ADVANCED CONCEPTS FOR FUTURE BROADBAND WIRELESS NETWORKS

Abstract

This document describes an Integrated Action within the FAST programme targeting at a research collaboration between University of South Australia (UniSA), the Institute Nationale de Recherche en Informatique et en Automatique (INRIA), École Nationale Supérieure des Télécommunications (ENST), and Institut Eurecom. The joint research aims at the development of advanced analysis and design methods for wireless multi-user networks relevant for future wireless communication systems. The integrated action will be executed via mutual exchanges and visits of the personnel involved from all four institutions. We provide some technical background information, describe the open problems to be addressed, and develop a concrete plan for the collaborative research and publication efforts. The ability of the researchers involved to carry out the proposed research is demonstrated by a summary of their relevant previous scientific and management experience.

1. Introduction

Future wireless communication networks will need to support extremely high data rates in order to meet the rapidly growing demand for broadband applications such as high quality audio and video. Existing wireless communications technologies such as third generation cellular telephony and wireless local area networks cannot support broadband data rates (of the order of hundreds of millions of bits per second) due to their sensitivity to severe wireless channel impairments such as the time-varying attenuation caused by user mobility. To make things even more difficult, there are limited resources such as the available frequency bandwidth, allowable transmission power and computational ability of portable devices. Furthermore, in order to accommodate the increasing number of subscribers, future mobile communication systems will require more capacity, flexibility and easy deployment. These difficulties may be overcome by designing clever networks and data transmission schemes specially suited for the wireless channel.

During the last decade, new cooperative networking approaches and very promising technologies emerged to respond to these demands. On the one hand, a new networking paradigm for wireless systems is offered by ad hoc networks. It promises broadband access, easy deployment, flexibility, and large capacity. On the other hand, the use of multiple antennas at both transmitter and receiver ends can enormously increase the data rate and performance robustness without increasing neither the transmit power nor the bandwidth.

The main aim of this project is to develop a unified framework for analyzing future wireless communications networks. In particular, the main objectives of the project are:

- Develop advanced methods for analyzing ad hoc broadband wireless communications networks and their combination with existing cellular networks (hybrid ad hoc networks).
- Design advanced low-complexity high performance data transmission schemes with multiple antennas suitable for implementation in wireless broadband communications networks.
- Study the impact of multiple antenna technology in the overall system capacity and performance of hybrid ad hoc broadband wireless networks.

2. Research Goals

The project focuses on improving the efficiency of wireless multi-user communications via an optimization of multi-cell and ad hoc networks using realistic channel modelling, information theoretic performance analysis, power control, and the optimization of network planning (node deployment). The research will provide means for improving user data rates, reducing spectrum requirements, and lowering emitted electromagnetic radiation, thus prolonging battery life time.
To achieve these ambitious goals, the project aims at solving several important open problems in wireless multi-user communications (described in the individual work packages (WP) below). The different parts of the project are strongly related and have been conceived in order to provide low complexity and user-friendly tools capable to compute and optimize physical layer performance metrics. The ultimate goal is to bridge the gap between physical and network level scientific communities. In fact, in current system level simulators only single access communications are modelled; intra- and inter-cell interference are treated as white Gaussian noise and potential gains of multi-user detection and other physical layer improvements are ignored at the network level.
To achieve these goals, collaborative efforts are required that bring together the complementary expertise existing at the four partner institutions.

2.1. WP 1: Capacity Analysis of Wideband Multi-User Networks

Within the project, the ultimate performance limits of wireless systems will be studied in terms of the maximum achievable data rates. One objective is to assess the capacity of the wireless propagation channel in wideband multi-user wireless networks (distributed MIMO systems) and to study the associated eigenmodes and degrees of freedom (DoF) of the channel. Coherent (perfect receiver channel state information (CSI)) and non-coherent (no CSI) situations will be considered as well as scenarios with imperfect CSI. Further extensions to multi-cell situations taking into account realistic intercell interference models are also planned. Recent work in this area relating to single-user and/or single-antenna systems has been published in [Tel00, Med02, Han05, Chu02, Gal85, Rhe03].
These channel capacity investigations will be conducted using practically relevant stochastic channel models. Additionally, we will also develop new channel models that reliably capture various aspects specific to the scenarios we are interested in (e.g. dispersion in the delay, Doppler, space, and polarization domain, multi-cell environments with high user mobility, etc.). The expected findings of this approach are as follows:

1) insights regarding the maximum achievable user data rates in wideband multi-user networks
2) deeper understanding of the propagation mechanisms that determine the channel's DoF and capacity
3) design guidelines for transmitter and receiver optimization techniques.

Partners involved: UniSA: L. Cottatellucci, A. Grant
Eurecom: M. Debbah, N. Fawaz

2.2. WP 2: Multi-Cell Analysis and Optimization

Until recently, the main research efforts focused on single cell wireless systems [Sha01, Ver99]. Today, the interest of the scientific community shifts towards multi-cell systems and hybrid ad-hoc networks [Zai01,Deb05,Gro02,Gup00]. Current studies of multi-cell and hybrid ad-hoc networks are based upon fundamental information theoretic models that are not yet fully understood. Those comprise combinations of multiple-access, broadcast, interference, and relay channels, potentially with MIMO and time-frequency selectivity, as well as fundamental network information theory aspects.
The goal of this work package is twofold. On the one hand, we will analyze and compare multi-cell and hybrid ad-hoc networks from a theoretical perspective using the models and techniques provided by the other work packages. On the other hand, special attention will be devoted to the design of tools able to

provide metrics of interest for link level simulation (e.g. output SINR, BER) in different scenarios [Tse99, Eva00,Kir00]. The performance analysis will be carried out by using random matrix theory [Bai99]. The asymptotic self-averaging properties of random matrices allow a terse description of the system characteristics in terms of few “macroscopic” system parameters.
We will further address the following design issues that will benefit from the performance analysis of multi-cell systems in different scenarios:

- *Optimal power allocation.* Conventional centralized power control requires that users with smallest channel gains transmit at the largest power level to render the received power of all users constant. However, this increases inter-cell interference since the users with smallest channel gains are usually the ones at the border of the cell (i.e., close to neighboring cells). We plan to design optimal power allocation strategies in a multi-cell context that should result in a trade-off between the required quality of service and the resulting inter-cell interference.
- *Optimal base station deployment.* In order to increase network capacity in hot spots, network providers usually increase the number of cells. This again implies an increase in inter-cell interference. Our research will address optimal base station deployment as a trade-off between the increase in capacity and the increase in inter-cell interference by introducing additional cells in the system.

Partners involved: UniSA: L. Cottatellucci, A. Grant
Eurecom: M. Debbah, N. Fawaz
INRIA: N. Bonneau

2.3. WP 3: Analysis and Optimization of Distributed Control Mechanisms in Ad Hoc Networks

Ad hoc networks are characterized by the delocalization of control mechanisms in all network nodes and a partial cooperation among adjacent nodes. From a theoretical point of view this requires a thorough understanding of the most basic information theoretic models. Those comprise combinations of interference and relay multiple-input multiple-output frequency selective channels as well as channels with jamming. From a practical perspective, it is necessary to develop techniques to solve decentralized power control problems in which mobiles determine their transmission power independently of each other as a function of the radio conditions of their respective channels (which is defined as a finite Markov chain). Mobiles are supposed to know only their own channel state and to have constraints on their average transmission power.

From this point of view, stochastic and evolutionary game theory was shown to be a very powerful tool both for the understanding of fundamental information theoretical models (e.g see [Yu02] and [Pop05] for the interference channel, [Kas05] for channels with jamming) and for the development of distributed power control algorithms (e.g. [Mes05], [Han05], [Alp02]). An extreme case of non-cooperative power control is the following: One or more mobiles try to jam the communications between other mobiles, or between mobiles and their base station. New tools in constrained stochastic zero-sum games have recently been developed at the Maestro team (INRIA) which allow to identify the power control policies of mobiles able to guarantee the best throughput under any strategy of the jammer, see [Alt05].

We plan to take benefit from the expertise in game theory and in information theory available in the team to achieve the following goals:

- To define in a more general context a "non-cooperative capacity" as well as the "worst case capacity" for ad hoc networks.
- To analyze interference, relay, and jamming channels.
- To develop optimum distributed power control algorithms for ad hoc networks.

Partners involved: UniSA: L. Cottatellucci, A. Grant

Eurecom: M. Debbah, N. Fawaz
INRIA: E. Altman, N. Bonneau

2.4. WP 4: Advanced Data Transmission Schemes using Multiple Antennas

Multiple antennas are a key technology for future wireless communications systems. They promise enormous data rate increases (multiplexing gain) as well as increased robustness against fading (diversity gain) in single user systems [Zhe03] as well as multi-user systems [Tse04]. Therefore, constructing practical low-complexity coding structures that achieve these gains and perform close to optimal becomes a relevant and challenging problem. In this setting, practical forward error-control codes performing very close to optimal have been recently proposed for the single transmit antenna case [Bou04,Bou05]. These codes are based on parallel concatenated codes and iterative decoding, and are able to perform within 0.8 dB of the fundamental limits of the channel. Furthermore, when packet oriented transmission is required, Automatic Repeat reQuest (ARQ) is known to be a very practical and robust solution [ElG04]. In this part of the project we will

- Construct codes using multiple transmit and receive antennas based on the concatenated approach in [Bou04,Bou05] that achieve both multiplexing and diversity gains in a single-user scenario.
- Extend the code construction to a multi-user scenario using [Tse04] as a benchmark.
- Study concatenated codes combined with ARQ for the multi-user case using the results of [ElG04,Tun01,Tun02].

Partners involved: UniSA: A. Guillen i Fabregas, A. Grant
ENST: J. Boutros, L. Yang

3. Research Impact

The project seeks to set-up a new long-term (well beyond the time frame of the project) collaboration between University of South Australia and the French Research Institutions, Eurecom, ENST and INRIA to increase the transfer of knowledge and research tools as well as to foster better understanding between the teams. This project is also aimed at strengthening the already existing research connections between University of South Australia and ENST.
It is the general aim to strengthen the technical and scientific expertise within the partner institutions concerning the development and standardization of 4^{th} generation (4G) mobile wireless systems. The timing is perfect for such a purpose since 4G systems are currently a hot topic internationally with a lot of open research problems and no standardization at the moment. It is expected that 4G roll-out will gradually start after 2010. The general aim is to be achieved through the following:

- striking up a close, active collaboration between researchers with complementary expertise on a variety of fundamental and important topics in modern mobile and wireless communications; this will be supported by half-day tutorial courses to be given by the visiting partner at the hosting institution
- educating **PhD students** on cutting-edge topics in mobile communications
- increasing the international scientific reputation and visibility of Australia and France in the area of wireless communications by publishing our joint research results in prestigious IEEE journals and in proceedings of highly reputed, refereed international conferences
- multilateral know-how transfer and internationalization, through cooperation with various national and international partners from industry and other research institutes.

4. Project Plan

This Integrated Action is intended to span the two-year period from January 2006 to December 2007. All the members in the teams are young scientists (six of them aged less than 35 years, two of them are women). This is in close alignment with one of the goals of the Integrated Action, namely, to encourage the participation of young scientists. This Integrated Action would allow the participants to start a fruitful collaboration, especially between the University of South Australia (UniSA) (on the Australian side) and Eurecom and INRIA (on the French side).

It is planned to continue and deepen the cooperation after Dec. 2007. In order to implement the cooperation in practice and to accomplish the goals of sharing expertise and providing cross-fertilisation of ideas, the partners will adopt the following methodology:

- a total of 2 long stays / year (see table below) be paid by Australian and French Fast funding, respectively.
- face-to-face meetings during conferences for which funding is not sought (see table below)
- distant cooperation via phone, email, and videoconferencing and progress assessment via UniSA / INRIA / ENST / Eurecom web sites
- dissemination of results by means of jointly authored papers in journals and conference proceedings

The planned stays and face-to-face meetings during conferences are scheduled as follows:

	2006	2007
January		
February		
March	**Cottatellucci** (WP 1, WP 2, WP 3) **Grant** (WP 1, WP 2, WP 3, WP 4) **Guillen i Fabregas** (WP 4)	**Cottatellucci** (WP 1, WP 2, WP 3) **Grant** (WP 1, WP 2, WP 3, WP 4) **Guillen i Fabregas** (WP 4)
April		
May		
June		
July	*Meeting at ISIT2006*	*Meeting at ISIT2007*
August		
September	**Boutros** (WP 4) **Debbah** (WP 1, WP 2, WP 3) **Fawaz** (WP 1) **Yang** (WP4)	**Altman** (WP 1, WP 2, WP 3) **Bonneau** (WP 2, WP 3) **Boutros** (WP 4) **Debbah** (WP 1, WP 2, WP 3)
October		

November		
December		

The above table shows the planned schedule for mutual visits (along with work packages affected) and face-to-face meetings (gray shading indicates visits of Australian team members to France, no shading indicates visits of French team members to SA University, italics indicates some flagship conferences for which face-to-face meetings are expected).

Cost Breakdown. The financial contribution applied for within the Fast Integrated Action from the French side amounts to 13600,- € per year (27200,- € in total). The following table provides a breakdown of the costs applied for:

	2006	**2007**
Travel 1	Flight: 4 x 1800,- € Stay (10 days): 4 x 1600,- €	Flight: 4 x 1800,- € Stay (10 days): 4 x 1600,- €
Total	13600,- €	13600,- €

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A. INFORMATION ABOUT INRIA

A.1 General Information

The INRIA Sophia Antipolis research unit was founded in 1983 within the Sophia Antipolis technology campus. The unit gathers together 500 persons, including 380 scientists, in its Sophia Antipolis, Marseille and Montpellier sites. The unit boasts about thirty research teams working in partnership with CNRS and several universities and engineering schools. Research concerns the design and programming of high performance computer systems, the representation and handling of complex information, and the creation, modeling and simulation of complex experiments. It results in advances in four major areas: networks and systems; software engineering and symbolic computation; human-machine interaction, images, data, knowledge; simulation and optimization of complex systems.

The research unit is in constant interaction with its partners in universities, engineering schools and research centers all over the world through scientific publications, software and international exchanges. It also hosts the ERCIM consortium services that regroups European research centers in information and communication science and technology. ERCIM also hosts an important team of the W3C consortium.

A strategic objective is technology transfer. INRIA Sophia Antipolis maintains partnerships with many local, national and international companies and institutions, within the framework of contracts, research networks and European programs. . Meetings are held on a regular basis to reinforce these partnerships, in the framework of Intech'Sophia, the unit's partners club. In addition, work by INRIA Sophia Antipolis researchers has led to the founding of some ten technology companies.

Further detailed information on INRIA Sophia Antipolis is available at http:// http://www-sop.inria.fr/

A.2 Curricula Vitae et Studiorum of INRIA Project Members

Eitan Altman received the B.Sc. degree in electrical engineering (1984), the B.A. degree in physics (1984) and the Ph.D. degree in electrical engineering (1990), all from the Technion-Israel Institute, Haifa. In (1990) he further received his B.Mus. degree in music composition in Tel-Aviv university. Since 1990, he has been with INRIA (National research institute in informatics and control) in Sophia-Antipolis, France. His current research interests include performance evaluation and control of telecommunication networks and in particular congestion control, wireless communications and networking games. He is in the editorial board of several scientific journals: Stochastic Models, JEDC, COMNET, SIAM SICON and WINET. He has been the general chairman and the (co)chairman of the program committee of several international conferences and workshops (on game theory, networking games and mobile networks).
More information can be found at http://www.inria.fr/mistral/personnel/Eitan.Altman/me.html

Nicolas Bonneau. After three years of study at the Ecole Polytechnique in Palaiseau (including a three-month period at the Centre de Mathematiques therein about "p-adic L-functions") and two years of study at the Ecole Nationale Superieure des Telecommmunications in Paris (including a Master in Algorithmics and a seven-month period at the Institut Eurecom in Sophia-Antipolis about "Joint decoding and estimation for Low-Density Parity-Check Codes in Satellite Communications"), he has started a Ph.D. thesis in INRIA.

A.3 Project Relevant INRIA Publications

INRIA Publications Related to WP 2 and WP3 (Multi-Cell and Ad Hoc Network Analysis and Optimization)

N. Bonneau, M. Debbah, E. Altman, "Spectral efficiency of CDMA Downlink Cellular Networks with Matched Filter," to appear in EURASIP Journal on Wireless Communications and Networking.

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D. Miorandi and Eitan Altman, Coverage and connectivity of Ad-Hoc networks in presence of channel randomness, IEEE Infocom, Miami, March 13-17, 2005.

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B INFORMATION ABOUT EURECOM

B.1 General Information

Institut Eurécom was founded on November 4, 1991 by the Swiss Federal Institute of Technology of Lausanne (EPFL) and the Ecole Nationale Supérieure des Télécommunications (ENST) in Paris. Since 1995, Politecnico di Torino is also an academic partner. The Helsinki University of Technology joined EURECOM in 2001 as an additional academic partner. EURECOM is a graduate-level research school that offers a 4-semester program in the area of Communication Systems and adheres to the ECTS credit system. About 100 students at master level are accepted each year from 8 European schools. Moreover, 35 PhD students are presently preparing their thesis work at the Institute where teaching and research are undertaken in three Departments:

- the Corporate Communications Department with a focus on network security, network management and agent technologies, protocols for high speed networks and Internet.
- The Multimedia Communications Department with a focus on multimedia networking, Web and Internet technologies, automatic indexing of multimedia documents, speech recognition, video representation and video coding.
- the Mobile Communications Department with a focus on digital signal processing for mobile communications, multi-user information theory , 3 rd generation systems, wireless protocols, and mobile ad hoc networks.

Institut Eurécom is located in the Sophia Antipolis Technopole in the South of France. It is a GIE (Groupement d'Intérêt Economique), a consortium under French Law. Its industrial members are currently Swisscom, Hasler Stiftung, THALES Communications, CEGETEL, France Telecom, HITACHI Europe, Texas Instruments, STMicroelectronics and Bouygues Telecom. The Institute has an approximate budget of 7 million Euros of which one million are from research contracts. It has some 92 employees among, which 63 are scientists (10 professors, 10 teaching and research assistants, 10

engineers, 35 PhD. students) whereas 29 constitute the Computers & Networks department and the administrative staff. Since its creation, the Institut Eurécom actively participates in several European framework projects.
Eurecom has been deeply involved in FP5 and FP6 IST programs. The Mobile Communications Department of EURECOM was involved in the FP5 IST program as a major partner of the Moby Dick project (Mobility and Differentiated Services in a Future IP Network). It is also actively involved in several industry/academia collaborative research projects in the framework of the French National RNRT (Réseau National de la Recherche en Télécommunications). These projects are mainly related to beyond-3G Cellular Mobile systems and their convergence with IPv6 networks (Specific Targeted Research Project). Eurecom is also a key member of the NEWCOM Network of Excellence. Note finally that Eurecom develops open-architecture multi-way real-time radio platforms (B3G, MIMO/OFDM and UWB). The platforms are for use in publicly-funded research projects aiming at demonstrating innovations at all protocols layers (RF to applications). The B3G platforms are also used in the ongoing FP6 projects E2R and Daidalos Integrated projects while the MIMO/OFDM platforms are being developed in the context of the WIDENS

Further detailed information on Eurecom is available at http://www.eurecom.fr

B.2 Curricula Vitae et Studiorum of Eurecom project members

Merouane Debbah was born in Madrid, Spain. He entered the Ecole Normale Supérieure de Cachan (France) in 1996 where he received the M.Sc and the Ph.D. degrees respectively in 1999 and 2002. From 1999 to 2002, he worked for Motorola Labs on Wireless Local Area Networks and prospective 4G systems. From October 2002, he was appointed Senior Reseacher at the Vienna Research Center for Telecommunications (ftw.), Vienna, Austria working on wireless channel modeling issues. He is presently an Assistant Professor with the department of Mobile Communications of the Institute Eurecom. His research interests are in information theory and wireless communications.

Nadia Fawaz was born in 1982 in Antony, France. In Sept. 2002, she entered Ecole Nationale Superieure des Telecommunications. Starting 2003, she joined Eurecom and received a joint diploma in Electrical Engineering from Eurecom/ENST Paris. Her diploma thesis focused on asymptotic multi-cell analysis in the CDMA setting. Nadia Fawaz is now working towards a Phd Degree in ad-hoc networks and virtual MIMO schemes.

B.3 Project Relevant Eurecom Publications

Eurecom Publications Related to WP 1 (Capacity Analysis of Wideband Multi-User Networks)

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Guillaud, Maxim, Slock, Dirk T M "MIMO frequency-selective channel modeling based on pathwise dynamics" Asilomar 2004, 38th Asilomar Conference on Signals, Systems and Computers, November 7-10, 2004, Pacific Grove, USA

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Medles, Abdelkader; Visuri, Samuli; Slock, Dirk T M, "On the effect of channel knowledge imperfections at the transmitter on the capacity of MIMO systems" ISSPA'03, 7th International symposium on signal processing and its applications, 1-4 July 2003, Paris, France

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Debbah, Merouane; Müller, Ralf R, "Capacity complying MIMO channel models" ASILOMAR'03, 37th IEEEE Annual Asilomar Conference on Signals, Systems and Computers, November 9-12, 2003, Pacific Grove, USA

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Eurecom Publications Related to WP2 (Multi-Cell Analysis and Optimization)

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Debbah, Merouane; Hachem, Walid; Loubaton, Philippe and De Courville, Marc,"MMSE Analysis of Certain Large Isometric Precoded Systems" IEEE Transactions on Information Theory, Vol. 49, May, No.5- 2003

Debbah, Merouane; Hachem, Walid; Loubaton, Philippe and De Courville, Marc "Asymptotic Performance of Redundant OFDM Precoders with MMSE Equalization", Proceedings of the 11th IEEE Signal Processing Workshop, 2001, Page(s): 389-392

N. Bonneau, M. Debbah, E. Altman, "Spectral efficiency of CDMA Downlink Cellular Networks with Matched Filter," to appear in EURASIP Journal on Wireless Communications and Networking.

N. Bonneau, M. Debbah, E. Altman, G. Caire, "Spectral efficiency of CDMA uplink cellular networks," ICASSP 2005, IEEE International Conference on Acoustics, Speech, and Signal Processing, March 19-23, 2005 - Philadelphia, USA.

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N. Bonneau, E. Altman, M. Debbah, G. Caire, "When to Synchronize in Uplink CDMA," 2005 IEEE International Symposium on Information Theory, Adelaide, Australia, Sept. 4-9, 2005.

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C. INFORMATION ABOUT University of South Australia

C.1 General Information

The Institute for Telecommunications Research (ITR), of the University of South Australia is a National and International leading research institution in the areas of communications, networks, signal processing, coding and information theory. ITR occupies a unique position in Australian telecommunications research and ranks at the top of Australian research groups in the areas of coding, information theory and communications. ITR researchers cover a wide range of areas in telecommunications, ranging from fundamental studies in information theory to modem design for satellite communications and hardware prototype development and construction for industrial partners. ITR members regularly contribute to the most relevant international journals and conferences in their respective areas of interest.

Further information can be found at http://www.itr.unisa.edu.au

C.2 Curricula Vitae et Studiorum of SA University Project Members

Laura Cottatellucci received the Dipl.-Ing. degree (summa cum laude – A.Y. 1994) in Electronic Engineering from La Sapienza University in Rome. Specialized in networking at Guglielmo Reiss Romoli School for Advanced Studies (1996, L'Aquila, Italy), she worked in Telecom Italia (1995 – 2000) as Design Engineer, responsible for technical design, development and implementation of data and voice telecommunication networks. From April 2000 to September 2005 she worked as Senior Research in ftw. (Forschungszentrum Telekommunikation Wien). Since October 2005 she is working at INRIA and in January 2006 she will join University of South Australia. Her research interests are multi-user

information theory and communications. Laura Cottatellucci authored about 20 peer-reviewed conference papers and journal articles. She is going to defend her Ph.D. on low complexity multi-user detectors for randomly spread CDMA Systems at the Technical University of Vienna by the end of 2005.

Albert Guillen i Fabregas received the Telecommunication Engineering Degree and the Electronics Engineering Degree from Universitat Politècnica de Catalunya, Barcelona, Catalunya, Spain, and the Politecnico di Torino, Torino, Italy, respectively, both in 1999, under the Double Degree Socrates-Erasmus Scholarship Program of the European Community, and the Ph.D. in Communication Systems from Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, in 2004. From August 1998 to March 1999, he conducted his Final Research Project at the Center for Communications and Signal Processing Research (CCSPR), at the New Jersey Institute of Technology (NJIT), Newark, NJ, supported with a Nokia-NJIT Research Fellowship. He was with Telecom Italia Research Laboratories, TILAB (old CSELT), Torino, Italy, from November 1999 to June 2000. From September 2000 to May 2001, he was with the European Space Research and Technology Centre (ESTEC), of the European Space Agency (ESA), Noordwijk, The Netherlands, developing a new class of high efficiency turbo coded modulations for next generation satellite digital video broadcasting. During his doctoral studies, from 2001 to 2004, he has been a Research and Teaching assistant at the Mobile Communications Department, Institut Eurecom, Sophia-Antipolis, France. From June 2003 to July 2004 he has been a visiting scholar at the Communications Theory Lab at EPFL. Since September 2004 he is at the Institute for Telecommunications Research, University of South Australia, Mawson Lakes, Australia, as a Research Fellow. During June-July 2005 he has held a visiting appointment at Ecole Nationale Superieure des Telecommunications, Paris, France. His specific research interests are in the area of communication theory, information theory, coding theory, digital modulation and signal processing techniques, particularly with wireless terrestial and satellite applications. Dr. Guillén i Fàbregas received a pre-doctoral Research Fellowship of the Spanish Ministry of Education to join ESTEC-ESA. He received the Young Authors Award of the 2004 European Signal Processing Conference EUSIPCO 2004, Vienna, Austria, and the 2004 Nokia Best Doctoral Thesis Award in Mobile Internet and 3rd Generation Mobile Solutions from the Spanish Institution of Telecommunications Engineers. He is also a member of the IEEE Information Theory and Communications Societies and the ARC Communications Research Network (ACoRN).

Alex Grant

Alex Grant received the B.E. and Ph.D. degrees from the University of South Australia in 1993 and 1996 respectively. In 1997, he was a research fellow at the Laboratory for Signal and Information Processing, Swiss Federal Institute of Technology (ETH), Zurich. Since March 1998 he has been with the Institute for Telecommunication Research, University of South Australia, where he is now a Professor. Prof. Grant is Leader of the Coding and Information Theory Research Group at ITR and his research concentrates on the application of information theory to multiple user communications problems. He has made contributions in the areas of random matrix analysis and iterative decoding methods for multiple-access channels. Prof. Grant is a member of the IEEE Information Theory and Communications Societies and serves as Chairman for the Australian Chapter of the IEEE Information Theory Society. He served as Technical Program Chair for the 2001 IEEE Information Theory Workshop and is an organizing committee member for the Australian Communications Theory Workshop (founding member) and the 2004 IEEE International Symposium on Spread Spectrum Techniques and Applications. He is General Co-Chair for the 2005 IEEE International Symposium on Information Theory, to be held in Adelaide. Prof. Grant has published various technical papers and is supported by several Australian Research Council grants and industry-sponsored projects. He is a Principal Fellow at the University of Melbourne and a Visiting Professor at the University of Alberta.

C.3 Project Relevant University of South Australia Publications

UniSA Publications Related to WP 1 (Capacity Analysis of Wideband Multi-User Networks)

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L. Hanlen and A. Grant, "Optimal Transmit Covariance for MIMO Channels with Statistical Transmitter side Information," IEEE Int. Symp. Inform. Theory, Adelaide, Australia, 4-9 Sept. 2005.

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Laura Cottatellucci and Ralf R. Müller, "A systematic approach to multistage detectors in multipath fading channels", IEEE Transactions on Information Theory, Sep 2005.

Ralf R. Müller and Laura Cottatellucci, "Joint antenna combining and multiuser detection. In Smart antennas in Europe, Stat-of-art", Stefan Kaiser editor, EURASIP book series on Applied Signal Processing, to appear 2005.

Laura Cottatellucci, Ralf R. Müller and Mérouane Debbah, "Efficient implementation of multiuser detectors for asynchronous CDMA", Proc. 42nd Allerton Conf. on Communication, Control and Computing, Monticello, Illinois, Sep/Oct 2004.

Laura Cottatellucci, Mérouane Debbah, Ralf R. Müller, Linear Multiuser Detection for Asynchronous CDMA Systems: Chip Pulse Design and Time Delay Distribution. Submitted to IEEE Information Theory Workshop (ITW), Montevideo, Uruguay, Oct. 2005.

Laura Cottatellucci and Ralf R. Müller, "A generalized resource pooling result for correlated antennas with applications to asynchronous CDMA", Proc. of International Symposium on Information Theory and its Applications (ISITA), Parma. Oct 2004.

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Laura Cottatellucci and Ralf R. Müller, "Multistage detectors for asynchronous CDMA", Invited for International Zurich Seminar on Communications (IZS), Zurich, Switzerland. Feb 2004.

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A. B. Reid, A. J. Grant and P. D. Alexander, "List detection for the K-symmetric multiple-access channel," IEEE Trans. Inform. Theory, vol 51, no. 8, pp. 2930-2936, Aug. 2005.

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UniSA Publications Related to WP 4

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A. Guillén i Fàbregas and G. Caire, "Turbo-like Codes in the Block-Fading Channel", in Proc. 2004 IEEE International Symposium on Information Theory (ISIT), Chicago, IL, June-July 2004.

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D. INFORMATION ABOUT Ecole Nationale Supérieure des Télécommunications

D.1 General Information

ENST laboratories are part of *GET-Recherche*, a research unit which gathers laboratories from ENST-Bretagne, INT and the GET subsidiaries.
Over the last few decades, ENST has gained international recognition in the technical domain. In addition to working on basic science developments, research at ENST also aims at broadening its field of study, particularly towards system integrations, innovative services on the Internet and in other media, and analysis of users' communication practices and their social impact. ENST thus covers all aspects of Information Technologies.

ENST is committed to maintaining an optimal balance between scientific research, where themes remain fairly stable, and applied research, which evolves more rapidly.

Research projects are organized principally in collaboration with universities and major research groups, like the CNRS (*Centre National pour la Recherche Scientifique*). Applied research is pursued through contractual agreements between ENST and its corporate partners.

ENST gathers more than 126 teachers-researchers, 17 CNRS researchers and 143 thesis students.

D.2 Curricula Vitae et Studiorum of ENST University Project Members

Joseph J. Boutros received the electrical engineering degree in 1992 and the Ph.D. degree in 1996 from the Ecole Nationale Superieure des Telecommunications, Paris, France. Since September 1996, he has been with the Communications and Electronics Department at ENST as an Associate Professor. His fields of interest are lattice sphere packings, codes on graphs, iterative decoding, and wireless CDMA/OFDM systems. Dr Boutros is an active IEEE member in both Information Theory and Communications societies. His research is performed under grants and tight collaboration with Motorola Labs, Mitsubishi Electric, STMicroelectronics and Thales communications.

Liu Yang received the BE and MS from Shanghai Jiao Tong University in Communications Engineering in 2001 and 2004 respectively. He has been with Sharp Corporation, Japan, from 2004 and will start his PhD at ENST in March 2006.

D.3 Project Relevant ENST Publications

G. Kraidy, N. Gresset and J.J. Boutros Information theoretical versus algebraic constructions of linear unitary precoders for non-ergodic multiple antenna channels, Canadian Workshop on Information Theory, Montreal, June 2005.

J.J. Boutros and G. Zémor On quasi-cyclic interleavers for parallel turbo codes, submitted to the IEEE Transactions on Information Theory, January 2005.

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