ADVANCED WIRELESS COMMUNICATION SYSTEMS AND SIGNAL PROCESSING

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Background and Mission

The demand for high-quality wireless communication services exceeded all expectations in the beginning of the 1990's. The demand will continue to grow in the new millennium. In addition to wireless telephony, wireless data and video transmission will also be required, which clearly will increase the data rate to several megabits per second. In wireless local area networks, the expected data rate is more than 100 Mbit/s. The research activities of the "Advanced Wireless Communication Systems and Signal Processing" (AWC) group are focused on advanced wireless communication systems and on the advanced signal processing methods and architectures needed in the implementation of the above-mentioned systems. The group consists of 3 sub-groups:

1. The group at the University of Oulu's Telecommunication Laboratory, directed by Professor Pentti Leppänen (TL),
2. The group at the University of Oulu's Centre for Wireless Communications, directed by Professor Matti Latva-aho (CWC) including also the CWC networking group's activities,
3. The group at VTT Electronics, directed by Research Professor Aarne Mämmelä (VTT).

The activities of the sub-groups together cover completely the lower layers of a generic communication system model, from the network and transmission system level down to the micro-architecture and logic gate levels.

The main goals of the group are:

- To support the development of the third generation mobile phone system (UMTS/IMT-2000), and future wireless local area networks and other systems to be used for fast wireless data and multimedia transmission.
- To analyze and design communication networks and protocols.
- To develop channel measurement systems and channel models based on measurements.
- To optimize communication systems, methods and algorithms based on the developed channel models. The channel models, and therefore systems, are developed for various different channels, for example, channels with intentional interference (military applications), channels with multiple users, and indoor-outdoor static channels.
- To develop floating-point and bit-true models of receiver algorithms for different systems. The models include, for example, multiuser detectors, channel decoders, synchronization algorithms, and cancellation of intentional interference.
- To develop VHDL architecture models for the most important algorithms.
- To develop experimental systems to verify the theoretical results.
- To produce international publications, doctoral theses and licentiate theses.

The groups at the University of Oulu (TL and CWC) focus on system and algorithm level studies of wireless communication networks and methods. The interest is in broadband transmission schemes (spread-spectrum, CDMA and multicarrier techniques), and their application to future wireless communication systems, as well as implementation of such systems by modern digital signal processing methods. Potential application areas are, for example, 3rd and 4th generation cellular systems, military communication on VHF/UHF bands and indoor wireless communications, especially wireless local area networks (WLANs).

The mission of the CWC and TL groups is scientific research and development of wireless communication methods and applications, and the transfer of the knowledge gained for use in industry, defence forces and society. CWC focuses on commercial and civilian applications, whereas TL specializes in military systems. The groups work in close co-operation, shar-

ing the information and know-how relevant to both groups.

The main effort of the VTT group is in the research and development of algorithms and implementation architectures for digital transmitters and receivers that are both typically adaptive. The group's research and the development knowledge has in the past been applied in several projects in which digital receiver algorithms and their architectures have been designed for mobile phones and base stations, a fast wireless WLAN system, a power line DS spread-spectrum system, and a fast microwave radio.

A great deal of emphasis is put on system design in telecommunication systems. For example, the design of implementation architectures is performed jointly with the design of algorithms. The work is focused on architectures suitable for ASIC implementation. For a given set of algorithms, the most promising architectures are selected and modelled using VHDL language. VHDL architecture models are synthesized to gate level descriptions from which accurate estimates of the complexity (in the number of gates) and the throughput (speed) of the ASIC can be achieved.

Scientific Progress

6HOP (Protocols for Heterogeneous Multi-Hop Wireless Ipv6 Networks) is a research project under the IST program of European Commission 5th research framework. The project is coordinated by CWC and it started in September 2002. The aim of the project is to specify, design and demonstrate heterogeneous multi-hop wireless IPv6 networks. The WAL (Wireless Adaptation Layer) concept developed in the previous project WINE (Wireless Internet Networks) will be extended and further developed towards a generic wireless API (Application Programming Interface) and an adaptive protocol framework. The Centre for Wireless Communications is the project coordinator and other partners are Philips Research, Intracom, AQL and the University of Cantabria.

6NET (Large-Scale International IPv6 Testbed) is an EC funded project which aims to build and demonstrate native IPv6 networks and services. The project is coordinated by Cisco who has also provided IPv6 capable routers for the network. The project started in January 2002 and its duration is 36 months. 6NET has more than 30 participants. Additional information is available in *http://www.6net.org/*.

The ABRAS (Advanced Baseband Receiver Algorithms for Wideband CDMA Systems) project was a multi-year effort studying the implementation of adaptive channel equalizer algorithms for WCDMA terminal receivers. Research covered adaptive algorithm design and analysis as well as their implications on system level performance. A few receiver algorithms have been implemented in the Texas Instruments C6x DSP environment. The project was funded by Nokia and Texas Instruments.

The FIXWIRE (Fixed Wireless Systems) project investigates and develops novel transmission and transceiver technologies for future fixed and low-mobility broadband wireless communication systems. The main focus of the project has been on MIMO techniques, link adaptation, multicarrier modulation and ad-hoc radio networks. The project will last for a number of years and is funded by Elektrobit Ltd.

FUBS (Future Ultra Wideband Radio Systems) is a research project focussing on licence-free, ultra wideband (UWB) communication systems. As part of the project, UWB link level system concepts are studied. UWB radio channel measurement and modelling and transceiver implementation also form significant components of the project. A co-existence measurement study with UWB transmitters and WLAN networks will be performed. FUBS is funded by Nokia, the Finnish Defence Forces Technical Research Centre, Elektrobit Ltd. and Tekes.

The aim of the FUTURA (Future Radio Access) project is to develop basic technology knowledge and expertise needed in creating future communication systems to be used within the next 10-15 years. The emphasis is therefore on the development of general theory and techniques for advanced transceiver algorithms, radio interfaces and wireless network techniques. Particular emphasis will be on adaptive systems utilizing space, time and frequency dimensions and issues related to counteract the effects caused by channel or various sources of interference. The application areas are cellular systems (beyond 3G systems), microwave links, wireless local area networks,

short range radio systems, positioning, satellite systems as well as new military communication networks. The project includes three research areas closely connected to each other: radio air interface solutions, transceiver techniques and wireless networks.

In the IGLU (Feasibility Study of Indoor Geolocation Concepts) project, novel geo-location solutions for an open terrain training environment are investigated. The project started with a feasibility study on different technologies and indoor radio channel measurements. IGLU is a joint project with an international partner.

LEMMINGS was a project to study novel concepts for location based routing and mesh network capability for ad hoc and hybrid ad hoc networking. Study on different routing algorithm possibilities, requirement & validation issues and architecture design were conducted during 2001. The project was funded by Nokia.

PEMUD (Performance Evaluation of Multi-Dimensional Torus-Knot Codes in Broadband Mobile Communication Channels) aims to create a concept for a software platform that can be used to evaluate the performance of Multi-Dimensional Torus-Knot Codes in broadband mobile communication channels using field measurement data. The project is supported by a venture company in Japan.

STICS (Space-time coding, modulation and signal processing for future cellular and broadband communication systems) is a three-year project funded by the Academy of Finland. The scope of the project is to investigate novel transmission and reception techniques of future wireless systems.

TRILLIAN / WIRSU is a co-operation project which is studying mostly proximity (short-range) wireless communicunication issues and small devices protocol stacks. The project is funded by Nokia.

ULTRAWAVES (ULTRA Wideband Audio Video Entertainment System) is an EU/IST project with the objective of providing a high performance, low cost wireless home connectivity solution, supporting applications requiring home multi streaming of high quality video and broadband multimedia. The objective will be to design and implement a complete UWB based system, optimised in terms of throughput, range, in-home/in-building performance and guaranteed multilevel QoS. Other partners in the project are Wisair, Chalmers University of Technology, the University of Roma, Philips and ENSTA.

WINNER (Wireless Inter-Technology Networks with Optimized Data Rates) was a Tekes funded project co-funded by Nokia and the Finnish Defence Forces. It studied networking technologies for future wireless heterogeneous networks. Its research themes included ad hoc routing protocols, hybrid ad hoc network architectures and solutions, and micro-and macromobility for IPv6 based systems. The Winner project started in May 2000 and it ended at the end of 2002. VTT Electronics participated in WINNER during 2000-2001 as a subcontractor.

The goal of Future Military Radio Communications projects in the TL group is to apply ideas and results based on intensive research made for next generation wireless communications to future military communication systems such as tactical systems, field radio links, wireless LANs, and radiolocation systems. The applicability of the software defined radio concept is also under study.

New results for future tactical military communication systems based on spread spectrum methods have been reported. Different architectures and technical challenges for a software defined radio have been studied. Methods and simulation environments to define the impact of nonlinearities and A/D-conversion have been developed. Performance requirements for a multiband multi-mode (MBMM) radio have been estimated and methods for hardware capacity estimation have been studied.

Preliminary study has been performed for a positioning system which is robust against jamming, and against other radio signals. This includes a study of present positioning systems like GPS and GLONASS, and their immunity against interference. It also includes studies for methods that can be used to realize a robust positioning system.

Future wireless networks will need improved spectral and energy efficiency. In our strategic research at VTT, we aim at improving the bit rate, in terms of distance, terminal mobility and user density, separately for the downlink and uplink. Thus far we have concentrated on the data and channel estimation algorithms in the receiver. Part of the work was funded by the Academy of Finland (ARCHIE project, 2001-2004).

We have prepared a detailed literature review on area spectral and energy efficiency. The spatial dimension is important since it covers the interference between different users. Link spectral efficiency in terms of bit/s/Hz is valid only for independent links, which we use rather seldom in practice. Some simulations were also performed and they show the area spectral efficiency (ASE) in terms of bit/s/Hz/km^2.

A general systematic classification of receiver algorithms was presented in an invited plenary lecture. The classification clearly shows the theoretical back-

ground, relationships and symmetry of algorithms. The algorithms are divided into data estimation, channel estimation and joint data and channel estimation algorithms. The recursive and adaptive versions are also discussed. The adaptive algorithms are separately defined for slow and fast time-variant channels.

Various channel estimation algorithms were analysed and simulated. These turbo processing algorithms are novel and have potential to be used in present systems to improve performance, for example, as a joint equalization and decoding algorithm. In space-time coded systems we use multiple antennas in the transmitter and in the receiver. The channel estimation problem is more demanding than in conventional systems since the receiver antenna receives the signals from all transmit antennas. This work was continued in our IST/STINGRAY project (2002-2003) with its application area in fixed wireless access networks. The aim is to extend the bit rate of the present IEEE802.16a standard to 50 Mbit/s.

IST/WIND-FLEX is a large project (2000-2003) partially funded by the European Commission. A high bit rate flexible, adaptive and reconfigurable modem architecture is considered that works in single-hop, ad-hoc networks and provides wireless access to the Internet in an indoor environment. The best possible performance with reasonable complexity is attained by using a jointly optimized run time adaptive system. The research reports will be a good basis for defining new standards. During the third year of the project (2002), the implementation of the first prototype was finished and presented at the IST Mobile Summit in Thessaloniki, Greece. At the end of the project a demonstrator with a maximum bit rate of about 200 Mbit/s will be implemented.

Future Goals

The goal of CWC research during the year 2002 was to open up new research directions into wireless systems and application that will be used in 10 - 15 years time. Those research areas include wireless networks and related protocols (Ad-Hoc Networks, mobile IPv6) and future digital transmission schemes (multicarrier modulation, ultrawideband systems). At the same time, the core competence of CWC (cellular CDMA systems) will be utilized in near-future applications, such as WCDMA. Research topics in the future include some implementation issues of practical baseband algorithms for WCDMA, WCDMA radio network traffic analysis, development of flexible air-interface solutions for future high data rate wireless systems, wireless packet data systems and unlicensed wideband radios.

The practical goal of many Future Military Radio Communications projects will be the development of adaptive air interfaces and ad hoc mobile networks for new tactical communication systems with Finnish industries.

At VTT, a future goal is to improve our system level understanding and integrate the work of different groups even better. This should be possible since in our groups most OSI layers are covered. Detailed trade-off between the network capacity and the link capacity will be important to make future systems more efficient. In addition, since diverse standards will exist also in the future, we must be prepared to work with many different system models, including, for example, conventional and spread spectrum single-carrier systems and also multi-carrier (OFDM) systems.

Personnel

professors & doctors	22
graduate students	77
others	32
total	**131**
person years (university 79%, VTT 21%)	87

External Funding

Source	EUR
Academy of Finland	192 000
Ministry of Education	118 000
Tekes	1 530 000
other public	2 083 000
domestic private	1 836 000
EU + other international	870 000
total	**6 629 000**

Doctoral Theses

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Selected Publications

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