Background and Mission
The mission of the Wireless Communication Systems Group (WICS) is to conduct world-class research, train world-class graduates, create new technology and IPRs, and support society by transferring technology to practical usage. WICS is internationally perceived as a forerunner in its field, and a valued partner for research cooperation. Much of its success is due to the capability to react fast to the changes taking place in the operational environment, as well as to the needs expressed by its research partners. As a provider of high-quality university training, WICS aims at producing theses and dissertations, and peer-reviewed publications of the highest rank.

On the global scale, WICS possesses the extraordinary knowledge and prestige demanded for cross-layer wireless system research and optimization. WICS is one of the largest university-based groups in the field of communications engineering and networking, and has a strong focus on industry cooperation and relevance. Currently, WICS employs approximately 130 research and teaching staff members, and operates with a total budget of €9.1 million, 81% of which comes from external funding sources. In essence, WICS is an extremely international research and working environment with 48% of its staff of non-Finnish origin, including two full-time and three part-time professors. Due to its composition and wide international research networks, the group has exceptionally strong potential influence on the global development of practical systems and research trends. WICS runs Master’s level training in Wireless Communications Engineering, and currently offers possibilities for international double degrees with four countries within the CWC International Double Degree Doctoral programme.

Scientific Progress
In 2013, WICS was running 65 research projects with external research funding, including nine projects with international funding, whereas in 2012 the total number of projects was 54. The results of intensive project work produced 48 peer-reviewed international journal papers and 81 peer-reviewed international conference papers. The year was also successful from the perspective of academic degrees, as 8 doctoral students from WICS defended their theses.

Excellent scientific results were produced in 2013 in both the fundamental research areas and applied research areas of WICS. Based on the WICS mission statement and strategy, fundamental research was conducted on Signal Processing for Wireless Systems, Radio Access Networks and the Future Wireless Internet as portrayed in Figure 1. The research focus and outcome of the three research areas, functioning as research groups, is presented in the following.

Signal Processing for Wireless Systems
WICS researchers involved in “Signal Processing for Wireless Systems” focus essentially on technologies required for efficient implementation of the multitude of wireless devices or network nodes of the future connected society by facilitating improved connectivity with moderate device and system complexity. This will enable improved energy, bandwidth and cost efficiency of wireless systems and the consequent applications. The research methodology of the research group is based on fundamental theories behind the signal processing paradigm, such as statistical inference, and communications and information theory. In addition, computing and signal processing architecture technologies and electromagnetism are applied to realise the developed solutions on real wireless devices; also electromagnetism, antenna design and related optimization are studied by the group members. The focal area of the research is to develop transceiver algorithms and their realizations for dense wireless networks, in particular for communication ranges diminishing in indoor and urban areas. Extreme examples include body area networks, and nanoscale or molecular communications. Efficient interference management, resource allocation and routing algorithms is one area of system algorithm research; this implies that minimization of system level control overhead is important. The focus is on the design and realization of the algorithms, in ad-
dation to which access and networking technologies are explored in order to guarantee seamless interplay of the network nodes. This enables on-line optimization for energy efficient system operation as configurability of the devices becomes more important in the future. Application layer processing is also taken into consideration from the perspective of compression and joint-source channel coding to improve the overall system efficiency via the signal processing research paradigm. The innovative research group aims at creating radically novel solutions that enable the convergence of networks and services. All this facilitates possible major breakthroughs in signal processing technologies, and their application for wireless connectivity and services from large area coverage to molecular communications. The practical application areas of the research include wireless access networks, Internet of Things, and wireless sensor networks covering various medical and well-being services.

In 2013, the research work carried out by the signal processing experts resulted, in, for example:

- joint source-channel coding inspired multihop link and code design for ad hoc networks
- new constellation and precoder designs for channels with channel estimation errors
- distributed optimization methods for rate maximization and power minimization in cellular networks with channel uncertainty and secrecy constraints.

The year 2014 will bring yet new major challenges in externally funded projects for the group. The European RESCUE project proposes an integrated concept “links on the fly”, encompassing the key technologies of distributed joint source/channel coding in lossy wireless networks, exploitation of multi-path information transfer in wireless mesh networks, and cross-layer design for interference management and error control. The approach is portrayed in Figure 2.

The planned concept will allow successful and robust information transfer through multi-path networks, and the integration of diverse communication infrastructures (e.g., base stations, relays, satellites, and terminals) taking into account the mobility of nodes, high density cells, dynamic and opportunistic frequency management which have a major impact on the challenges of future 5G networks.

The radio engineering team, operating within the signal processing research group, will carry out extended measurements and simulations in 2014 where the integrated LTE-A (long term evolution - advanced) and EM (electromagnetic) simulation tools developed by the team will be used for verifying against signal throughput measurements in order to define the accuracy of the MIMO OTA (multiple input multiple output over the air) test method for MIMO terminal devices. One goal of the simulations is to find cost effective and sufficiently accurate measurement configurations for different communication cases, in different radio channel environments. An important part of the project is to study the effects of user proximity, and the previously developed compensation methods for capacity, using different radio channel models and communications standards. The results are expected to be significant, for example, for standardization of the test methods of MIMO devices.

Radio Access Technologies

“Radio Access Technologies” - the largest fundamental research group in WICS - focuses on access solutions for the next generation wireless systems. The expertise areas of the group cover all the critical aspects for future radio access design, from the physical layer to wireless networking, with the major application areas being 5G cellular systems and wireless systems for crisis management. The potential key technologies related to 5G include massive MIMO techniques, next generation physical layer techniques, heterogeneous networking, and self-organized networking. The research on dependable wireless systems is looking at robust and self-healing wireless connectivity, utilizing both commercial and proprietary technologies. Also co-design of future smart grids and wireless infrastructure is being investigated by the research group. The group is very active in various international research projects, including METIS (www.metis2020.com), the European spearhead 5G project. The overall goal of METIS is to provide a system concept that supports 1000 times higher system spectral efficiency, as compared with current LTE deployments, but with a similar cost and energy dissipation per area as in today’s cellular systems.

In 2013, the Radio Access group developed improved algorithms to determine and predict user context/activity by combining the various approaches of system optimization in order to cater for the end-to-end context specific user requirements and direct scarce resources (spectrum, energy, etc.). The ultimate goal of the research work was to optimize the network on all levels towards where most value is created for the users in their respective contexts. Some of the key research results of 2013 were

- algorithms for decentralized massive MIMO
- full duplex underlay device-to-device transmission
- filter bank multicarrier techniques for high capacity air interface and multiple access
- novel method for joint resource and routing optimization in wireless sensor networks based on the alternating direction method of multipliers
- evaluated data from the new channel measurement campaign in 2 and 5 GHz to support large scale MIMO and
vehicle-to-vehicle communications
• the initial dependable system design prototype for LTE type commercial communication system

In 2014 the research group will intensify its 5G activities with a large Tekes project focusing on 5G radio access solutions to 10 GHz and beyond frequency bands. The research focus will be on METIS use cases, supporting a very high data rate, very dense crowds of users and mobility (see Figure 3). Radio channel measurements and modelling at 10 GHz, co-primary spectrum sharing in multi-operator small cell networks, and core 5G system concept design are some of the key themes in 2014. The group will also be active in preparing and finalising its Horizon 2020 project proposals in the applicable thematic calls, and organising the 1st International Conference on 5G for Ubiquitous Connectivity - 5GU.

Future Wireless Internet
The Networking group (NET) of WICS focusing mainly on “Future Wireless Internet” consists of three teams: Networking, Future Wireless Internet and Sensor Network Architectures, and Sensor Networking. The group carries our research in the field of 5G/6G network architectures, spectra management, networks economics and security, as well as the future Internet applications, as portrayed in Figure 4.

Scientific problems in which group is engaged in include network optimization on the 2.5 (MAC), 3 and 4 layers; development of secure network architectures; development of efficient sensor network architectures; and efficient protocols on the application layer. In 2013, the group was involved in the development of networking protocols for cognitive networks, economic models for multi-operator spectra management, 5G network architectures, and security solutions for advanced networks as well as efficient sensor network architectures. The main results in the field of cognitive network architectures were obtained within the CoCaHaNe (WiFiUS) project, the economic models were obtained within EcoMoCo (WiFiUS) project, 5G network architectures (ADTECH, Mammoth and Sigmona) and advanced network architectures (NEWCOM) have been published in the most prestigious scientific journals.

The work of the NET group has an impact on raising awareness in the research community and industry of the importance of networking as a science in the development of the future communication systems. The impact is materialised through both the educational programme and research results.

In 2013, the NET group had significant international cooperation with the US (WiFiUS), Europe (NEWCOM) and Asia (ADTECH), and had activities in Japan. Cooperation within WiFiUS has given the group the opportunity to generate top scientific results in the field of cognitive networks, jointly with US universities. The group has also developed a significant European network of excellence within the NEWCOM project, providing access to the best research resources in Europe. Furthermore, the cooperation with Asia has provided additional necessary funding for the group.

In addition to the regular project meetings, a dissemination event in Lisbon (NEWCOM), and summer school (WiFiUS) gave group members opportunities to promote their latest results and the overall vision on future wireless networks.

In 2014 the group will be working on developing new networking paradigms for future wireless networks with
the goal of convincing the community and all the relevant players in the field of the necessity to support networking science in order to enable further progress in the wireless business.

Selected samples of research
Selected samples of research carried out by WICS research teams (in total 15) are presented next, including key results in 2013 as well as plans for year 2014.

Radio Resource Management Algorithms Research Team
The WICS research team focusing on algorithms for radio resource management, consisting of 6 members, considers the effects and requirements of the inevitable massive densification of the network infrastructure, from the point of view of area spectral efficiency and capability to support - in a controllable manner - various types of direct communications, e.g., device-to-device (D2D) and machine-to-machine (M2M) communications to realise the Internet of Things (IoT). In the complex operating environment of future heterogeneous networks, advanced interference and mobility management across different transmission/reception points with overlapping coverage becomes of utmost importance, making interference coordination especially vital for cell-edge users, who in the end dictate the dimensioning of the wireless networks.

The team has explored the effect of reliable channel state information (CSI) at the transmitter on the use of coordinated/cooperative multi-cell transmission resulting in efficient multi-user precoding techniques across distributed antenna elements or access nodes. In 2013, team members published promising results on fast converging downlink precoding algorithms for multicell systems with perfect and imperfect CSI at the transmitter. Another key research topic in 2013 was using cooperation and information exchange between base stations for joint multiuser detection and decoding in multi-cell multicarrier uplink communications. To improve the performance of the turbo receiver and reduce the intra- and intercell interference generated by the multiuser transmission, the convergence properties of the receiver were taken into account, resulting in highly efficient resource (power, bandwidth) allocation, and beamforming schemes for coordinated uplink systems. Subsequently, a decentralised framework was proposed for the coordinated multi-cell minimum power beamformer design problem which is able to guarantee feasible solutions even if the interference information is outdated or incomplete. A practical but efficient decentralised algorithm and corresponding signalling concepts of effective CSI for weighted sum rate maximization in multi-cell multi-user MIMO systems operating in the TDD mode was also proposed.

In 2014, in addition to the aforementioned research topics, the team will direct some of its research efforts towards large-scale multiple antenna wireless systems with hundreds of low-power antennas, that may be co-located at the base station site or distributed geographically, often called massive MIMO. In a special case with very large number of base station (BS) antennas, the processing can be simplified in a way that even matched filter (MF) and zero-forcing (ZF) can be used in an ideal i.i.d. channel for near optimal detection and beam-forming. However, in practical multi-cell environments with non-ideal correlated channels the use of more complicated precoder design algorithms is justified as the performance gains for simple MF or ZF based schemes are still significant. We demonstrated for the first time that the inter-cell interference (ICI) terms coupling the coordinating BSs can be approximated using the random matrix theory when the problem dimensions grow large, and the approximated ICI values depend only on the channel statistics (large-scale fading, load). This leads to a significant reduction in the required information exchange between BSs, as the approximated ICI values remain valid for several channel coherence periods.

The Optimization Techniques for Wireless Networks and Signal Processing Research Team
A WICS research team of half dozen researchers focuses on optimization techniques for wireless networks and signal processing. The research interests of the team include distributed optimization, large scale optimization, l1-norm methods for cardinality problems, dynamic programming and global (non-convex) optimization. Since 2013, the team’s interests have expanded to compressed sensing techniques, with special emphasis on Machine-to-Machine (M2M) communications and Internet of Things (IoT) applications. The aim is to understand the fundamental design principles, and investigate the ultimate capabilities of compressed sensing in wireless sensor networks. The main focus is on large sensor networks that rely on wireless interconnections (without the support of a pre-existing infrastructure), and are subjected to arbitrary temporal and spatial variability (caused, for example, by channel fading, addition/ removal of nodes, node mobility, etc.).

During the first half of 2013, the main focus was on distributed optimization methods for cellular systems and wireless sensor networks. Specifically, the team derived a novel method for joint resource and routing optimization in wireless sensor networks, based on the alternating direction method of multipliers. As a result, the team introduced a new robust beam-forming design method for cognitive radio systems, and proposed several distributed optimization methods for rate maximization and power minimization in cellular networks. The team members also studied the effect of the spectrum sensing errors on the stability region of a cognitive radio system.

In the second half of 2013, research interests were directed to compressed sensing techniques for wireless sensor networks. Consequently, the team proposed novel signal reconstruction algorithms for streaming systems and worked on the mathematical modelling and analysis of the real-time status update systems in which the emerging concept of “age” (or freshness) of information plays a key role. In these systems, status updates arrive randomly at a source node and are transmitted through a (possibly wireless) network to an intended destination node. Since the receiver has interest in fresh information, the goal is to minimize the “age” of the received updates.
A major achievement in 2013 was the launching of the five-year Academy Research Fellow project “Optimized Compressed Sensing in Wireless Sensor Networks” (ComingNets) which started in September 2013. The essential forms of international cooperation in 2013 were multiple joint international publications, research visits and student exchanges. The team also organized the Fourth Nordic Workshop on System & Network Optimization for Wireless (SNOW) 2013 (http://www.snow2013.net).

The future goals related to optimization techniques for wireless networks and signal processing include gaining a better understanding of the fundamental design principles and performance limits of the compressed sensing techniques. A special emphasis will be on revealing the information theoretic connections between traditional distributed source coding and compress sensing. Another goal is to obtain a statistical characterization of the “age” of information in the status update systems, where the source node has the capability to manage the arriving samples and decide which packets will be transmitted to the destination. The team will also work on developing a unified optimization framework that will enable a systematic study of the spectrum sharing techniques in multi-operator cellular systems.

The Channel Modelling and Physical Layer Techniques Research Team

One of the WICS research team is focusing on channel modelling and physical layer techniques with eight researchers. The aim is to solve problems related to channel modelling in the case of massive MIMO, by creating new channel models taking into account elevation information and performing measurements in the cm region. Knowledge on channel models is utilized in the creation and evaluation of physical layer techniques, specifically: focusing on very high rate data rates with combined modulation and coding; in the creation of new signalling methods using novel waveforms and transceiver processing; in improvement of bandwidth-energy efficiency; and in reduction of transceiver complexity in design with massive MIMO.

In 2013, the team succeeded, for example: in defining filter bank techniques for access and multiple access; in creating full duplex underlay device-to-device (D2D) transmission solutions; in investigating physical layer network coding (PNC) for D2D underlay communications; and novel decentralized coordination algorithms for massive MIMO. The performed channel measurement campaigns also provided unique information in the 2.5 GHz band for large MIMO and vehicle-to-vehicle (V2V) communication.

The research efforts and results of the team are of major interest to industry, as channel models in new frequencies with additional parameters are vital for major technological development. The team also contributed to the evolution of access and novel transmission methods, together with massive MIMO. In 2013, research results were disseminated through several research projects and submitted to/published in esteemed journals, including EURASIP, EUCAP, JSAC, TCOM, as well as large in international conferences, including ICC, WCNC and PIMRC. International cooperation was also lively in 2013, especially within the European METIS project, and the internships from University of Alberta, Canada and University of California, San Diego, USA. The team also further enlarged its cooperation network in several project proposals for the European Commission as well as through proposals for joint projects with the University of Surrey, UK; and KTH, Sweden. Universities in Sri Lanka were also approached for both researcher training and joint research opportunities. Possibilities for new double degree programmes in doctoral studies were also discussed with several partners. Members of the team also gave talks to industry partners, as well as organised short courses on selected topics.

In 2014, the team aims at performing further measurements in the cm wave region and finalising channel models for massive MIMO. Considering physical layer techniques, objectives include validation of non-orthogonal waveforms for access; novel coding modulation schemes; full duplex d2d for a multiuser multi-cell; PNC for d2d and multi-cell massive MIMO BS; as well as efficient error control techniques for distributed storage and small cell integrated environment.

The Dependable Wireless Research Team

The recently established Dependable Wireless research team of WICS, consisting of 8 persons, is specialized in defining algorithms and system concepts that offer system level resilience in cases of unexpected events and disasters, and at the same time provide communication solutions for critical infrastructure protection by withstanding most sources of interference. Most commercial communication systems are based on the best effort design paradigm. For critical infrastructure and authorities’ communication systems, also robust and interference resistant designs are sought to provide “always connected” solutions.

In 2013, the Dependable Wireless team studied exploitation of MANET and ad hoc networking solutions for enhanced redundancy and resiliency. This work was supported by studying routing mechanisms, as well as MAC protocols suitable for distributed control of such systems. For authorities’ systems mechanisms for robust communication algorithms for the physical layer (PHY) were studied, including robust estimators, channel coding, and interference suppressors to name but a few. As a result, an initial dependable system design prototype for an LTE type commercial communication system was drafted. The system concept was named citizen radio – a system that can provide connectivity during communication infrastructure failures. The system can also be deployed as a critical infrastructure communication system. Also several system improvements were drafted for an authorities’ communications system. At this stage, the concept shows plenty of promise. The impact could be remarkable if the system designs, or parts thereof, is included in future standards releases of LTE. As for system design improvements for authorities’ communication system, the designs shall be included in operational devices within the next years. The team was also active in funding acquisition, as several EU project proposals were generated (security oriented maritime LTE, peer-to-peer smart grid system, authorities’ communications system) to be submitted to H2020 calls.
In 2014, the team will concentrate on finalizing the dependable LTE system design, which will be evaluated both in citizen radio and critical infrastructure configurations. Also the authorities’ communication system’s algorithmic designs will be finalized after which key results will be published in international fora.

The Medical ICT Research Team

Healthcare and the medical sector are increasing their significance as an important application area of wireless communications. Due to the requirement of highest reliability in health-related issues, extremely robust, secure and safety communication must be guaranteed. The WICS Medical ICT team is investigating the concept and the problematic resulting from this requirement focusing on short range communication (up to tens of meters), wideband communication (in all the forms), channel modelling (crucial for system development), knowledge on antennas, and physical layer and medium access control (MAC). The wireless body area network (WBAN) is a key element of the research approach. In 2013, the central research topics included channel models for WBAN, performance evaluation of ultra wideband receivers, low-power MAC protocols for WBANs, in-body antennas, the effect of body tissues, as well as environmental challenges in medical WBANs. The team submitted a patent application on a method of improving IEEE Std 802.15.6 dependability and channel utilization. It also contributed to on-body WBAN channel modelling for static and pseudo-dynamic links, produced a Matlab simulator extension and performance comparison of different WBAN receivers using CWC’s & IEEE802.15.4-2011 and IEEE802.15.6-2012 channel models, and created novel antenna solutions designed for on-body. These results were presented in four accepted international journal papers, and 14 international conference papers. The team had also a major role in initiating and contributing to the ETSI SmatBAN standardisation work. International relations were further developed in 2013 through the advisory Board membership of the Research Centre in the area of wireless medical technologies and applications in Macquarie University (Australia), as well as through new collaborations related SmatBAN standardization work. Furthermore, new partners for Horizon2020 were identified and contacted. WICS also contributed to the scientific community by organising UWBAN 2013 (in conjunction with Bodynets 2013), serving as ISMICT2013 board members (International Steering Committee, International Advisory Board, Technical Program Committee), and co-chairing the IEEE ICUWB 2013 Technical Programme Committee. In 2014, the Medical ICT team is focusing its research essentially on solutions of dual use in homes and institutions; receiver performance evaluation and new MAC protocols; dependable WSN networks (robustness, security and secrecy); antennas; interference modelling; nanoscale communications; mobile clouds for medical ICT; and visible light communication for medical ICT.

The Small and Nanoscale Communications Research Team

Nanotechnology is an extremely diverse field with very promising research being carried out in many areas. In the future, nanotechnology will be a significant part of people’s everyday lives. Nano-machines refer to integrated devices consisting of nanoscale components. The WICS research team specialises in small and nanoscale communications concentrating on wireless communication between nanomachines with realistic channel models. The team leader has been on a 6 months research visit to the Georgia Institute of Technology, USA during 2013. One student was on a 3 month research visit to the Tokyo University of Agriculture and Technology, Japan during 2013. This research visit was very useful for establishing cooperation on nano-machines with Japanese partners. During 2014, the team will address many challenges related to wireless communication of nano-machines, including the effects based on quantum mechanical considerations. Several journal papers will be submitted during 2014.

Personnel

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Doctoral Theses


**Selected Publications**


