations, some of which have been distributed over extensive computer networks. For this purpose, an 80-core computer cluster was acquired in 2010 and will be extended by a 256-core cluster in 2013.

Software libraries for solving various common combinatorial problems have been developed along the years. The program libexact solves instances of the so-called exact cover problem. This piece of software is frequently useful in the study of combinatorial structures, and forms an important complement to the Cliquer routines, also released by the team. The libexact and Cliquer routines were invaluable building blocks in the algorithms used to obtain several of the particular results listed above. Algorithms have further been developed in the framework of Russian doll search. Stochastic methods - in particular, tabu search - have also been considered for certain construction problems. Other types of algorithms that have been studied include approximation algorithms.

Researcher training plays a central role in the team and all doctoral students in the research team are about to defend their theses within the next couple of years. The team is collaborating extensively and internationally. The work of the team has received international recognition and the team leader is a frequent plenary speaker at international meetings. He is also a co-Editor-in-Chief for the Journal of Combinatorial Designs.

CORE GROUP

Prof. Patric Östergård

Dr. Alexandru Popa

M. Sc. Simon Crevals

M.Sc. Ashik Kitzhakkepallathu

M. Sc. Pekka Lampio

M.Sc. Ville Pettersson

PERFORMANCE ANALYSIS

Professors: Samuli Aalto (pro tem) and Jorma Virtamo (emeritus)

Performance analysis group focuses on the mathematical modeling, performance analysis and optimization of modern communications systems and networks from the traffic point of view. The mathematical methods applied include stochastic modeling, queueing theory, and teletraffic theory. In addition, scheduling theory, optimization theory, discrete-event simulation, and various numerical methods play a central role. We strive both for new theoretical breakthroughs in the area of queueing and teletraffic theory and an insightful analysis of modern communications systems, networks, and applications.

RESEARCH CHALLENGES

The work done by the group is challenged by a multidisciplinary race after ever increasing technological complexity of communications systems as well as methodological innovations in related applied mathematics. The focus areas are as follows:

Optimal control of queueing systems

Along with new applications from modern computer and communications systems, scheduling theory has been revived in recent years. The group has found new fundamental results for age and size-based scheduling in the classical M/G/1 queueing context and beyond (e.g. related to opportunistic scheduling). The group has also participated in the development of near-optimal size-aware dispatching policies for parallel queueing systems typical to e.g. data centers and other server farms. Even more important in such systems is to consider the trade-off between performance and energy efficiency, which is a new line of research for the group.

Performance analysis of elastic data traffic

Bandwidth sharing networks are used to model the performance of data networks loaded with elastic traffic. The group has contributed to the extension of the concept of Balanced Fairness, which allows analytical studies of bandwidth sharing networks at the flow level. In recent years, the group has developed and analyzed various flow level models for elastic data traffic in the context of heterogeneous wireless networks.

Capacity of wireless multi-hop networks

The fundamental capacity limits of wireless multi-hop networks can be elegantly analyzed in the limit of massively dense networks. The capacity maximization separates into two distinct problems: routing at the global scale and forwarding at the local scale. For the optimal routing problem innovative applications of concepts from physics have been applied. Multiple computational methods have been developed to analyze and estimate the multidirectional forwarding capacity.

Traffic aspects of IoT

The number of devices which connect to the Internet is exponentially increasing with the emergence of Internet of Things. It generates a new traffic type, machine-to-machine communication, characterized by a huge number of potential sources but with small actual data, the analysis, modeling and optimization of which poses entirely new challenges for the performance analysis community.

PROJECTS

Euro-NF (Network of the Future)

Euro-NF (2008-2012) is an EC FP7 Network of Excellence (NoE). It is formed by 35 European institutions (from the academia and industry) and coordinated by Institut Telecom (from France). Within the project, we have international collaboration in the area of mathematical modeling and performance analysis of future networks.

HEWINETS (Dynamic Heterogeneous Wireless Access Networks)

The group is responsible for the national HEWINETS project (2011-2013) funded by TEKES and industry. This is a joint project with the COMNET research groups of Prof. Jyri Hämäläinen, Prof. Riku Jäntti, and Prof. Olav Tirkkonen. The focus of the project is to analyze the key issues affecting the radio resource management of heterogeneous wireless access networks relevant in LTE systems and beyond. In the second year, our focus has been on the fundamental capacity limits of multi-hop wireless networks and on the load balancing of elastic data traffic in heterogeneous networks.

ICT SHOK IoT (Internet of Things)

The group participates in the Internet of Things Programme (2012-2015) of TIVIT. In the first year, our focus has been on the mathematical modeling and performance analysis of the initial random access procedure in LTE motivated by the potential huge signaling load of the machine-to-machine (M2M) traffic in future networks. The work has been carried out in a close collaboration with researchers in Ericsson Nomadic Lab.

CORE GROUP

Prof. (pro tem) Samuli Aalto, group leader

Prof. (emeritus) Jorma Virtamo

Dr. Pasi Lassila

Dr. Aleksi Penttinen (until March 2012)

M.Sc. Jarno Nousiainen

M.Sc. Prajwal Osti

APPENDICES

PUBLICATIONS

All publications

2010 ■ 2011 ■ 2012

	2010	2011	2012
Value	143	170	186

Journal publications

2010 ■ 2011 ■ 2012

	2010	2011	2012
Value	33	53	60
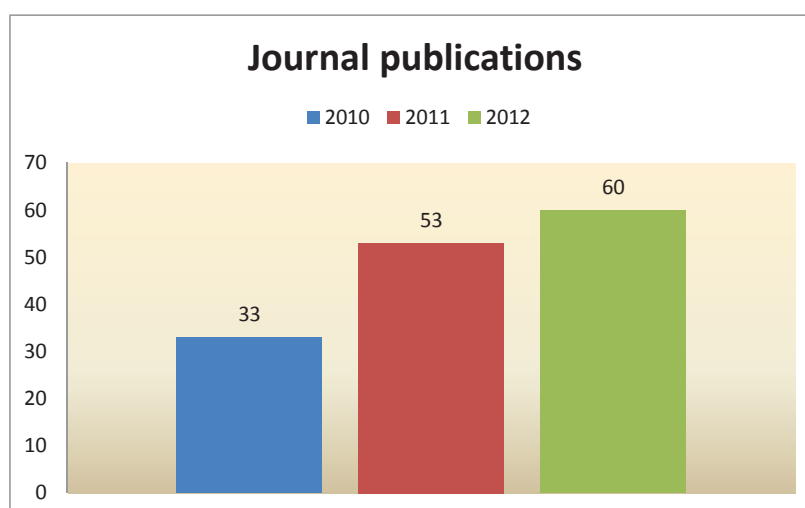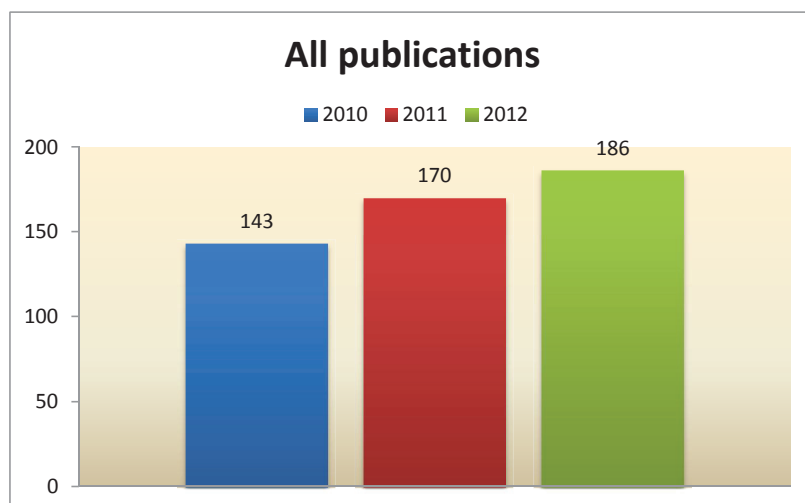
ABSTRACTS OF DOCTORAL THESES 2012

Mikko Heikkinen: Techno-Economic Analysis of Mobile Peer-to-Peer Systems and Services

Supervisor: Prof. Heikki Hämmäinen

Peer-to-peer (P2P) systems are an integral part of many technology and business domains of the Internet. P2P-based services are disrupting established business models, and they are emerging in the mobile domain. The aim of this thesis is to analyze the effect of emerging mobile P2P-based services and systems in the technology and business domains of the Internet by using a multimethod research design.

The contribution of this thesis consists of the following studies: Applying the scenario planning method to decision making related to emerging mobile services in a case study of a novel P2P communications protocol. Developing a framework to analyze the value distribution of ICT services, and conducting case studies on value flows and role constellations of centralized and distributed communications and video streaming. Assessing value in the technology evolution of mobile P2P communications, which potentially disrupts the positions of incumbents by introducing Internet-driven, telecom-driven, and proprietary evolution paths. Operationalizing the Theory of Planned Behavior conceptual model and finding novel mobile P2P communications and content sharing services to have high adoption potential among respondents with advanced handsets. Surveying consumer attitudes towards different aspects of mobile P2P services, such as usage intention, usage satisfaction, revenue models, battery consumption, and social sharing. Measuring mobile P2P usage in Finland during 2005-2007 by analyzing traffic traces from the networks of three major Finnish mobile operators and by investigating the usage log files from a panel of Finnish advanced handset users.

In conclusion, the research contribution of this thesis consists of applying multiple research methods to case studies on novel distributed mobile services, developing frameworks for the analysis of such services, extending existing theories and methods for such analysis, and reporting results from surveys and usage measurements on relevant topics. The main technoeconomic challenges in deploying mobile P2P systems and services are related to business models, resources, incentives, usability, security, and policy. Based on value distribution and usage analyses, one can assert that mobile peer-to-peer systems and services are transforming the technology and business domains of the Internet.

Iiro Jantunen: System Architecture for Mobile-phone-centric Ambient Intelligence Applications

Supervisor: Prof. Jyri Hämäläinen

The aim of this study is to develop an open architecture platform for mobile-phone-centric ambient intelligence applications. The two main application fields are 1) local wireless sensor networks for health-related applications and 2) ubimedia, meaning digital content embedded in the environment.

In the proposed architecture, a mobile phone acts as a central node hosting applications and connecting a local, e.g. sensor, network to back-end servers in the Internet. The technologies used in the architecture include Simple Sensor Interface (SSI) protocol, nanoIP, and lowpower short-range radios, e.g. Bluetooth Low Energy (formerly BTLEE), Radio-frequency Identification (RFID), 5 kHz inductive links, and impulse ultra-wideband (UWB). The sensor network architecture has been implemented and successfully demonstrated using several applications with commercially available mobile phones with add-on electronics.

A system architecture, including both the hardware and software architecture, enabling mobile phones to read Ubimedia with sufficiently high data rates for multimedia applications is also presented. This architecture could also be used as a new type of high-speed wireless internet access.

Antti Mäkelä: On providing reliable and economical intranet connectivity

Supervisor: Prof. Jukka Manner

In recent years, the Internet and data networks in general have been a huge driver in how communications are conducted. Internet-based communication technologies have transformed the way data is handled and transferred both around the world and within organizations. As the modern society and especially businesses have become completely dependent on reliable network connectivity in their operations, we need to have proper measures to ensure fault tolerance.

Telecommunication systems can be designed in a reliable fashion by using redundant components throughout the network, including items such as multiple different, independent links, ports, and nodes. Additionally, environmental factors, such as the stability of power supply have to be accounted for. Obtaining contractually binding reliability guarantees for a flexible network connection has traditionally been very expensive compared to connectivity without such guarantees. This is because of both implementation costs and low competition among solutions and providers.

This thesis is focused on creating a new approach to network reliability that would have equal performance with traditional approaches, act independently of specific service providers and their chosen access technologies, and be more cost-effective. The thesis analyzes whether such an approach is technically feasible, preserves network usability, and is economically sound. The proposed new approach is called 'RAIIC' (Redundant Array of Independent Internet Connections). RAIIC is based on the assumption that while a cheap, unguaranteed network connectivity may experience outages, several such connections can be bundled together. Such a bundle can then provide equivalent service to the traditional reliability approaches.

The thesis conducts a quantitative analysis on the economical feasibility of the concept, as well as evaluates the feasibility of implementing RAIIC based on Mobile IP technology. The work is concerned primarily in the end-user perception of the networking service.

After considering all the studied factors, including results from simulations, implementation work and possibilities to conduct operations over multiple paths concurrently, the conclusions can be drawn that RAIIC fulfills the design goals perfectly. Even the most demanding of common applications, do not overtly degrade in performance during an outage. The technology has been adopted by the Internet Engineering Task Force as an experimental standard.

Helka-Liina Määttänen: Linear transmission methods and feedback for downlink MIMO systems

Supervisor: Prof. Olav Tirkkonen

Multiple-input multiple-output (MIMO) systems have potential to provide the capacity needed for future generation wireless systems and have been adopted by 3GPP Long Term Evolution (LTE) system. However, due to several practical limitations the theoretical benefits of MIMO are not fully achieved. The degree of channel state information (CSI) at the transmitter is one key limiting factor when aiming at high performance.

In this thesis, the performance possible to achieve under different CSI assumptions at the transmitter is studied. In the beginning, full CSI is assumed at the receiver and the problem of sum rate maximization for

two multiplexed users with linear receiver and transmit processing is investigated. A new simple transmission scheme is presented for the case when the users have more than one receive antennas and the MIMO channels are rank deficient.

Next, an LTE-type system is considered with a limited rate feedback link. The tradeoff between system performance and the number feedback bits is considered. Feedback schemes related to closed loop precoding and adaptive modulation and coding (AMC) for single user MIMO are studied. By optimizing the feedback, performance improvements or savings in feedback bits are achieved. For closed loop precoding, the precoding matrix is partitioned into a Grassmannian part, which steers the transmit power, and an orthogonalizing part, which controls the inter-stream interference. The optimality of orthogonalization has been investigated and a codeword selection metric is introduced for the orthogonalization part. For AMC, a relative channel quality indication (CQI) report optimization has been considered.

In the last part, a system where dynamic mode switching is possible between single user and multiuser transmissions without higher layer signaling is considered. The feasible feedback to support such a system in LTE context is studied. It is investigated how feedback derived under single user transmission assumption can support the dynamic switching and whether multiuser specific additional precoding or CQI feedback is needed.

Jari Nieminen: Media access control and time synchronization in delay-sensitive multi-channel wireless sensor networks

Supervisor: Prof. Riku Jäntti

Wireless Sensor Networks (WSNs) consist of sensor nodes that measure the environment and one or more gateway nodes that collect the wirelessly sent information from sensor nodes. Wireless systems are free from the constraints of cables while they provide low installation costs, ease of maintenance, and flexibility. Hence, it is natural that WSNs offer an interesting solution for an innumerable number of applications although the exploitation of wireless networks brings new challenges as well because of shared and unreliable transmission media. Improving robustness and efficiency, together with the minimization of communication delays are the most important research challenges en route towards the large-scale implementation of WSNs.

Media Access Control (MAC) protocols are responsible for sharing the transmission media among sensor nodes and avoiding collisions of transmissions. Motivation for the research of multi-channel MAC protocols is due to the fact that the performance of a wireless network can be significantly enhanced using multiple frequency channels simultaneously. Multi-channel communications can be used for minimization of delay which is crucial in delay-sensitive applications, such as in wireless automation and target tracking. Time synchronization is essential for many WSN applications and the use of multi-channel communications enables faster execution of the synchronization process which improves network efficiency. Most current WSNs use unlicensed parts of the frequency spectrum which have become very crowded lately. Cognitive Radio (CR) technology can be used in WSNs to avoid problems related to coexistence with other systems and enable efficient spectrum use.

In this thesis a novel multi-channel MAC protocol is presented that has been designed especially to correspond to the requirements of WSN applications. By means of theoretical analysis it is shown that the proposed protocol outperforms other existing solutions with respect to delay, which is of significant importance for many WSN applications. Impacts of multi-channel communications on wireless automation and target tracking are investigated and the results show the interdependencies between communication and application parameters. In addition to these topics, a novel multi-channel time synchronization protocol is presented and practical issues related to time synchronization in CR networks are studied.

Timo Smura: Techno-economic modelling of wireless network and industry architectures

Supervisor: Prof. Heikki Hämmäinen

Rapid innovation in the domains of wireless communications and Internet brings new opportunities and challenges for the industry stakeholders. As Internet services and applications migrate to mobile devices, increasing demands for wireless networks arise. At the same time, increasing uncertainty exists about the role of different wireless technologies and actors providing services in the future network environment. Decision-making and forecasting requires therefore a holistic view, taking into account technology, business, and policy-related aspects.

This dissertation applies and develops techno-economic modelling methods for the study of wireless networks and services in the context of evolving industry architectures. The research is organised both chronologically and logically into two parts: 1) techno-economic modelling of selected wireless network and industry architecture scenarios, and 2) development of the techno-economic modelling methods in selected areas.

The dissertation makes several contributions to the theory and practice of techno-economic modelling. First, the dissertation explores the use of the predominantly technology-focused modelling methods in studying alternative industry architectures. Three separate techno-economic modelling studies are presented, analysing the feasibility of fixed WiMAX network deployments, virtual operator models in mobile networks, and industry architectures for DVB-H -based mobile television. In each of these studies, a systematic modelling process is followed, consisting of the following steps: market and service definition, technology definition, industry architecture definition, revenue modelling, cost modelling, discounted cash flow analysis, and sensitivity analysis. Second, the dissertation advances the theory and practise of techno-economic modelling in selected areas. A novel approach for planning and forecasting technology product evolution and new product feature diffusion is developed, combining existing models of product category diffusion and product unit replacement behaviour with a previously unexplored phenomenon of product feature dissemination. In addition, a holistic framework for analysing the usage of mobile services is developed, linking available usage measurement points to the four main technical components of mobile services: devices, networks, applications, and content. The framework is utilised in a study of mobile data service usage in Finland. Finally, scenario planning methods are used to manage and bound uncertainties related to the future of local area access networks, and more generally suggested as a complement to techno-economic modelling in defining and selecting the technology and industry architectures for analysis.

Hao-Chia Yu: Radio Resource Management for Cellular Networks Enhanced by Inter-User Communication

Supervisor: Prof. Olav Tirkkonen

The importance of radio resource management will be more and more emphasized in future wireless communication systems. For fair penetration of wireless services and for improved local services, inter-user communication has been receiving wide attention as it opens up various possibilities for user cooperation. The capability of inter-user communication imposes higher demands on radio resource management as additional considerations are needed. The demands for intelligent management of radio resources is also emphasized by the sparsity of radio resources. As the available spectral resources are assessed as under-utilized, much effort is devoted to developing advanced resource management methods for improving the spectral usage efficiency.

The research of this thesis has contributed to the radio resource management for cellular networks enhanced by inter-user communication. Recognizing that inter-user communication can be used for

message relaying or for direct communication purposes, two use cases are considered that leverage the synergy of users: cooperative relay selection and Device-to-Device (D2D) communication. We identify the importance of stochastic geometry consideration on cellular users for evaluating system performance in cooperative networking. We develop an algorithm for efficiently selecting cooperative users to maximize an End-to-End (e2e) performance metric. We analyze the optimal resource sharing problem between D2D communication and infrastructure-supported communication. We study the impact of imperfect Channel State Information (CSI) on the performance of systems with inter-user communication.

Simulation results show that the performance of users with unfavorable propagation conditions can be improved with cooperative communication in a multi-cell cellular environment, at the expense of radio resources. Further, our results show that the selection of multiple cooperative users is beneficial in cases where the candidate cooperative users are spatially distributed. For resource sharing between the D2D and infrastructure-supported communication, our results show that the proposed resource sharing scheme enables higher intra-cell resource reuse without blocking the infrastructure-supported communication.

PUBLICATIONS IN 2012

DOCTORAL DISSERTATIONS

Heikkinen, Mikko V.J
Techno-Economic Analysis of Mobile Peer-to-Peer Systems and Services.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. (Doctoral Dissertations 46/2012).

Jantunen, Iiro
System Architecture for Mobile-phone-centric Ambient Intelligence Applications.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. (Doctoral Dissertations 81/2012).

Mäkelä, Antti
On providing reliable and economical intranet connectivity.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. (Doctoral Dissertations 66/2012).

Määttänen, Helka-Liina
Linear transmission methods and feedback for downlink MIMO systems.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. (Doctoral Dissertations 65/2012).

Nieminen, Jari
Media Access Control and Time Synchronization in Delay-Sensitive Multi-Channel Wireless Sensor Networks.
Espoo: Aalto University, School of Electrical Engineering, 2012. (Doctoral Dissertations 22/2012).

Smura, Timo
Techno-economic modelling of wireless network and industry architectures.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. . (Doctoral Dissertations 23/2012).

Yu, Chia-Hao
Radio Resource Management for Cellular Networks Enhanced by Inter-User Communication.
Espoo: Aalto University School of Electrical Engineering, Department of Communications and Networking, 2012. (Doctoral Dissertations 8/2012).

ARTICLES IN REFEREED JOURNALS

Aalto, Samuli; Lassila, Pasi; Savolainen, Petri; Tarkoma, Sasu
How impatience affects the performance and scalability of P2P video-ondemand systems.
ACM SIGMETRICS Performance Evaluation Review, 2012. Vol. 39, nro 3, pp. 58-60.

Aalto, Samuli; Penttinen, Aleksi; Lassila, Pasi; Osti, Prajwal
Optimal size-based opportunistic scheduler for wireless systems.
Queueing systems, 2012. Vol. 72, nro 1-2, pp. 5-30.
Electronic publication http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s11134-012-9285-y

Alam, Mirza Nazrul; Jäntti, Riku; Kneckt, Jarkko; Nieminen, Johanna
Performance Analysis of the IEEE 802.11s PSM.
Journal of Computer Networks and Communications, 2012. Nro ., 14 pp..
Electronic publication http://www.hindawi.com/journals/jcnc/2012/438654/ (Article ID 438654, doi:10.1155/2012/438654)

Ali-Vehmas, Timo; Casey, Thomas R.
Evolution of wireless access provisioning: A systems thinking approach.
Competition and Regulation in Network Industries, 2012. Vol. 13, nro 4, ..

Behbahani, Majid ; Lam, Clement; Östergård, Patric R. J.
On triple systems and strongly regular graphs.
Journal of combinatorial theory. Series A, 2012. Vol. 119, nro 7, pp. 1414-1426.

Bou Saleh, Abdallah; Bulakci, Omer; Hämäläinen, Jyri; Redana, Simone; Raaf, Bernhard
Analysis of the Impact of Site Planning on the Performance of Relay Deployments.
IEEE transactions on vehicular technology, 2012. Vol. PP, nro 99, 1.
Electronic publication http://ieeexplore.ieee.org.libproxy.aalto.fi/xpl/articleDetails.jsp?tp=&arnumber=6210402&contentType=Early+Access+Articles&searchField%3DSearch_All%26queryText%3DAnalysis+of+the+Impact+of+Site+Planning+on+the+Performance+of+Relay+Deployments

Bulakci, Ömer; Bou Saleh, Abdallah; Hämäläinen, Jyri; Redana, Simone
Performance of Relay Site Planning over Composite Fading/Shadowing Channels with Co-channel Interference.
IEEE transactions on vehicular technology, 2012. Nro 99, pp. 14.
Electronic publication http://ieeexplore.ieee.org.libproxy.aalto.fi/stamp/stamp.jsp?tp=&arnumber=6378481

Bulakci, Ömer; Bou Saleh, Abdallah; Redana, Simone; Raaf, Bernhard; Hämäläinen, Jyri
Resource Sharing in LTE-Advanced Relay Networks: Uplink Optimization Methods and Performance Analysis.
European Transactions on Telecommunications (ETT), Special Issue on Multi-Carrier Transmission & Applications, LTE & LTE-Advanced, 2012. Vol. 24, nro 1, pp. 32-48.
Electronic publication http://onlinelibrary.wiley.com/doi/10.1002/ett.2569/abstract

Casey, Thomas R; Töyli, Juuso
Dynamics of two-sided platform success and failure: An analysis of public wireless local area access.
Technovation, 2012. Vol. 32, nro 12, pp. 703–716.
Electronic publication http://www.sciencedirect.com/science/article/pii/S0166497212000958

Cho, Byungjin; Koufos, Konstantinos; Ruttik, Kalle; Jäntti, Riku
Power Allocation in the TV White Space under Constraint on Secondary System Self-Interference.
Journal of Electrical and Computer Engineering, 2012. Vol. 2012, nro ., 12 pp..
Electronic publication http://www.hindawi.com/journals/jece/2012/245895/ (Article ID 245895, doi:10.1155/2012/245895.)

Cui,Qimei; Luo, Bing; Huang, Xueqing; Dowhuszko, Alexis; Jiang, Jun
Closed-form solution for minimizing power consumption in coordinated transmissions.
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING,
2012. Nro 122.
Electronic publication http://jwcn.eurasipjournals.com/content/2012/1/122 (doi:10.1186/1687-1499-2012-122)

De, S; Sharma, A; Jäntti, Riku; Cavdar, H.D.
Channel adaptive stop-and-wait ARQ protocols for short-range wireless links.
IET COMMUNICATIONS, 2012. Vol. 6, nro 14, pp. 2128-2137.
Electronic publication http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6353310&tag=1

Dinitz, Jeffrey H.; Östergård, Patric R. J.; Stinson, Douglas R.
Packing Costas arrays.
Journal of Combinatorial Mathematics and Combinatorial Computing, 2012. Vol. 80, pp. 385-403.

Dowhuszko, Alexis A; Husso, Mika; Hämäläinen, Jyri
Combined Transmit Beamforming and Channel-Aware Scheduling for Interference Mitigation in Femtocells.
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING, 2012.
Electronic publication http://jwcn.eurasipjournals.com/content/2012/1/293/abstract

Elmusrati, Mohammed; Tarhuni, Naser; Jäntti, Riku
Framework for Random Power Allocation of Wireless Sensor Networks in Fading Channels.
Wireless Sensor Network, 2012. Vol. 4, nro 3, pp. 76-83, 2012.
Electronic publication http://www.scirp.org/journal/PaperInformation.aspx?paperID=18311 (doi: 10.4236/wsn.2012.43011.)

Ermolova, Natalia Y.; Tirkkonen, Olav
Distribution of diagonal elements of a general central complex Wishart matrix.
IEEE communications letters, 2012. Vol. 16, nro 9, pp. 1373-1376.
Electronic publication http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6244788

Ermolova, Natalia Y.; Tirkkonen Olav
Multivariate 'eta-mu' fading distribution with constant correlation model.
IEEE communications letters, 2012. Vol. 16, nro ., pp. 454-457.

Ermolova, Natalia Y; Tirkkonen, Olav
Outage probability over composite 'eta-mu' fading-shadowing radio channels.
IET COMMUNICATIONS, 2012. Vol. 6, nro 13, pp. 1898-1902.

Freudiger, Julien; Jadliwala, Murtuza; Hubaux, Jean-Pierre; Niemi, Valtteri; Ginzboorg, Philip
Privacy of Community Pseudonyms in Wireless Peer-to-Peer Networks.
ACM/Springer Mobile Networks and Applications (MONET): Special Issue on Context-Awareness of Mobile Systems, 2012.
Electronic publication http://link.springer.com/content/pdf/10.1007%2Fs11036-012-0406-y

Ginzboorg, Philip; Niemi, Valtteri; Ott, Jörg
Fragmentation algorithms for DTN links.
Computer communications, 2012. Nro ., pp. 12.
Electronic publication http://dx.doi.org/10.1016/j.comcom.2012.10.001

Heikkinen, Mikko; Nurminen, Jukka; Smura, Timo; Hämmäinen, Heikki
Energy Efficiency of Mobile Handsets.
Measuring User Attitudes and Behavior, Telematics and Informatics, 2012. Vol. 29,
nro 4, pp. 387-399.

Huang, Xin; Ma, Xiao; Chen, Bangdao; Markham, Andrew; Wang, Qinghua; Roscoe, Andrew William
Human Interactive Secure ID Management in Body Sensor Networks.
Journal of Networks, 2012. Vol. 7, nro 9, pp. 1400-1406.
Electronic publication
http://ojs.academypublisher.com/index.php/jnw/article/view/jnw070914001406/5437
(doi:10.4304/jnw.7.9.1400-1406)

Hyytiä, Esa; Aalto, Samuli; Penttinen, Aleksi
Minimizing slowdown in heterogeneous size-aware dispatching systems..
ACM SIGMETRICS Performance Evaluation Review, 2012. Vol. 40, nro 1, pp. 20-40.
Electronic publication http://dl.acm.org/citation.cfm?id=2254763

Hyytiä, Esa; Aalto, Samuli; Penttinen, Aleksi; Virtamo, Jorma
On the value function of the M/G/1 FCFS and LCFS queues.
Journal of applied probability, 2012. Vol. 49, nro 4, pp. 1052-1071.
Electronic publication http://projecteuclid.org/euclid.jap/1354716657

Hyytiä, Esa; Penttinen, Aleksi; Aalto, Samuli
Size- and State-Aware Dispatching Problem with Queue-Specific Job Sizes.
European Journal of Operational Research, 2012. Vol. 217, nro 2, pp. 357-370.

Hyytiä, Esa; Penttinen, Aleksi; Sulonen, Reijo
**Non-Myopic Vehicle and Route Selection in Dynamic DARP with Travel Time
and Workload Objectives.**
Computers & Operations Research, 2012. Vol. 39, nro 12, pp. 3021-3030.
Electronic publication http://dx.doi.org/10.1016/j.cor.2012.03.002

Hyytiä, Esa; Virtamo, Jorma; Lassila, Pasi; Ott, Jörg
Continuum Percolation Treshold for Permeable Aligned Cylinders and Opportunistic Networking.
IEEE communications letters, 2012. Vol. 16, nro 7, pp. 1064-1067.
Electronic publication http://dx.doi.org/10.1109/LCOMM.2012.051512.120497

Jo, Hang-Hyun; Karsai, Márton; Karikoski, Juuso; Kaski, Kimmo
Spatiotemporal correlations of handset-based service usages.
EPJ Data Science, 2012. Vol. 1, nro 10
Electronic publication http://www.epjdatascience.com/content/1/1/10/abstract
(doi:10.1140/epjds10)

Karikoski, Juuso
Handset-based data collection process and participant attitude.
International Journal of Handheld Computing Research, 2012. Vol. 3, nro 4, pp. 1-21.
Electronic publication http://www.igi-global.com/article/handset-based-data-collectionprocess/
73803

Kaski, Petteri; Khatirinejad, Mahdad; Östergård, Patric R. J.
Steiner triple systems satisfying the 4-vertex condition.
Designs, Codes and Cryptography, 2012. Vol. 62, nro 3, pp. 323-330.
Electronic publication http://dx.doi.org/10.1007/s10623-011-9520-2

Katsigiannis, Michail
Mobile network offloading: Deployment and energy aspects.
International Journal of Interdisciplinary Telecommunications and Networking, 2012.
Vol. 4, nro 3, pp. 40-53.
Electronic publication http://www.igi-global.com/article/mobile-network-offloading/70594 (DOI:
10.4018/jitn.2012070103)

Kivi, Antero; Smura, Timo; Toyli, Juuso
Technology product evolution and the diffusion of new product features.
Technological forecasting and social change, 2012. Vol. 79, nro 1, pp. 107-126.

Korhonen, Timo; Vaaramaki, Tapio; Riihimaki, Vesa; Salminen, Reijo; Karila, Artpo
**Selecting telecommunications technologies for intelligent transport system
services in Helsinki Municipality.**
IET intelligent transport systems, 2012. Vol. 6, nro 1, pp. 18-28.
Electronic publication http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6157096
(Digital Object Identifier: 10.1049/iet-its.2010.0090)

Koufos, Konstantinos; Ruttik, Kalle; Jäntti, Riku
Voice Service in Cognitive Networks over the TV Spectrum.
IET COMMUNICATIONS, 2012. Vol. 6, nro 8, pp. 991-1003.
Electronic publication
http://ieeexplore.ieee.org/xpl/tocresult.jsp?asf_arn=null&asf_iid=0&asf_pun=4105970&asf_in=8&asf_rpp=
null&asf_iv=6&asf_sp=991&asf_pn=1

Lee, Hyun-kwan; Hwang, June; Kim, Seong-Lyun; Jäntti, Riku
Throughput and Delay Analysis of Network Coded ALOHA in Wireless Networks.
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING,
2012. Electronic publication http://jwcn.eurasipjournals.com/content/2012/1/277

Leinonen, Jouko; Hämäläinen, Jyri; Juntti, Markku
Capacity Analysis of Downlink MIMO-OFDMA Resource Allocation with Limited Feedback.
IEEE transactions on communications, 2012. Vol. PP, nro 99, pp.1-11.
Electronic publication http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6341775

Levä,Tapio; Komu, Miika; Keränen, Ari; Luukkainen, Sakari
Adoption Barriers of Network-layer Protocols: the Case of Host Identity Protocol.
Computer networks, Special issue on Security and Identity Architecture for Future
Internet, 2012.

Lizarraga, Enrique Mariano; Dowhuszko, Alexis A.; Sauchelli, Victor Hugo
Improving out-of-band power emissions in OFDM systems using double-length symbols.
IEEE Latin America Transactions, 2012. Vol. 10, nro 3, pp.1710-1718.

Maham, Behrouz; Tirkkonen, Olav
Transmit Antenna Selection OFDM Systems With Transceiver I/Q Imbalance.
IEEE transactions on vehicular technology, 2012. Vol. 61, nro 2, pp. 865-871.

Maham, Behrouz; Tirkkonen, Olav; Hjorungnes, Are
Impact of Transceiver I/Q Imbalance on Transmit Diversity of Beamforming OFDM Systems.
IEEE transactions on communications, 2012. Vol. 60, nro 3, pp. 643-648.

Mäkelä, Antti; Siikavirta, Sebastian; Manner, Jukka
Comparison of load-balancing approaches for multipath connectivity.
Computer networks, 2012. Vol. 56, nro 8, pp. 2179-2195.
Electronic publication http://www.sciencedirect.com/science/article/pii/S138912861200093X

Määttänen, Helka-Liina; Tirkkonen, Olav; Koivisto, Tommi; Enescu, Mihai
CSI Feedback for Dynamic Switching between Single User and Multiuser MIMO.
Wireless personal communications, 2012. Vol. 64, nro 1, 33-49.
Electronic publication http://dl.acm.org/citation.cfm?id=2311981

Nickray, Mohsen; Afzali-Kusha, Ali; Jantti, Riku
MEA: an energy efficient algorithm for dense sector-based wireless sensor networks.
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING, 2012. pp. 39.
Electronic publication http://jwcn.eurasipjournals.com/content/2012/1/85/abstract

Nieminen, Jari; Björkbom, Mikael; Jäntti, Riku; Eriksson, Lasse
Multichannel Communications in Wireless Automation: Interdependencies between Communication and Control Parameters.
International Journal of Distributed Sensor Networks, 2012. Nro 1.
Electronic publication http://www.hindawi.com/journals/ijdsn/2012/614358/

Oruthota, Udesh; Tirkkonen, Olav
SER/BER Expression for M-QAM OFDM Systems with Imperfect Channel Estimation and I/Q Imbalance.
EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING, 2012. Nro 9.
Electronic publication http://jwcn.eurasipjournals.com/content/2012/1/303/abstract
(doi:10.1186/1687-1499-2012-303)

Peltomaki, Matti; Koljonen, Juha-Matti; Tirkkonen, Olav; Alava, Mikko
Algorithms for Self-Organized Resource Allocation in Wireless Networks.
IEEE transactions on vehicular technology, 2012. Vol. 61, nro 1, pp. 346-359.

Pitkänen, Mikko; Kärkkäinen, Teemu; Ott, Jörg; Conti, Marco; Passarella, Andrea; Giordano, Silvia; Pucinelli, Danielle; Legendre,Franck; Trifunonic, Stefan; Hummel, Karin; May, Martin; Hedge, Nidhin; Spyropoulos, Akis
SCAMPI: Service platform for soCial Aware Mobile and Pervasive computIng.
ACM Computer Communications Review, 2012. Vol. 2, nro 4, pp. 503-508..

Poikonen, Jussi; Lehtonen, Eero; Laiho, Mika
On synthesis of Boolean expressions for memristive devices using sequential implication logic.
IEEE transactions on computer-aided design of integrated circuits and systems, 2012. Vol. 31, nro 7, pp. 1129-1134.

Reichl, Wolfgang; Reichl, Peter; Reichel, Peter
Out of the Wireless Access Bottleneck Trap: Technologies, Economics, Regulation and Standardization Perspectives.
e & i Elektrotechnik und Informationstechnik, 2012. Vol. 129, nro 6, pp. 400-406.
Electronic publication http://link.springer.com/article/10.1007%2Fs00502-012-0056-6#

Sridhar, Varadharajan; Casey, Thomas; Hämmäinen, Heikki
Flexible spectrum management for mobile broadband services: How does it vary across advanced and emerging markets.
Telecommunications policy, 2012.
Electronic publication http://www.sciencedirect.com/science/article/pii/S0308596112001310)

Suomi, Henna; Kilkki, Kalevi; Hämmäinen, Heikki
Modeling the Value of End-to-End Multipath Protocols.
Journal of Universal Computer Science, 2012. Vol. 18, nro 14, pp. 2071-2092.
Electronic publication http://www.jucs.org/jucs_18_14/modeling_the_value_of

Ukhanova, Anna; Belyaev, Evgeny; Wang, Le; Forchhammer, Søren
Power consumption analysis of constant bit rate video transmission over 3G networks.
The International Journal for the Computer and Telecommunications Industry, 2012. Nro 35, pp. 1695-1706.

Wei, Lu; Tirkkonen, Olav
Spectrum sensing in the presence of multiple primary users.
IEEE transactions on communications, 2012. Vol. 60, nro 5, pp. 1268-1277.

Yan, Zheng; Chen, Yu; Shen,Yue
A Practical Reputation System for Pervasive Social Chatting.
Elsevier's Journal of computer and system sciences, 2012.
Electronic publication http://www.sciencedirect.com/science/article/pii/S0022000012001717
(DOI: 10.1016/j.jcss.2012.11.003 (IF: 1.157))

Yan, Zheng; Zhang, Peng; Deng, Robert H.
TruBeRepec: A Trust-Behavior-Based Reputation and Recommender System for Mobile Applications.
PERSONAL AND UBIQUITOUS COMPUTING, 2012. Vol. 16, nro 5, pp. 458-506.
Electronic publication http://www.springerlink.com/content/u53573ul1657t7w4/

Yigitler, Huseyin; Mahmood, Aamir; Virrankoski, Reino; Jäntti, Riku
Recursive clock skew estimation for wireless sensor networks using reference broadcasts.
IET Wireless Sensor Systems, 2012. pp. 1-13.

Electronic publication http://dx.doi.org/10.1049/iet-wss.2011.0137

Yilmaz, Osman N. C.; Hämäläinen, Jyri; Hämäläinen, Seppo
Self-optimization of random access channel in 3rd Generation Partnership Project Long Term Evolution.
Wireless Communications and Mobile Computing, 2012. Vol. 11, nro 12, pp. 1507–1517.
Electronic publication http://dx.doi.org/10.1002/wcm.1217

Yilmaz, Osman N.C.; Hämäläinen, Jyri; Hämäläinen, Seppo
Optimization of Adaptive Antenna System Parameters in Self-organizing LTE networks.
Journal of Wireless Networks, 2012.
Electronic publication http://link.springer.com/article/10.1007%2Fs11276-012-0531-3# (doi:
10.1007/s11276-012-0531-3)

Yu, Chia-Hao; Tirkkonen, Olav
Opportunistic Multiple Relay Selection with Diverse Mean Channel Gains.
IEEE transactions on wireless communications, 2012. Vol. 11, nro 3, pp. 885-891.

Zheng, Zhong; Wei, Lu; Hamalainen, Jyri; Tirkkonen, Olav
Approximation to Distribution of Product of Random Variables Using Orthogonal Polynomials for Lognormal Density.
IEEE communications letters, 2012. Vol. 16, nro 12, Pages 2028- 2031.
Electronic publication http://ieeexplore.ieee.org/search/searchresult.jsp?
newsearch=true&queryText=Zhong+Zheng+Wei+Lu+H%C3%A4m%C3%A4l%C3%
A4inen+Jyri&x=6&y=23

Zhou, Min; Cui, Qimei; Jäntti, Riku
Energy-Efficient Relay Selection for Two-Way Relay Channel with Analog Network Coding.
IEEE communications letters, 2012. Vol. 16, nro 6.

Östergård, Patric Ralf Johan
Switching codes and designs.
Discrete mathematics, 2012. Vol. 312, nro 3, pp. 621-632.

ARTICLES IN CONFERENCE PROCEEDINGS

Ahmed, Furqan; Dowhuszko, Alexis; Tirkkonen, Olav
Distributed Algorithm for Downlink Resource Allocation in Multicarrier Small Cell Networks.
1st International Workshop on Small Cell Wireless Networks, ICC 2012,Ottawa,
Canada June 15th, 2012.

Alam, Mirza Nazrul; Jäntti, Riku; Kneckt, Jarkko; Nieminen, Johanna
Performance Study of IEEE 802.11s PSM in FTP-TCP.
IEEE VTC2012-Fall, Québec City, Canada, September 3-6 , 2012.

Amin, Parth; Ganesan, Vishnu; Tirkkonen, Olav
Bridging Interference Barriers in Self-Organized Synchronization.
IEEE International Conference on Self-Adaptive and Self-Organizing Systems, Lyon,
France, Sept 10-14 2012. pp. 1-10.

Amin, Parth; Tirkkonen, Olav; Henttonen, Tero; Pernila, Esa
Primary component carrier selection for a heterogeneous network: A comparison of Selfish, Altruistic and Symmetric Strategies.
IEEE Wireless Communications and Networking Conference, Paris, France, April 1-4,
2012 April. pp. 115-119.

Arianfar, Somaya; Sarolahti, Pasi; Ott, Jörg
Marooned Magic Numbers - An Adaptive Congestion Control Architecture.
IEEE International Conference on Network Protocols (ICNP'12), Austin, Texax, USA,
Oct 30 - Nov 2, 2012.

Arianfar, Somaya; Sarolahti, Pasi; Ott, Jörg
Reducing Server and Network Load with Shared Buffering.
ACM CoNEXT Capacity Sharing Workshop (CSWS '12), Nice, France, Dec 10-13,
2012.

Basaure, Arturo; Casey, Thomas R.; Hämmäinen, Heikki
Different regulation paths towards cognitive radio technologies: Cases of Finland and Chile.
23rd European Regional Conference of the International Telecommunication Society,
Vienna, Austria, 1-4 July 2012.
Electronic publication http://hdl.handle.net/10419/60373

Berg, Kimmo; Katsigiannis, Michail
Optimal cost-based strategies in mobile network offloading.
7th International Conference on Cognitive Radio Oriented Wireless Networks,
(CROWNCOM), 18-20 Jun. 2012.

Bilogrevic, Igor; Jadliwala, Murtuza; Lam, Istvan; Aad, Imad; Ginzboorg, Philip; Niemi,Valtteri;
Bindschaedler, Laurent; Hubaux, Jean-Pierre
Big Brother Knows Your Friends: on Privacy of Social Communities inPervasive Networks.
10th International Conference on Pervasive Computing (PERVASIVE 2012), Newcastle, UK, June 18-22,
2012.

Bindschaedler, Laurent; Jadliwala, Murtuza; Bilogrevic, Igor; Aad, Imad; Ginzboorg,Philip; Niemi, Valtteri;
Hubaux, Jean-Pierre
Track Me If You Can: On the Effectiveness of Context-based Identifier Changes in Deployed Mobile Networks,.
19th Annual Network & Distributed System Security Symposium (NDSS 2012), San
Diego, USA, 5-8 February 2012.
Electronic publication http://www.internetsociety.org/track-me-if-you-can-effectiveness-contextbased-
identifier-changes-deployed-mobile-networks

Bou Saleh, Abdallah; Bulakci, Ömer; Redana, Simonen; Raaf, Bernhard; Hämäläinen, Jyri
Evaluating the Energy Efficiency of LTE-Advanced Relay and Picocell Deployments.
IEEE Wireless Communications and Networking Conference (WCNC), Paris, France,
April 1-4, 2012. , pp. 2335-2340.
Electronic publication http://ieeexplore.ieee.org.libproxy.aalto.fi/xpl/articleDetails.jsp?
tp=&arnumber=6214184&contentType=Conference+Publications&searchField%3DSearch_All%
26queryText%3DEvaluating+the+Energy+Efficiency+of+LTEAdvanced+
Relay+and+Picocell+Deployments

Bulakci, O.; Nedelcu, A.S.; Bou Saleh, A.; Redana, S.; Hämäläinen, J.
Impact of backhaul subframe misalignment on uplink system performance of LTE-advanced relay networks.
76th IEEE Vehicular Technology Conference, VTC Fall 2012, Quebec City, QC, 3 September 2012 - 6 September 2012. 6399103.
Electronic publication http://dx.doi.org/10.1109/VTCFall.2012.6399103

Casey; Thomas R; Ali-Vehmas, Timo
Value system evolution towards a cognitive radio era: Implications of underlying market dynamics.
The 6th IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks,
Washington, USA, Oct 16, 2012 - Oct 19, 2012.

Chen, J.; Ding, M.; Zhang, Q.T.
Interference statistics and performance analysis of MIMO Ad hoc networks in binomial fields.
the Seventh International Wireless Communications and Mobile Computing Conference, Istanbul, Turkey, July 5–8, 2011. 2012, IEEE, pp. 2033-2043.
Electronic publication http://dx.doi.org/10.1109/TVT.2012.2189252

Chen, Yu; Yan, Zheng
Gemini: a Handbag for Pervasive Social Communications.
IEEE TrustID 2012, Liverpool, UK, June 25-27, 2012.

Costa-Requena, Jose; Ferrater, Carles; Manner, Jukka; Peuhkuri, Markus
Analysis of Energy Efficiency Metrics in Data Centres.
The 2012 IEEE SG-TEP. 2012 IEEE International Conference on Smart Grid Technology, Economics and Policies (SG-TEP). Nuremberg, Germany, December 3-4, 2012.

Czeizler, Eugen; Popa, Alexandru
Synthesizing Minimal Tile Sets for Complex Patterns in the Framework of Patterned DNA Self-Assembly.
DNA Computing and Molecular Programming - 18th International Conference (DNA 18) DNA, Aarhus, Denmark, August 14-17, 2012. **2012**, Springer, pp. 58-72.
Electronic publication http://link.springer.com/chapter/10.1007/978-3-642-32208-2_5

Dharmawansa, P.; McKay, M.R.; Smith, P.J.
Generalized framework for the level crossing analysis of ordered random processes.
2011 IEEE International Conference on Communications. pp. 3536-3547.
Electronic publication http://dx.doi.org/10.1109/TIT.2012.2184737

Dinu, L.P.; Popa, A.
On the closest string via rank distance.
23rd Annual Symposium on Combinatorial Pattern Matching, CPM 2012, Helsinki, 3 July 2012 - 5 July 2012. pp. 413-426.
Electronic publication http://dx.doi.org/10.1007/978-3-642-31265-6_33

Dinu, Liviu; Popa, Alexandru
On the center string via rank distance.
Combinatorial Pattern Matching (CPM) 2012 Helsinki July 3–5 2012. pp. 413-426.

Elsherif, Ahmed R.; Ding, Zhi; Liu, Xin; Hämäläinen; Jyri
Shadow Chasing Enhancement in Resource Allocation For Heterogeneous Networks.
IEEE Global Communications Conference (GLOBECOM), Anaheim, California, USA,
December 3-7, 2012.

Elsherif, Ahmed Ragab ; Ding, Zhi; Liu, Xin; Hämäläinen, Jyri; Wichman, Risto
Shadow Chasing : A Resource Allocation Scheme For Heterogeneous Networks.
7th International Conference on Cognitive Radio Oriented Wireless Networks (CrownCom), WiFiUS Track, Stockholm, Sweden, 18-20, June 2012.

Ginzboorg, Philip; Niemi, Valtteri; Ott, Jörg
Message fragmentation for a chain of disrupted links.
IEEE WoWMoM workshop on Autonomous and Opportunistic Communication (AOC), San Francisco, California, USA June 25-28, 2012.

Haile, Beneyam Berehanu; Mutafungwa, Edward; Warma, Henna
Development of the Wi-Fi Offloading Business Concept with the African Market Context.
The 6th Scientific Conference on Electrical Engineering in AAiT, Addis Ababa, Ethiopia 12th Oct, 2012. pp. 7.

Heikkinen, M.V.J.; Berger, A.W.
Comparison of user traffic characteristics on mobile-access versus fixedaccess networks.
13th International Conference on Passive and Active Measurement, PAM 2012, Vienna, 12 March 2012 - 14 March 2012. pp. 32-41.
Electronic publication http://dx.doi.org/10.1007/978-3-642-28537-0_4

Heikkinen, M.V.J.; Nurminen, J.K.
Measuring and modeling mobile phone charger energy consumption and environmental impact.
2012 IEEE Wireless Communications and Networking Conference, WCNC 2012, Paris, 1 April 2012 - 4 April 2012. 2012, IEEE, pp. 3194-3198.
Electronic publication http://dx.doi.org/10.1109/WCNC.2012.6214357

Holopainen, Visa
On finding multicast paths in the Internet.
IEEE International Conference on Communications, ICC 2012, Ottawa, Canada, June10.-15, 2012. pp. 2838-2843.

Holopainen, Visa
Towards robust, scalable, and fast Internet via Explicit Forwarding Engines (EFE).
IEEE International Conference on Communications, ICC 2012, Ottawa, Canada, June 10-15, 2012. pp. 2850-2855.

Hunanen, Tero; Tissari, Jari; Paavola, Jarkko; Poikonen, Jussi
Distributed Beamforming for Inter-cluster Communication in Ad Hoc Networks.
IEEE International Symposium on Wireless Communication Systems (ISWCS 2012), Paris, France, August 28-31, 2012.

Hwang, June; Yu, Seung Min; Kim, Seong-Lyun; Jäntti, Riku
On the Frequency Allocation for Coordinated Multi-Point Joint Transmission.
IEEE VTC2012-Spring, Yokohama, Japan, May 6-9, 2012.

Hyytiä, Esa; Lassila, Pasi; Ott, Jörg; Kangasharju; Jussi
Floating information with stationary nodes.
Eighth Workshop on Spatial Stochastic Models for Wireless Networks (SpaSWin) May 14th - 18th, 2012Paderborn, Germany. pp. 361-366.

Kantola, Raimo
Evolution Inspired Internet, position paper.
Future Internet Workshop, EU Commission, Information Society and Media Directorate, Bryssel, 9/2012.

Karikoski, Juuso; Mäkinen, Olli
Mobile social phonebooks.
The 16th International Conference on Intelligence in Next Generation Networks, Berlin, Germany, Oct 8, 2012 - Oct 11, 2012. pp. 157-164.
Electronic publication http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6376019

Kerttula, Jussi; Ruttik, Kalle; Jäntti, Riku
Dimensioning of secondary cellular system in TVWS.
CROWNCOM 2012, Stockholm, Sweden, June 18-20, 2012.

Kifle, Dereje Woldemedhin; Bulakci, Omer; Saleh, Abdallah Bou; Redana, Simone; Granelli, Fabrizio
Joint backhaul co-scheduling and relay cell extension in LTE-advanced networks uplink performance evaluation.
18th European Wireless Conference, University of Trento, via Sommarive 14 - 38123, Italy, 18-20 April 2012. pp. 1-8.
Electronic publication
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6216848&contentType=Conference+Publications&queryText%3Dbulakci

Korhonen, Timo
Invited Presentation: User-Centric Design of Medical Applications, Case: Developing Electronic Application Utility for Follow-Up of Wet Macular Degeneration.
XXXX Nordic Congress of Ophthalmology, Helsinki Finland, 25-28 Aug. 2012.

Koufos, Konstantinos; Ruttik, Kalle; Jäntti, Riku
Aggregate interference from WLAN in the TVWS by using terrain-based channel model.
IEEE International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM), Stockholm, Sweden, June 18-20, 2012.. pp.1-5.

Kärkkäinen, Teemu; Pitkänen, Mikko; Ott, Jörg
Enabling Ad-hoc Communication in Public WLAN Hot-Spots.
ACM MobiCom CHANTS workshop, August 22, 2012,Istanbul, Turkey.

Kärkkäinen, Teemu; Pitkänen, Mikko; Ott, Jörg
SCAMPI Application Platform.
ACM MobiCom CHANTS workshop, August 22, 2012, Istanbul, Turkey.

Lampinen, Marko; Del Carpio, Felipe; Kuosmanen, Tero; Koivisto, Tommi; Enescu, Mihai
System-Level Modeling and Evaluation of Interference Suppression Receivers in LTE System.
IEEE 75th Vehicular Technology Conference (VTC Spring), Yokohama, Japan, 6-9 May 2012. pp.1-5.
Electronic publication
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6239964&isnumber=6239848
(doi: 10.1109/VETECS.2012.6239964)

Lassila, Pasi; Penttinen, Aleksi; Aalto, Samuli
Flow-level modeling and analysis of dynamic TDD in LTE.
NGI 2012 (8th EURO-NF Conference on Next Generation Internet), Karlskrona, Sweden, June 25-27, 2012. pp. 33-40.

Electronic publication http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6252162

Lehtonen, Eero; Poikonen, Jussi; Laiho, Mika
Applications and limitations of memristive implication logic.
IEEE International Workshop on Cellular Neural Networks and their Applications (CNNA 2012), Turin, Italy,
August 29-31, 2012.

Lehtonen, Eero; Poikonen, Jussi; Laiho, Mika
Implication logic synthesis methods for memristors.
IEEE International Symposium on Circuits and Systems (ISCAS 2012), Seoul, Korea, May 20-23, 2012.

Leskinen, J.
Evaluation criteria for future identity management.
11th IEEE International Conference on Trust, Security and Privacy in Computing and Communications,
TrustCom-2012, Liverpool, 25 June 2012 - 27 June 2012. pp. 801-806.
Electronic publication http://dx.doi.org/10.1109/TrustCom.2012.153

Lizarraga, Enrique Mariano; Dowhuszko, Alexis A; Sauchelli, Victor Hugo
Symbol Merging Approach for Intercell Interference Mitigation in Wireless OFDM Systems.
IEEE Global Communications Conference, Globecom, Anaheim, California, USA, Dec. 3-7, 2012.

Lähetkangas, Eeva; Pajukoski, Kari; Tiirola, Esa; Hämäläinen, Jyri; Zheng, Zhong
On the Performance of LTE-Advanced MIMO: How to Set and Reach Beyond 4G Targets.
European Wireless (EW 2012), Posnan, Poland, 18-20 April 2012 .
Electronic publication
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6216849&contentType=Conference+Publi
cations&searchField%3DSearch_All%26queryText%3DAdmission+Control+for+LTE-
Advanced+Relay+Systems

Markendahl, J; Casey, Thomas R.
Business opportunities using white space, spectrum and cognitive radio for mobile broadband services.
7th International Conference on Cognitive Radio Oriented Wireless Networks, Stockholm, Sweden, June 18-
20, 2012.

Mazhelis, Oleksiy; Luoma, Eetu; Warma, Henna
Defining an Internet-of-Things Ecosystem.
The 5th conference on Internet of Things and Smart Spaces (ruSMART 2012), August 27-29, 2012, St.
Petersburg, Russia.

Michal Cierny, Risto Wichman, Jyri Hämäläinen, Cassio Ribeiro, Zhi Ding, Xin Liu
On TDD Cross-Tier In-Band Interference Mitigation: A Practical Example.
Crowncom 2012, Invited paper track at NSF WiFiUS meeting, Stockholm, June 18-20 2012. IEEE Xplore
2012, 6.

Moktan, Gautam Raj; Siikavirta, Sebastian; Särelä, Mikko; Manner, Jukka
Favoring the short.
Computer Communications Workshops (INFOCOM WKSHPS), the 15th Global Internet Symposium
workshop Orlando Florida, March 30 2012. pp. 31-36.
Electronic publication http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06193513

Määttänen, Helka-Liina; Tirkkonen, Olav
Simple Zero Interference Transmissions to Users with Rank Deficient Channels.

WPMC, Sept. 24.-27. 2012, Taipei, Taiwan. 5 pp.

Määttänen, Helka-Liina; Tirkkonen, Olav
Sum Rate Maximizing Zero Interference Linear Multiuser MIMO Transmission.
IEEE VTC, May 6.-9. 2012, Yokohama, Japan. pp. 1-5.

Nelimarkka, Matti; Karikoski, Juuso
Categorizing and measuring social ties.
RC33 Eighth International Conference on Social Science Methodology. Sydney, Australia, July 9-13 2012. ..
Electronic publication http://conference.acspri.org.au/index.php/rc33/2012/paper/view/347

Niemi, O.-P.; Levomaki, A.; Manner, J.
Dismantling intrusion prevention systems.
ACM SIGCOMM 2012 Conference Applications, Technologies, Architectures, and Protocols for Computer
Communication, SIGCOMM 2012, Helsinki, 13 August 2012 - 17 August 2012. pp. 285-286.
Electronic publication http://dx.doi.org/10.1145/2342356.2342412

Nieminen, J.; Jantti, R.; Eriksson, J.
Performance of target tracking applications in multi-channel wireless sensor networks.
2012 IEEE Wireless Communications and Networking Conference, WCNC 2012,
Paris, 1 April 2012 - 4 April 2012. pp. 1532-1537.
Electronic publication http://dx.doi.org/10.1109/WCNC.2012.6214025

Nieminen, Jari ; Qian, Lijun; Jäntti, Riku
Per-Node Throughput Performance of Overlapping Cognitive Radio Networks.
7th International Conference on Cognitive Radio Oriented Wireless Networks, June
18–20, 2012 Stockholm, Sweden.

Nousiainen, Jarno; Lassila, Pasi; Virtamo, Jorma
Instantaneous forwarding capacity under the SINR threshold interference model.
The 11th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net 2012) Ayia Napa, Cyprus 19-
22 June 2012. pp. 67-74.
Electronic publication http://dx.doi.org/10.1109/MedHocNet.2012.6257125

Nousiainen, Jarno; Virtamo, Jorma; Lassila, Pasi
Multidirectional Forwarding Capacity in a Massively Dense Wireless Network.
The 24th International Teletraffic Congress (ITC 24) pp. 1-8, 4-7 September 2012.

Ojaniemi, Jaakko; Poikonen, Jussi; Wichman, Risto
Effect of geolocation database update algorithms to the use of TV white spaces.
International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM 2012), Stockholm,
Sweden, June 18-20, 2012.

Oruthota, Udesh; Tirkkonen, Olav
I/Q Imbalance Compensation in Precoded MIMO-OFDMA Systems.
The 15th International Symposium on Wireless Personal Multimedia Communications, WPMC 2012,Taipei,
Taiwan, 24-27 September, 2012. pp.294-298.

Osti, Prajwal; Lassila, Pasi; Aalto, Samuli
Optimal intercell coordination for multiple user classes with elastic traffic.
NGI 2012 (8th EURO-NF Conference on Next Generation Internet), Karlskrona, Sweden, June 25-27, 2012.
pp. 25-32.

Electronic publication http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6252161

Ott, J.
404 not found? - A quest for DTN applications.
3rd ACM International Workshop on Mobile Opportunistic Networks, MobiOpp'12, Zurich, 15 March 2012 - 16 March 2012. pp. 3-4.
Electronic publication http://dx.doi.org/10.1145/2159576.2159579

Ott, Jörg; Kangasharju, Jussi
Opportunistic Content Sharing Applications.
ACM MobiHoc NOM workshop, June 11th, 2012, Head Island, South Carolina, USA.

Panchakarla, Nagasai; Ott, Jörg
Delay-tolerant Adaptive Real-time Communication: A Case Study for Voice.
ExtremeCom, March 10-14, Zurich, Switzerland.

Peuhkuri, Markus; Lääkkölä, Riku; Costa-Requana, Jose; Manner, Jukka
Datacenters — Energy Hogs or Helping to Optimize Energy Consumption.
The 2012 IEEE SG-TEP. 2012 IEEE International Conference on Smart Grid Technology, Economics and Policies (SG-TEP). Nuremberg, Germany, December 3-4, 2012.

Pietikäinen, Kari; Del Carpio, Felipe; Määttänen, Helka-Liina; Lampinen, Marko; Koivisto, Tommi; Enescu, Mihai
System-level performance of interference suppression receivers in LTE systems.
IEEE VTC, May 6.-9. 2012, Yokohama, Japan. pp. 1-5.

Pitaval, Renaud-Alexandre; Tirkkonen, Olav
Grassmannian Packings from Orbits of Projective Group Representations.
Asilomar Conference on Signals, Systems and Computers, Monterey, California,
USA, Nov. 4-7, 2012. 5 pp.

Pitaval, Renaud-Alexandre; Tirkkonen, Olav
Incorporating Stiefel Geometry in Codebook Design and Selection for Improved Base Station Cooperation.
IEEE Vehicular Technology Conference (VTC), Yokohama, Japan, May 6-9, 2012. 5 pp.

Pitaval, Renaud-Alexandre; Tirkkonen, Olav
Volume of Ball and Hamming-type Bounds for Stiefel Manifold with Euclidean Distance.
Asilomar Conference on Signals, Systems and Computers, Monterey, California, USA, Nov. 4-7, 2012. 5 pp.

Pitkänen, Mikko; Kärkkäinen, Teemu; Ott, Jörg; Conti, Marco; Passarella, Andrea; Giordano, Silvia; Pucinelli, Danielle; Legendre,Franck; Trifunonic, Stefan; Hummel, Karin; May, Martin; Hedge, Nidhin; Spyropoulos, Akis
SCAMPI: Service platform for soCial Aware Mobile and Pervasive computIng.
The ACM SIGCOMM workshop on Mobile Cloud Computing (MCC), Helsinki, Finland, Aug 13-17, 2012.

Pitkanen, M.; Karkkainen, T.; Ott, J.
Mobility and service discovery in opportunistic networks.
2012 IEEE International Conference on Pervasive Computing and Communications Workshops, PERCOM Workshops 2012, Lugano, 19 March 2012 - 23 March 2012. pp. 204-210.
Electronic publication http://dx.doi.org/10.1109/PerComW.2012.6197480

Pom nková, J; Ries, M; Reichl, Peter
Saturation Boundary Estimation for Social Networks.
11th Conference of Telecommunication, Media and Internet Techno-Economics (CTTE'12), Athens, Greece, June 7-8, 2012.

Popa, Alexandru
Approximating the rainbow - better lower and upper bounds.
International Computing and Combinatorics Conference (COCOON) 2012, Sydney, Australia 20 - 22 August 2012. pp. 193-203.

Popa, Alexandru; Wong, Prudence W.H.; Yung, Fencol C.C.
Hardness and Approximation of The Asynchronous Border Minimization Problem.
Theory and Applications of Models of Computation (TAMC) 2012- Beijing 16 - 21 May 2012. pp. 164-176.

Prochkova, Irena; Singh, Varun; Nurminen, Jukka K.
Energy Cost of Advertisements in Mobile Games on the Android Platform.
6th International Conference on Next Generation Mobile Applications, Services and Technologies (NGMAST), Paris, France 12-14 Sept, 2012. pp. 147 - 152.
Electronic publication http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=6327947
(Digital Object Identifier: 10.1109/NGMAST.2012.32)

Pääkkönen, Joonas; Dharmawansa, Prathapasinghe; Hollanti, Camilla; Tirkkonen, Olav
Distributed storage for proximity based services.
Swedish Communication Technologies Workshop (Swe-CTW), 2012.. pp. 30-35.

Ren, Zhe; Bou Saleh, Abdallah; Bulakci, Ömer; Redana, Simone; Raaf, Bernhard; Hämäläinen, Jyri
Joint Interference Coordination and Relay Cell Expansion in LTE-Advanced Networks.
IEEE Wireless Communications and Networking Conference (WCNC), Paris, FranceApril 1-4, 2012. pp. 2874-2878.
Electronic publication
http://ieeexplore.ieee.org.libproxy.aalto.fi/xpl/articleDetails.jsp?tp=&arnumber=6214292&contentType=Conference+Publications&searchField%3DSearch_All%26queryText%3DJoint+Interference+Coordination+and+Relay+Cell+Expansion+in+LTE-Advanced

Saarinen, M.-J.O.
The PASSERINE public key encryption and authentication mechanism.
15th Nordic Conference on Secure IT Systems, Espoo, 2012, Springer, pp. 283-288.
Electronic publication http://dx.doi.org/10.1007/978-3-642-27937-9_20

Sackl, A; Zwickl, P; Egger, S; Reichl, Peter
The QoE Alchemy: Turning Quality into Money. Experiences with a Refined Methodology for the Evaluation of Willingness-to-Pay for Service Quality.
4th International Workshop on Quality of Multimedia Experience (QoMEX'12), Yarra Valley, Australia, 5-7, July 2012.

Sevalnev, Mark ; Aalto, Samuli; Kommeri, Jukka; Niemi, Tapio
Using queueing theory for controlling the number of computing servers.
Third International Conference on Green IT Solutions,ICGREEN 2012, Geneva, Switzerland, July 2-3, 2012.

Shen, Yue; Yan, Zheng; Kantola, Raimo
Implementation of an Evaluation Platform for Unwanted Traffic Control via Trust Management.
IEEE iThings 2012, Besançon, France, November 20-23, 2012.

Singh, Varun; Ott, Jörg; Curcio, Igor
Predictive Buffering for Streaming Video in 3G Networks.
13th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), San Francisco, California, USA June 25—28, 2012. 10 pp.
Electronic publication http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6263710

Singh, Varun; Ott, Jörg; Curcio, Igor
Rate-control for Conversational Video Communication in Heteroge- neous Networks.
IEEE WoWMoM Video Everywhere (VIDEV) workshop, San Francisco, California, USA June 25—28, 2012. 6 pp.
Electronic publication http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6263800

Singh, Varun; Ott Jörg; Perkins Colin
Congestion Control for Interactive Media: Control Loops & APIs.
Internet Architecture Board (IAB)/Internet Research Task Force (IRTF) Workshop on Congestion Control for Interactive Real-Time Communication, Vancouver, Canada, July 2012. 3 pp.
Electronic publication http://www.tschofenig.priv.at/cc-workshop/irtf_iab-ccirtcpaper19.pdf

Soikkeli, Tapio; Karikoski, Juuso; Hämmäinen, Heikki
An End User Context Framework for Handset-based Studies.
International Telecommunications Society 19th Biennial Conference. Bangkok, Thailand, November 18-21 2012.
Electronic publication http://its2012bangkok.com/uploadfiles/fullpaper/full%20paper/3A-4_Tapio%20Soikkeli_An%20end%20user%20context%20framework%20for%20handset-based%20studies.pdf

Soni Garcia, Alejandra; Ott, Jörg; Ellis, Martin; Perkins, Colin
Virtual RTCP: A Case Study of Monitoring and Repair for UDP-based IPTV Systems.
Packet Video Workshop, 10-11 May, 2012 - Munich, Germany. pp. 6.

Studers, Mikelis; Ali, Yusein R.; Jäntti, Riku
Mobile Gateway for Connecting Wireless Sensor Networks to Internet.
3rd Workshop on Wireless Communication and Applications (WoWCA 2012), Vaasa, Finland,April 25-26 2012.

Talmola, Pekka; Kalliovaara, Juha; Paavola, Jarkko; Ekman, Reijo; Kokkinen, Heikki; Heiska, Kari; Wichman, Risto; Poikonen, Jussi
Field measurements of WSD-DTT protection ratios over outdoor and indoor reference geometries.
International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM 2012), Stockholm, Sweden, June 18-20, 2012.

Taparia, Ankit; Casey, Thomas R; Hämmäinen, Heikki
Towards a market mechanism for heterogeneous secondary spectrum usage: An evolutionary approach.
The 6th IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks, Washington, USA, Oct 16-19, 2012.

Tirkkonen, Olav; Jäntti, Riku
On alpha-Proportional Fair Packet Scheduling in OFDMA downlink.
50th Annual Allerton Conference on Communication, Control, and Computing, University of Illinois at Urbana-Champaign, IL, USA, October 1 - 5, 2012.

Tissari, Jari; Hurnanen, Tero; Poikonen, Jussi
Adaptive algorithm and parameter optimization for distributed beamforming in OFDM systems.
IEEE International Symposium on Wireless Communication Systems (ISWCS 2012), Paris, France, August 28-31, 2012.

Toivonen, Hannes; Mutafungwa, Edward; Hyvönen, Jukka; Ngogo, Elikana
Micro-Entrepreneurship and Local ICT Innovation Ecosystem in Iringa, Tanzania.
IST-Africa 2012 Conference, Dar es Salaam, Tanzania, 9-11 May 2012.

Ullah, Inam; Zheng, Zhong; Mutafungwa, Edward; Hämäläinen, Jyri
On the Use of Nomadic Relaying for Emergency Telemedicine Services in Indoor Environments.
The 3rd International ICST Conference on Wireless Mobile Communication and Healthcare (MOBIHEALTH 2012), Paris, 21-23 November 2012.

Vitiello, Federica; Redana, Simone; Hämäläinen, Jyri
Admission Control for LTE-Advanced Relay Systems.
European Wireless (EW 2012), Pozna , Poland April 18-20, 2012.
Electronic publication
http://ieeexplore.ieee.org.libproxy.aalto.fi/xpl/articleDetails.jsp?tp=&arnumber=6216849&contentType=Conference+Publications&searchField%3DSearch_All%26queryText%3DAdmission+Control+for+LTE-Advanced+Relay+Systems

Wahmüller, S.; Zwickl, P; Reichl, Peter
Pricing and Regulating Quality of Experience.
8th Euro-NF Conference on Next Generation Internet (NGI'12), Karlskrona, Sweden, June 25-27, 2012. ..

Wang, Qinghua
Resource-constrained teaching - a 'networking lab' practice, finalized as a project report to the Aalto University pedagogical training course Work-based project on educational development.
PEDA Forum 2012, Espoo, Finland, August 2012.

Wang, Qinghua; Jäntti, Riku; Ali, Yusein
On network management for the Internet of Things.
8th Swedish National Computer Networking Workshop (SNCNW'12), Stockholm, Sweden, June 2012.
Electronic publication http://users.tkk.fi/wangq1/SNCNW_OnNetworkManagement.pdf

Wang, Qinghua; Yigitler, Huseyin; Jäntti, Riku
System monitoring and fault diagnosis in wireless sensor networks.
Aalto University Workshop on Wireless Sensor Systems (WoWSS 2012), Espoo Finland, 11 December 2012.
Electronic publication http://wsn.aalto.fi/en/activities/wowss2012/program/

Wei, Lu; Dharmawansa, Prathapasinghe; Tirkkonen, Olav
Locally best invariant test for multiple primary user spectrum sensing.
International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Stockholm 18-20, June 2012.

Wei, Lu; Tirkkonen, Olav; Dharmawansa, Prathapasinghe; McKay, Matthew R.
On the exact distribution of the scaled largest eigenvalue.
IEEE International Conference on Communications (ICC), Ottawa, June 2012.

Yan, Zheng; Chen, Yu; Zhang, Peng
An Approach of Secure and Fashionable Recognition for Pervasive Face-to-Face Social Communications.
IEEE WiMob 2012, Barcelona, Spain, Oct. 8-10, 2012.

Yan, Zheng; Kantola, Raimo; Shen, Yue
Unwanted Traffic Control via Hybrid Trust Management.
IEEE TrustCom 2012, Liverpool, UK, June 25-27, 2012.

Yilmaz, Osman N.C.; Mutafungwa, Edward; Hämäläinen, Jyri
Performance of Relay Enhanced LTE-Advanced Networks for Selected Suburban Scenarios in Emerging Market Environments.
International Wireless Communications and Mobile Computing Conference (IWCMC), 2012 8th International, Paris, France, August 2012.

Yu, Chia-Hao; Mumey, Brendan; Tirkkonen, Olav
Distributed Multiple Relay Selection by an Auction Mechanism.
IEEE GLOBECOM, Anaheim, California, USA, 3-7 Dec, 2012. 6 pp.

Yu, Chia-Hao; Tirkkonen, Olav
Device-to-Device Underlay Cellular Network Based on Rate Splitting.
IEEE Wireless Communications and Networking Conference (WCNC 2012), Paris, France, April 1-4, 2012. pp. 262-266.

Zhang, Miaomiao; Wang, Qinghua
Classifying web texts based on syntactic and grammatical modeling.
8th Swedish National Computer Networking Workshop (SNCNW'12), Stockholm, Sweden, June 2012.
Electronic publication http://users.tkk.fi/wangq1/SNCNW_ClassifyingWebTexts.pdf

Zhang, Nan; Hämmäinen, Heikki; Levä, Tapio
Future Scenarios of Commercial Internet Content Delivery.
The 23rd European Regional Conference of the International Telecommunication Society, July 1-4, Vienna, Austria.

Zhang, Peng; Sun, Hanlin; Yan, Zheng
A Novel Architecture based on Cloud Computing for Wireless Sensor Network.
The 2nd International Conference on Computer Science and Electronics Engineering (ICCSEE 2013), March 22-23, 2013 Hangzhou, China.

Zhang, Peng; Sun, Hanlin; Yan, Zheng
Mechanism for Security Enhancement in Mobile Application Installation.
International Conference on Computer Science and Communication Technology (CSCT2012), Qingdao, China, Dec 23-25, 2012.

Zheng, Yu; Ali, Yusein; Wang, Qinghua; Jantti, Riku
6LoWPAN-based Networking for Wireless Sensor Network - A survey.
3rd Workshop on Wireless Communication and Applications (WoWCA 2012) Vaasa, April 25-26, 2012.

THESES

| Author: Topic	Supervisor
Acharya, Vivek: Energy Consumption of IP vs Ethernet	Jukka Manner
Adhikari, Aashish: Mobile Device Identification from Network Traffic Measurements – A HTTP User Agent Based Method	Heikki Hämmäinen
Alemu, Tizazu Bayileyegn: Spectrum Availability Assessment Tool for TV White Space	Riku Jäntti
Apajalahti, Lauri: Asiakaslähtöisyyden vahvistaminen asiantuntijayrityksen toimintaprosesseissa	Kalevi Kilkki
Beyene, Yihenew Dagne: TV Black-space Spectrum Access for Wireless Local Area and Cellular Networks	Riku Jäntti
Bisalbutra, Sarantorn: Publish/Subscribe Gateway for Real-time Communication	Jörg Ott
Chemmagate, Binoy: An Experimental Study of Web Transport Protocols in Cellular Networks	Lars Eggert
Del Carpio Vega, Luis Felipe: System level modeling and evaluation of advanced linear interference aware receivers	Olav Tirkkonen
Elkadi, Ibrahim: Impact of Content Caching on Competitive Dynamics of Internet Content Delivery Ecosystem	Heikki Hämmäinen
Elo, Matias: Hardware Accelerated Software Packet Processing	Jukka Manner
Erkkilä, Juho: Pääsynhallintamenetelmät ja niiden tehostaminen IT-ulkoistuspalveluntarjoajan näkökulmasta	Kalevi Kilkki
Ferrater Grau, Carles: Measurements and power performance of data centers	Jukka Manner
Finley, Benjamin: Time Dependent Mobile Broadband Pricing	Kalevi Kilkki
Gürlek, Gonca: Simulation of measurement devices in medical network	Jörg Ott
Harjanne, Atte: Engaging Small and Medium Size Enterprises in European Union Funded Research and Development Projects	Jukka Manner
Hassen, Tewodros Wolde: Synchronization in Cognitive Overlay Systems	Olav Tirkkonen
Helenius, Atte: Performance of Handover in Long Term	Raimo Kantola

Evolution

Junni, Heikki: Uuden radiolinkin käyttöönotto	Jyri Hämäläinen
Kajander, Antti: Integrating a Third-Party IS-IS Software Component into a Distributed Routing System	Jukka Manner
Kaleva, Esko: Taktisen IP-keskuksen järjestelmävaatimusten laadinta	Riku Jäntti
Karonmaa, Kalle: Performance evaluation of software switching using commodity hardware	Jukka Manner
Khattak, Fida Ullah: Dual Stack Mobile IP Security and Bootstrapping	Jörg Ott
Kiiskilä, Mikko: Product Discovery Toolkit – Four Steps to Transform Business Ideas into Feasible Concepts	Timo Korhonen
Kivistö, Atte: Telepalveluihin kohdistuvien kuluttajayhteydenottojen käsittelyprosessin kehittäminen	Raimo Kantola
Kolenchery, Jipson Paul: Metropolitan Area Network Evolution	Raimo Kantola
Kuikka, Sanna-Mari: VoIP Design with Unified Communications	Jukka Manner
Laaksonen, Paavo: Critical Factors of High-Speed Broadband Investments in Rural Areas from Perspective of Operators	Heikki Hämmäinen
Lahtinen, Niko: Integrating and Dimensioning Security Camera Systems	Jörg Ott
Leppäaho, Petri: Design of Application Layer Gateways for Collaborative Firewalls	Raimo Kantola
Lindroos, Reijo: Käyttäjäroolit rakennusten tietomallien tarkastamisessa	Kalevi Kilkki
Llorente Santos, Jesus: Private Realm Gateway	Raimo Kantola
Mikola, Joona: Analysis of Migration Scenarios from Synchronous to Packet Transmission in an Operator Network	Raimo Kantola
Mörsky, Marika: Real-time Media Transport over World Wide Web	Raimo Kantola
Nagy, Marcin: Using FEC for Rate Adaptation of Multimedia Streams	Jörg Ott
Neissi Shooshtari, Ali: Optimizing handover performance in LTE networks containing relays	Jyri Hämäläinen

Nieminen, Jani: Radio Resource Optimisation for Smartphone Data Users in 3G Networks — Jukka Manner

Othman, Taha: Usability and User Interface Development for Packet Core Network Element — Jukka Manner

Paaso, Juho: Guaranteed access over consumer-level connections — Jukka Manner

Panchakarla, Nagasai: Adaptive Voice Applications over Delay Tolerant Networks — Jörg Ott

Pérez Trigal, Alberto: Measurement Methodology for Smartphone Data Service Quality — Jukka Manner

Poikonen, Henri: Impact of mobile packet core delays to overall radio system performance — Jyri Hämäläinen

Pääkkönen, Joonas: Distributed Storage for Proximity Based Services — Olav Tirkkonen

Rahikka, Olli: Usability Evaluation in Mobile Operating Systems for Touchscreen Smartphones — Timo Korhonen

Rozain, Sèbastien: Cost-efficiency in energy-efficient data centers — Jukka Manner

Shah, Syed Safi Ali: Media Processing in Video Conferences for Cooperating Over the Top and Operator Based Networks — Jörg Ott

Sidhwani, Reema: Antenna tuning for WCDMA RF front end — Olav Tirkkonen

Srinivasan, Ashvin: Codebook Design for Limited Feedback Multiple Input Multiple Output Systems — Olav Tirkkonen

Taipale, Tuomas: Feasibility of wireless mesh for LTE-Advanced small cell access backhaul — Jukka Manner

Taparia, Ankit: Market Mechanisms Towards Secondary Spectrum Usage — Heikki Hämmäinen

Ullah, Inam: Performance Analysis of LTE-Advanced Relay Node in Public Safety Communication — Jyri Hämäläinen

Ullah, Zia: Energy Consumption Measurements of Wireless Systems — Riku Jäntti

Wang, Xirui: Service Localization of Ubiquitous Health Care in China — Timo Korhonen

Vanipenta, Sarala: Application of Self Organizing Map in
Understanding Cultural Factors and Change

Timo Korhonen

Vehanen, Joona: Handover between LTE and 3G Radio Access
Technologies: Test measurement challenges and field
environment test planning

Jyri Hämäläinen

Venkata, Karthik: External Media Announcement Approach for
Media Resource Function Processor

Jukka Manner

Vihervuori, Lauri: Enabling IPv6 on Customer Edge Firewall

Jukka Manner

Yin, Junxi: Mobile Implementation of Floating Content Service

Jörg Ott

Younge, Edward Sereko: A Testbed for Protocol Analysis for the
Internet of Things

Jörg Ott

ACTIVITIES
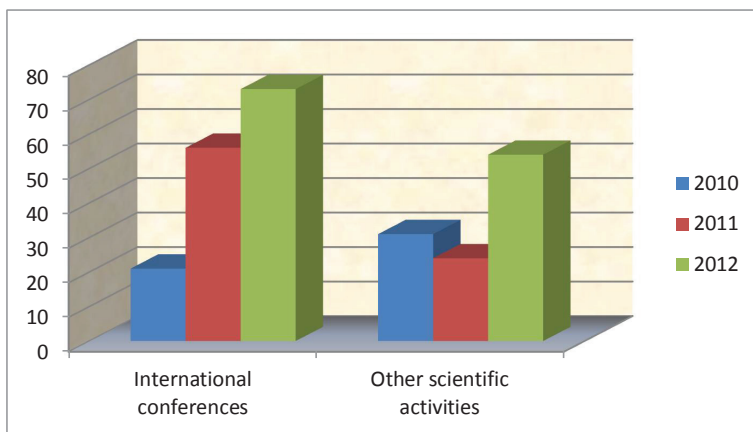
ACADEMIC ACTIVITIES

Esa Hyytiä

- External Examiner of Doctoral Thesis, Joni Pajarinne, Aalto University

Heikki Hämmäinen

- Opponent to Erkki Kurkinen, University of Jyväskylä

Raimo Kantola

- External Examiner, Tapio Saarelainen, National Defense University

Jyri Hämäläinen

- Opponent to Henrik Martikainen, University of Jyväskylä
- Opponent to Tero Isotalo, Tampere University of Technology
- Opponent to Ari Pouttu, University of Oulu
- External Examiner of Doctoral Thesis, Tero Isotalo, Tampere University of Technology
- External Examiner of Doctoral Thesis, Yong Fan, Tampere University of Technology

Riku Jäntti

- Opponent to Marja Matinmikko, University of Oulu
- External Examiner of Doctoral Thesis, Jarkko Itkonen, Tampere University of Technology
- External Examiner of Doctoral Thesis, Jukka Suhonen, Tampere University of Technology
- External Examiner of Doctoral Thesis, Marja Matinmikko, University of Oulu
- External Examiner of Doctoral Thesis, Seong-Woo Ko, Yonsei University

Jörg Ott

- Opponent to Michael Doering, TU Braunschweig
- Opponent to Amir Krifa, l'Université de Nice Sophia Antipolis
- Opponent to Erik Kuiper, Linköping University
- External Examiner of Doctoral Thesis, Tiia Ojanperä, University of Oulu

Jussi Poikonen

- External Examiner of Doctoral Thesis, David Gozálvez Serrano, Universidad Politécnica de Valencia

Patric Östergård

- Opponent to Thomas Westerbäck, Kungliga Tekniska Högskolan
- Opponent to Anton Malevich, Otto-von-Guericke-Universität Magdeburg
- External Examiner of Doctoral Thesis, Anton Malevich, Otto-von-Guericke-Universität Magdeburg

CHAIRMANSHIPS AT THE CONFERENCES IN 2012

Riku Jäntti

- Crowncom 2012, Stockholm, Sweden

Raimo Kantola

- The 2nd IEEE International Symposium on Trust and Identity in Mobile Internet, Computing and Communications (TrustID 2012), Liverpool, UK

Jukka Manner

- ACM SIGCOMM 2012, Helsinki, Finland

Jussi Poikonen

- Crowncom 2012, Stockholm, Sweden

Jörg Ott

- ACM SIGCOMM 2012, Helsinki, Finland

Lu Wei

- IEEE International Conference on Communications (ICC): Spectrum Sensing for Cognitive Radio Session, Ottawa, Canada

Zheng Yan

- IEEE DASC 2012, Changzhou, China
- The IEEE International Conference on Internet of Things, IEEEiThings 2012 CPSCom/GreenCom2012, iThings application, Besançon, France
- The 11th IEEE International Conference on Trust, Security and Privacy in Computing and Communications, Liverpool, UK
- The 2nd IEEE International Symposium on Trust and Identity in Mobile Internet, Computing and Communications (TrustID 2012), Liverpool, UK

Patric Östergård

- ICTP-IPM Workshop and Conference in Combinatorics and Graph Theory, Trieste, Italy

VISITS ABROAD IN 2012

Visa Holopainen

- Grafenwoehr, Germany, 2 weeks

Esa Hyytiä

- Berkeley, USA, 1 month

Marko Luoma

- Grafenwoehr, Germany, 2 weeks

Zheng Yan

- Xidian University, China, 4 months

FOREIGN VISITORS IN 2012

- Bhamri, Ankit from Eurecom, France
- Bhatnagar, Manav from Indian Institute of Technology, India
- Berardinelli, Gilberto from Aalborg University, Denmark
- Bourreau, Marc from Telecom ParisTech, France
- Bulakci, Ömer from NSN, Germany
- Danziger, Peter from Ryerson University, Canada
- Hartke, Klaus from Universität Bremen, Germany
- Hess, Andrea from University of Vienna, Austria
- Madden, Gary from Indian Institute of Technology, India
- Mo, Jeonghoon from Yonsei University, Korea
- Mähönen, Petri from RWTH Aachen University, Germany
- Rupp, Markus from Institute of Telecommunications, Austria
- Schulzrinne, Henning from Columbia University, USA
- Schürmann, Dominik from TU Braunschweig, Germany
- Uykan, Zekeriya from Dogus University, Turkey
- Zander, Jens from Kungliga Tekniska högskolan, Sweden
- Zavalnij, Bogdan from University of Pecs, Hungary
- Zhang, Jialiang from University of Electronic Science and Technology of China, China
- Zhang, Yingni from Beijing University of Posts and Telecommunications (BUPT), China
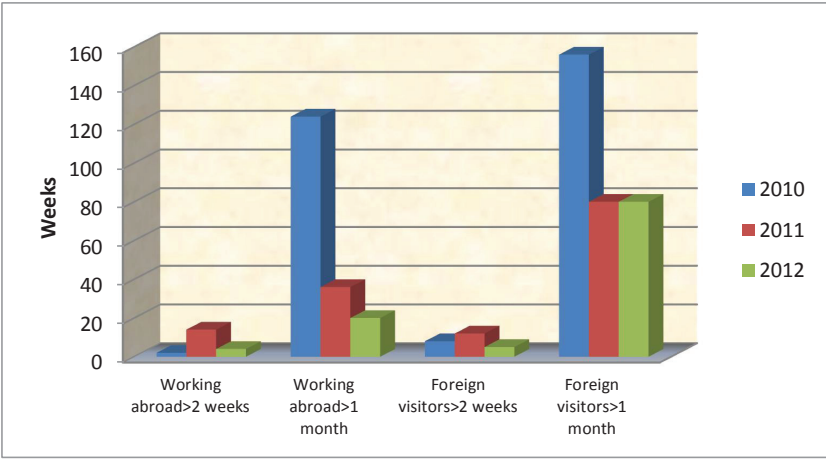
BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL
DISSERTATIONS