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 century. 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 (TIL),
2. The group at the University of Oulu's Centre for Wireless Communications, directed by Dr. Matti Latva-aho (CWC),
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 (CDMA applications), and indoor-outdoor static channels (WLL applications).
- 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 (TIL and CWC) focus on system and algorithm level studies of wireless communication networks and methods. The interest is on spread-spectrum and CDMA 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 generation cellular sys-

tems, military communication on VHF/UHF bands and indoor wireless communications, especially wireless local area networks (WLANs).

The mission of the CWC and TIL groups is scientific research and development of wireless communication methods and applications, and the transfer of the gained knowledge for the use of industry, defence forces and society. CWC focuses on commercial and civilian applications, whereas TIL is specializing in military systems. The groups work in close co-operation, sharing 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 receivers. The group's research and the development knowledge has been applied in several projects in which digital receiver algorithms and their architectures have been designed for a fast wireless WLAN (Wireless Local Area Network) system, power line DS spread-spectrum system, fast microwave radio, satellite UMTS and an experimental DS spread-spectrum system.

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 by using VHDL language. VHDL architecture models are synthesized to gate level descriptions from which accurate estimates of the complexity (in number of gates) and the throughput (speed) of the ASIC can be achieved.

Scientific Progress

Long term research considering advanced receiver and network control algorithms for future wireless communications has been carried out in the AWICS project (Advanced Wireless Communication Systems). AWICS is a basic research project funded by TEKES, Nokia, the Finnish Air Force and Elektrobit. In 1999 the research concentrated on initial CDMA receiver synchronization, advanced CDMA receivers, space-time coding and processing, turbo coding and interference suppression in spread-spectrum systems. As an outcome new promising receiver algorithms have been developed, and performance analyses for the CDMA receiver algorithms have been presented. New coding methods have been proposed for space-time coded systems. Several interference suppression methods have been evaluated.

The FUBS project (Future Ultra wideBand radio Systems) is focusing to unlicenced ultra wideband (UWB) communication systems. The aim of the project is first to become familiar with UWB and impulse radio technology and as a final goal to define hardware demonstration equipment that utilizes this technology. The idea of licence free systems is based on the very low power spectral density of transmission. The spectrum of a carrierless UWB signal is spread to a frequency band between ~kHz and ~GHz, offering very good LPD/LPI and penetration properties and also very good time and space resolution at the same time. UWB technology can be used in short range communication, geolocation, (ground penetrating) radars, proximity and motion

sensors etc. The project is planned to last several years. TEKES, Nokia, Elektrobit and the Finnish Defence Forces are funding this project.

The ABRAS (Advanced Baseband Receiver Algorithms for Wideband CDMA Systems) project is a long term effort studying the implementation of advanced receiver algorithms for the WCDMA system. These receivers, suitable to the uplink and downlink environments, will be developed and implemented in the Texas Instruments C6x DSP environment. The ABRAS project is funded by Texas Instruments and Nokia.

The goal of the SPAM (Spatial Channel Modelling) project was to develop a statistical channel model for wideband mobile communications channels centred on 2.4 GHz and 5.7 GHz. Outdoor to indoor propagation environments for wireless local loop (WLL) were considered. Existing models have been extended to include small scale spatial correlation, angle of arrival and cross-polarisation information. A Markov chain description was used to describe the statistics. Partners in the project are Nokia Mobile Phones, Elektrobit, CWC and Southern Poro Communications (Sydney).

The WINGIP (Wireless INdoor Geolocation and IPv6 traffic analysis) project is a joint project between CWC, University of Oulu, Finland and WLRL/CWINS at Worcester Polytechnic Institute, USA. The project started in May 1999, and is funded by TEKES, Nokia and the Finnish Defence Forces. The WINGIP project studies new network oriented applications in two major areas. The first task develops a network infrastructure to provide wireless geolocation services in the smart buildings of the future. It determines system architecture to implement the infrastructure, identifies physical and MAC layer issues, and analyzes the radio propagation for deployment of such networks. The second research task analyzes IPv6 in the use of real-time application in a wireless multi-user environment and defines a system architecture for future telecommunication services.

The goal of many Future Military Radio Communications projects in the TIL group is to apply ideas and results based on intensive research made for next generation wireless communications to future military communication systems, like tactical systems, field radio links, wireless LANs, 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. During 1999, different architectures and technical challenges for a software defined radio have been studied. Methods and simulation environments to define impact of nonlinearities and A/D-conversion have been developed. Performance requirements for a multi-band multi-mode (MBMM) radio have been estimated and the methods for hardware capacity estimation have been studied.

A preliminary study has been finalized for a positioning system robust against jamming, and 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.

The KOMA project (Implementation of 3rd Generation Mobile Phone Systems) and the MULTICS project (Architecture Study of Next Generation Multistandard Mobile Terminal and Base Station) are joint projects between VTT Electronics (KOMA and MULTICS), VTT Information Technology (MULTICS) and CWC (KOMA) and TIL (MULTICS) funded by TEKES, Nokia and Elektrobit. The goal of the KOMA project is to implement a complete transmission link (transmitter - channel - receiver), using advanced multi-user receiver concepts previously studied by CWC. This will provide information on the feasibility and implementation of the advanced methods involved.

The research themes in the MULTICS project are focused on algorithms (other than multi-user), the high level architecture of a multistandard mobile terminal and base station, efficient low-power configurable DSP, SW architecture for the WB multiprotocol terminal and partly in RF technology.

In the KOMA project, DSP algorithms for a WCDMA receiver utilising parallel interference cancellation (PIC) were modelled with the COSSAP tool in 1998. Design of parallel implementation of the PIC algorithm for a multi-processor environment was carried out. Implementation of the algorithms in a commercial multi-processor DSP-board has been started in co-operation with the group of VTT Electronics. In the MULTICS

project, a case study of the next generation multistandard mobile terminal was defined and some feasibility studies were completed in 1999.

In the VTT group, the strategic DARTS project (1996-1998) on digital receivers came to an end in 1998. Some key results were a review paper on wireless channel equalizers, journal papers on the analysis of optimal and adaptive receivers, and decision threshold control. A semi-analytical method for concatenated coding was published as a conference paper. A general multi-user system was also published as a conference paper, including most of the known multiple-access and modulation methods as special cases. Various MATLAB and COSSAP models were developed for frame, symbol and carrier frequency synchronization in single-carrier and multi-carrier (OFDM) systems. In addition, a fixed-point bit-true model was developed for the FFT processor and a frequency tracking algorithm. A VHDL model was developed for the PSP/Viterbi algorithm and a Turbo decoder. Some of these results were made jointly in the ACTS/MEDIAN project (1995-1999) on fast wireless local area networks.

Exploitation of Results

In the AWICS project, the main applications for the results are found in the third generation cellular mobile communication systems as well as in new military communication networks. The research supports industrial partners in designing new system concepts as well standards, terminals and base stations for them. The basic research carried out will find potential applications in a wide range of future mobile systems, both commercial and military.

The results of the FUBS project are used when evaluating the usefulness of future unlicenced wireless radio systems.

The results of the ABRAS project can be utilized when designing high-performance receiver architecture for a UMTS system.

The results of the SPAM project can be used when evaluating the performance of space-time processing based wireless systems and algorithms either by computer simulations or real-time hardware tests.

The results of the WINGIP can be used in industry and standardization. The results open scenarios for new applications and network management, and provide a means for wireless indoor geolocation by using emerging WLAN standards and short range radio systems. The protocol analysis helps industry understand the nature of IP protocol evolution in novel network solutions, and defines a system architecture for further studies.

The results of many Future Military Radio Communications projects have been used in specifying and developing new tactical systems by Finnish industry. Research results and simulation environments are now used in defining suitable architecture for flexible and reconfigurable software defined radios for military applications.

The results of the MULTICS project will be a recommendation for a multistandard system architecture development, which integrates algorithm, functionality and platform views.

The simulation environment and DSP demonstrator developed in the KOMA project are used for testing the performance and implementation complexity of the receiver algorithms in the WCDMA system. Parallel implementation of the PIC algorithm can be studied to set initial requirements for the hardware used in commercial implementation.

In the VTT group, the results were exploited in various joint and contract research and development projects. Joint TEKES projects on fast wireless modems, multi-standard radios and multi-user CDMA detectors were started. Third generation mobile phone systems, digital subscriber line modems, digital microwave links and robust wireless modems were considered in contract research and development projects.

Future Goals

The goal of CWC research during the year 2000 is to open new research directions into wireless systems and application that will be used in 10 - 15 years time from now. At the same time, the core competence of CWC (cellular CDMA systems) will be utilized in near-future applications, such as WCDMA. Research topics during the year 2000 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 unlicenced wideband radios.

The goal of many Future Military Radio Communications projects will be the development of the adaptive air interfaces and flexible mobile point to multipoint networks for tactical communication systems with Finnish industries.

At VTT, a new strategic research program called ELEDSP or Telecommunications Electronics (1999-2001) has been started. The research is based on the vision that future applications request faster and more reliable communications services. The design of a complicated communication system will be a very challenging task. There are trade-offs, for example between simulation times of detailed models and the cost of developing prototypes. Single chip (SoC, System-on-Chip) receivers will become more feasible, but functional tests must still be performed with macro prototypes in realistic environments. The ELEDSP program has two general aims:

1. To improve and maintain our international competitiveness in the research into optimized wireless transmission technology. Special emphasis will be given to the problems in the design of fast DSP systems (DSP algorithms and their HW/SW implementations).
2. To significantly increase our know-how in system design in development projects related to wireless transmission technology, by narrowing the existing gap between telecommunications and electronics design. The implementation technology can be either circuit boards with its components or SoC circuits. A case system will be selected which forms an integrating element for the system design.

Personnel

professors & doctors	13
graduate students	39
others	35
total	**87**
University	74%
VTT	26%

External Funding

Source	**FIM**
Academy of Finland	140 000
Ministry of Education	557 000
Tekes	5 153 000
Infotech	240 000
other domestic public	5 939 000
domestic private	5 828 000
EU + other international	1 158 000
total	**19 015 000**

Selected Publications

Iinatti J & Kerhuel S (1999) Code synchronization in two-path channel: effect of interpath interference on acquisition. Electronics Letters 35(12): 960-962.

Juntti M & Latva-aho M (1999) Bit error probability analysis of linear receivers for CDMA systems in frequency-selective fading channels. IEEE Transactions on Communications 47(12): 1788-1791.

Kaasila V-P & Mämmelä A (1999) Bit error probability of a matched filter in a Rayleigh fading multipath channel in the presence of interpath and intersymbol interference. IEEE Transactions on Communications 47(6): 809-812.

Glisic S & Pirinen P (1999) Wideband CDMA network sensitivity function. IEEE J. Select. Areas Commun.17(10): 1781-1793.

Pirinen P (1999) Sensitivity analysis of conditional co-channel interference in cellular FDMA/TDMA systems. In: Leung K & Vojcic B (eds.) Multiaccess, Mobility and Teletraffic for Wireless Communications 3:171-185, Kluwer Academic Publishers.

Glisic S, Nikolic Z, Pokrajac D & Leppänen P (1999) Performance enhancement of DSSS systems: two-dimensional interference suppression. IEEE Transactions on Communications 47(10): 1549-1560.

Leppänen P & Talvitie J (1999) Special series on wideband wireless local access. Guest Editorial, International Journal of Wireless Information Networks 6(4).

Latva-aho M & Juntti M (1999) Advanced receivers for WCDMA. Full-day tutorial at IEEE Vehicular Technology Conference (VTC'99 fall), Amsterdam, the Netherlands, 19-22.