WIRELESS COMMUNICATIONS LABORATORY

NORMAN C. BEAULIEU

iCORE Chair
Electrical and Computing Engineering, University of Alberta
http://www.ece.ualberta.ca/~iwcl/

Professor Norman C. Beaulieu was awarded the first iCORE Chair, September 1, 2000, forming a team with existing University of Alberta Faculty Professor Witold A Krzymieñ and Associate Professor Ivan Fair. The establishment of the iCORE Chair in Broadband Wireless Communications at the University of Alberta seeded the institution of the iCORE Wireless Communications Laboratory (iWCL). Associate Professor and iCORE Research Associate Chinthananda Tellambura joined the team in July 2002. Dr Xiaodai Dong is an Assistant Professor and iCORE Research Associate She joined the University of Alberta in February 2002. Dr Oussama Damen is a Research Engineer recruited from a leading American university. In November 2003, the team expanded to include a University of Calgary based researcher, Professor Abraham Fapojuwo. This expansion is technical as well as geographical.

EXECUTIVE SUMMARY

The overall goal of the research program is to create new engineering science and technologies that will lead to high capacities in broadband wireless communication systems at lower cost. The primary thrust is on topics related to broadband wireless communications systems. Research activity of Professor Krzymieñ and his graduate students supported through the iCORE Chair is currently focused on broadband high throughput packet data access to the Internet for mobile and nomadic users, employing OFDM (orthogonal frequency division multiplexing) and spread spectrum signalling, and MIMO (multiple-input multiple-output) antenna techniques. Dr Krzymieñ has done collaborative research with Nortel Networks and Ericsson Wireless Communications. Dr Fair and his graduate students are investigating efficient channel coding techniques for wireless communication systems. Dr C. Tellambura's interests are focussed on multicarrier techniques and wireless fading channel communications. In particular, he is working on techniques for the design of high rate, high reliability wireless networks that integrate orthogonal frequency division multiplexing and space-time coding. Dr Abraham Fapojuwo and his graduate students are investigating efficient protocols and algorithms for high performance wireless communication networks. Dr Dong's research focuses on the development of theory and applications that aid the design of high capacity broadband wireless communications systems.

Successful collaborations have resulted in journal papers, conference papers, and patent applications. The iWCL has also been successful in obtaining external funding. The team has brought $804,096 in addition to iCORE funding to the research program. In addition, research trainees of the team have received $907,789 in external awards.

Fifteen refereed journal papers appeared in the reporting period, all in leading international journals. A further nine refereed journal papers were accepted in the reporting period, again all in leading international journals. Twenty conference papers were presented by the iCORE Chair and his research trainees in the reporting period. A further six conference papers were accepted for presentation in June 2004. In addition, one invited paper was presented in the United States.

Having established an internationally recognized program of scholarly research and personnel training, the iCORE Chair will build an intellectual property portfolio in the future while maintaining its scholarly activities. In consequence of the achievements, awards, recognition and growth of the first 43 months, the iCORE Wireless Communications Laboratory is now well known in the international communications research community and is increasing international and national awareness of Alberta, iCORE and the University of Alberta.

RESEARCH PROGRAM OVERVIEW

Wireless communications research has been given great impetus by the advent of cellular telephony, mobile satellite and portable personal communication services. The exponentially growing user demand for services, together with the increasing demands for higher speed transmission of large amounts of data, as well as customer requests for multimedia services, create the need for new technologies. In order to provide higher data transmission rates to more users without sacrificing the integrity of the received information, advances must be made in the transmission system designs and in the transmission system components. In turn, achieving the best advances in wireless systems and components requires better modelling of the wireless channels, including the long-term, long-range prediction of the fading channel. The team is investigating a number of topics, including:

- Space-time coding for multiple transmit and multiple receive antenna systems
- Multiple input multiple output (MIMO) antenna systems
- Channel modeling and channel prediction
- Improving wireless transmission technology
- Error rates of orthogonal frequency division multiplexing systems
- Symbol assisted modulation receivers with adaptive constellation mapping

November 2003 marked an important milestone in the development and future of the iCORE Wireless Communications Laboratory (iWCL). The team expanded to include a University of Calgary based researcher, Professor Abraham Fapojuwo, an expert in wireless networking. Until this year the primary thrust has been on the physical layer of broadband wireless communications systems.

The activities of Professors Krzymieñ, Fair, Tellambura, Fapojuwo, and Dong have also been outstanding. Together with Beaulieu, this team has produced over 80 referred journal and conference papers during this funding period.

RESEARCH PROJECTS

BEAULIEU: RESEARCH PROJECTS

The team is investigating a number of scientifically important and industrially relevant topics. Some of them are briefly described here to give an idea of the nature, relevancy and impact of the work.

Linear Threaded Algebraic Space-Time Constellations

Space-time coding for multiple transmit and multiple receive antenna systems is a very “hot” topic in the wireless communications area. It has been shown theoretically that the capacity of a wireless system is increased by using multiple antennas. In multiple antenna systems, the coding and modulation, called space-time coding, employed for signal transmission is a key building block. Space-time coding exploits the available capacity in multiple antenna systems. However, the space-time code design problem is very challenging. Linear space-time constellations are an important class of space-time constellations. Our work has established some fundamental limits to the performance achievable by this class of signals, while characterizing the fundamental tradeoff between diversity and rate under different constraints. Significantly, we have found a new family of constellations that achieve optimal or near-optimal performance, and in addition, we have derived a systematic construction method for generating new space-time constellations. Comparisons show that our proposed

constellations outperform or rival the best-known designs. The codes and the systematic construction method are the subjects of a patent application. This work was done in collaboration with a researcher at the University of Ohio.

Fading Channel Modelling and Long Range Prediction

Future wireless systems will achieve increased capacity by employing multiple input multiple output (MIMO) antenna systems. There is a need for new fading channel models for these new MIMO systems. We are developing new fading channel models that will be essential for the engineering design of future high capacity wireless systems, including MIMO systems.

A mathematically related problem to channel modelling, is channel prediction. In principle mathematically, a bandlimited channel can be perfectly predicted. That is, one can predict the channel amplitude and phase at a future time. It is clear that such long range prediction could be used to enhance the transmission capacity of fading channels; for example, by increasing the data transmission rate at times that the channel will be good and decreasing the rate at times when the channel will be bad. However, it is unclear to what extent one can predict the state of a practical channel with a practical system. We are working on answers to many important questions. Can real world channels be usefully predicted with reasonable complexity and cost? How accurate can such prediction be for a limited observation time of the channel? What are the best transmitter and receiver designs for exploiting channel state prediction information?

Ultra-Wide Bandwidth Systems

Ultra-wide bandwidth (UWB) refers to new systems and technologies that are envisioned to provide short range, high data rate services to multiple users in an unlicensed format. These systems are radical in that they spread the information signal over an extremely wide bandwidth, occupying many gigaHertz of spectrum. Correspondingly, the signals have an extremely small power spectral density and appear as low level noise to existing users. The development of UWB is at an early stage and there are many questions to be answered and things to be learned. Our team has derived the only mathematical solution for predicting the bit error rate due to multi-user interference that is accurate. Other solutions can be in error by more than an order of magnitude. Using this solution we have undertaken the first accurate comparison of time-hopping UWB systems employing pulse position modulation, binary phase shift keying, and direct sequence code division multiple access. We have also derived a new paradigm for pulse shaping in UWB systems. Using this paradigm, we have designed a family of pulses for UWB that have the advantage over pulses in the Gaussian monocycle family that they are naturally limited in time and possess a time-limited autocorrelation function.

iCORE Chair Norman C. Beaulieu and some members of his associated research team at the 2004 Banff Informatics Summit

Reduction of Intercarrier Interference in Orthogonal Frequency Division: Multiplexing using Pulse-Shaping

Orthogonal frequency division multiplexing (OFDM) is a transmission technology that will likely be employed in fourth generation wireless systems. A shortcoming of OFDM is the intercarrier interference (ICI) that results from frequency offsets. This ICI causes a substantial degradation in the average error rate of the OFDM system. Our team has found that appropriate pulse-shaping can reduce substantially the ICI caused by frequency offset in OFDM systems. Using a pulse-shape designed by the Chair (this pulse-shape is the subject of a University of Alberta patent application), the average ICI power is sufficiently reduced that the tolerable frequency offset is increased by 80 percent in some practical cases.

Assessment of Error Rates of Orthogonal Frequency Division Multiplexing: Systems in The Presence of Intercarrier Interference

The assessment of the average bit error rate in an OFDM system that has ICI due to frequency offsets is a very difficult analytical problem. An exact method for calculating the bit error rate of pulse-shaped OFDM systems in the presence of frequency offsets has been derived in our work. This method represents a unified way to calculate the bit error rate of different one-dimensional and two-dimensional subcarrier modulation formats, such as binary phase shift keying (BPSK), quaternary phase shift keying (QPSK), and 16-ary quadrature amplitude modulation (16-QAM).

Norman C. Beaulieu

This accurate method has been used to examine and compare the average error rate performances of OFDM with different pulse-shapings, allowing us to reduce the performance degradation caused by ICI through proper pulse-shaping.

A Novel and Improved Orthogonal Frequency Division Multiplexing System

Orthogonal frequency division multiplexing (OFDM) is being widely used in physical layer specifications, such as IEEE802.11a, IEEE802.16a and HIPERLAN/2, of many broadband wireless access systems. In addition, OFDM is also being used in digital audio broadcasting and digital video broadcasting systems in Europe. Our group has discovered a novel and improved OFDM system design. Our new scheme has superior bit error rate performance in the presence of frequency offset and is the subject of a patent application. The performance gain of the new design over the conventional OFDM system design can be as much as 5 dB in some practical cases.

Novel Pilot Symbol Assisted Modulation Receiver with Superior Performance

Many wireless communication techniques and components require knowledge of the channel state to achieve good performances. More specifically, receivers for higher-order (high data rate) modulations and diversity combiners use channel state information. In practice, this knowledge is often acquired by estimation. The estimation can be performed blindly by using the unknown data symbols only. More frequently, it is performed with the aid of some known symbols. In this case, pilot symbols are interspersed with the data symbols and the channel gain at the position of a data symbol is obtained by interpolation from the values of the channel gain at the locations of the pilot symbols. Pilot symbol assisted modulation (PSAM) is used to estimate channel gain (amplitude and phase) in fading wireless channels. The channel gain estimate is used in a conventional coherent signal detector to make a data decision and in a diversity combiner to weight the signals as they are combined.

At the iCORE Wireless Communications Laboratory, we have invented a novel PSAM receiver which has superior performance to the conventional PSAM receivers. In particular, the gain of iCORE PSAM (iPSAM) over conventional PSAM is greatest when needed most, at small values of signal-to-noise ratio (SNR), or relatively large error rates. The new iPSAM does not require any changes at the transmitter. The performances of all systems now employing PSAM can be improved by employing an iPSAM receiver. It is noted that the greatest benefits of iPSAM relative to conventional PSAM are realized in Rician (line-of-sight plus scatter) fading channels and at fast fading rates. Importantly, the minimum threshold SNR required for acceptable

communication (for example, to achieve a specified target error rate) is lowered significantly in some practical cases, resulting in reduced outage. Patent protection will be sought for this receiver design.

Adaptive Constellation Mapping

Many data sources (for example, image and speech signals) are nonuniformly distributed; that is, they contain substantial amounts of redundancy. Furthermore, even when such signals are compressed, they may still exhibit residual redundancy due to the suboptimality of the compression scheme. In cases where the information is transmitted over a noisy channel, using a standard signaling constellation, its redundancy can be appropriately exploited by using a maximum a posteriori (MAP) detector instead of a maximum-likelihood (ML) detector; doing so will reduce the error rate of the communication system. While this benefit is well understood, it is less clear whether the conventional Gray mapping of data symbols to signal constellation points will provide the minimum bit error rate performance, as it does in the case of uniformly distributed signals. We have now shown that for nonuniform sources, Gray mapping is not necessarily optimal for minimizing the average error rate. Further, we proposed and implemented design criteria for constellation mappings for the transmission and MAP decoding of nonuniform memoryless sources. Our work shows that with nonuniform signals, constellation mappings which follow the objective of minimizing the average symbol energy and, given this, maximizing the decoding probability of the most likely signals, yield error rate performance that is significantly better than Gray encoding maps when the constellations are fixed. We also found that, with an appropriate mapping, both average error rate performance and spectral efficiency can be improved for a highly nonuniform source.

Carrying this work and these concepts further, we have designed an adaptive constellation mapping scheme for non-uniform source data to best exploit the nature of the signals while improving the quality of transmission and the spectral efficiency. A patent on this technology has been applied for. This work has been done in collaboration with researchers at Queen's University at Kingston, Ontario.

KRZYMIEÑ: RESEARCH PROJECTS

The overall objective of Professor Krzymieñ's current research work is the creation of key technologies essential for the future design of advanced broadband wireless packet data systems enabling bandwidth and power efficient high bit rate access to the Internet for nomadic and mobile users of data and multimedia services. Work is currently focused on broadband high throughput packet data access to the Internet for mobile and nomadic users, employing OFDM (orthogonal frequency division multiplexing) and spread spectrum signalling, and MIMO (multiple-input multiple-output) antenna techniques.

Specific projects include:

- "Enabling Technologies for Future High Throughput Packet Data Access," an NSERC Strategic Grant and iCORE Research Chair supported project;
- "Techniques for Efficient Digital Wireless Multiple Access," an NSERC Individual Research Grant project and iCORE Research Chair supported project;
- "Space-Time Processing and Coding for Wideband CDMA and Future Wireless Access," a TRLabs and iCORE Research Chair supported project;
- "Multiple-Access Interference Cancellation for Efficient CDMA Wireless Communications," a TRLabs supported project;
- "High Bit Rate Packet Data Wireless Access on Single and Multi-Carrier Forward Links," a TRLabs and iCORE Research Chair supported project;
- "Advanced Transmitter and Receiver Processing for Adaptive MIMO and Multi-Carrier Packet Data Access Systems," a TRLabs and iCORE Research Chair supported project;
- "Scheduling Algorithms for High Throughput Multiple Antenna Wireless Packet Data Systems," a TRLabs and iCORE Research Chair supported project.

FAIR: RESEARCH PROJECTS

Dr Ivan Fair and his graduate students are investigating efficient channel coding techniques for digital communication systems. During the past year, this research has resulted in the publication or acceptance of three journal papers and the acceptance or publication of eight conference papers. The goal of Dr Fair's research is to develop efficient, easily implemented coding algorithms that result in improved performance in digital communication systems. This is particularly relevant in power-limited wireless systems.

Research projects with which Dr Fair is involved include the development of:

- efficient turbo decoding techniques;
- error control codes for multiple-input multiple-output wireless systems;
- techniques to limit the peak-to-average power ratio in OFDM systems;

- techniques which integrate error control codes with codes for other system constraints such as limited PAPR and specific spectral characteristics.

TELLAMBURA: RESEARCH PROJECTS

Next generation wireless systems should be highly spectrally efficient to handle the ever-increasing demand for wireless communication in a cost-effective manner. Orthogonal frequency division multiplexing (OFDM) has emerged as a leading technology in this regard. Dr Chinthananda Tellambura's research aims to develop coding techniques that will reduce the fluctuations of the OFDM signal amplitude and will reduce interference in OFDM systems. Some of the potential applications and significance of this research are:

- Digital subscriber loops;
- Improved coding techniques;
- Wireless local area networks, digital video broadcasting, digital audio broadcasting and wireless access for mobile satellite services and wireless data networks.

At a theoretical level research aims to develop new performance bounds, design and construction methods. A greater understanding of theoretical limits of the different techniques will also be gained.

Some topics currently under investigation are listed below.

- Peak reduction in OFDM;
- Interference cancellation in OFDM;
- Hybrid selection/maximal ratio diversity over correlated fading channels;
- Novel suboptimal diversity combining receivers;
- Analysis of lognormal fading channels;
- Adaptive modulation for OFDM;
- Space-time codes over correlated fading channels;
- Efficient decoding algorithms.

FAPOJUWO: RESEARCH PROJECTS

The goal of Dr Abraham Fapojuwo's research is to propose, develop and analyze the performance of new and efficient protocols at the data link, transport and network layers of the open system interconnection (OSI) reference model to achieve enhanced capacity and performance in future generation wireless wide area (cellular) networks (WWANs), wireless local area networks (WLANs), and mobile ad hoc networks (MANETs).

Research projects with which Dr Fapojuwo is involved include:

- Radio resource management schemes for wireless Internet protocol (IP) networks;
- Adaptive quality of service (QoS) techniques for CDMA2000 wireless networks;
- Quality of service support in IEEE802.11 wireless local area networks;
- Traffic measurements, modeling and characterization in wireless networks;
- Impact of hidden nodes on wireless local area network performance;
- Security mechanisms in wireless local area networks;
- Quality of service routing protocol for mobile ad hoc networks;
- Analysis of secure routing protocols for mobile ad hoc networks;
- Scheduling protocols for Bluetooth Scatternets;
- Service discovery protocols for mobile ad hoc networks;
- Application of software agents to resource management in wireless networks.

DONG: RESEARCH PROJECTS

Professor Xiaodai Dong's research activities include the development of theory and applications which aid the design of high capacity broadband wireless communications systems. Research projects are being carried out with focus on efficient channel estimation algorithms for wireless fading channels, link adaptation techniques integrating temporal, spatial and spectral components of a communication system, and effective transceiver design of ultra-wideband communications.

The wireless communications industry is witnessing rapid growth in both mobile and fixed applications. The continued increase in demand for voice, data and multimedia wireless services is impetus for higher capacity and higher data rates. Dr Dong's research focuses on the development of theory and applications that examine and deploy high capacity broadband wireless communications systems. Specific interests include adaptive modulation and coding, communication theory, fading channels, transmitter and receiver diversity, multi-carrier communications, spread spectrum technique and ultra-wideband technology.

The overall objective of the research program is to propose and investigate innovative solutions to the capacity, quality and complexity challenges imposed by today's wireless systems. Technology advancements are pursued from both academic and practical perspectives. To achieve this goal, research projects focusing on highly effective channel estimation schemes, performance analysis of wireless systems, link adaptation technologies, and ultra-wideband communication transceiver designs are currently being investigated.

RESEARCH TEAM MEMBERS AND CONTRIBUTIONS

Team Leader

PROFESSOR NORMAN C. BEAULIEU
iCORE Chair in Broadband Wireless Communications
Canada Research Chair in Broadband Wireless Communications
Médaille K.Y. Lo Medal (2004)
Fellow of the Royal Society of Canada
NSERC E.W.R. Steacie Memorial Fellow
Fellow of the Institute of Electrical and Electronics Engineers (IEEE)
Fellow of the Engineering Institute of Canada (EIC)
Editor-in-Chief of the IEEE Transactions on Communications (2000-2003)
President of the Canadian Society for Information Theory

Beaulieu: Faculty Team Members

	ROLE	
Dr Witold A. Krzymieñ, Professor	Faculty Team Member	Rohit Sharma Professorship in Communications and Signal Processing (2003) Fellow of the Engineering Institute of Canada (EIC)
Dr Ivan Fair, Associate Professor	Faculty Team Member	
Dr Chintha Tellambura, Associate Professor	Faculty Team Member	
Dr Abraham Fapojuwo, Associate Professor	Faculty Team Member	
Dr Xiaodai Dong, Assistant Professor	Faculty Team Member	
Dr Moussama Damen, Research Engineer	Team Member	

Beaulieu: Postdoctoral Fellows

	TOPIC	AWARDS
Dr Julian Cheng	Advanced Wireless Technologies for 3G and 4G	
Dr Zheng Du	OFDM and Space-Time Coding	
Dr Seung Joon Lee	Multirate DS-CDMA for Multimedia Applications	Korea Science and Engineering Foundation (KOSEF) Grant

Beaulieu: PhD Students

	TOPIC	AWARDS
Kevin Altman	Symbol Synchronization in Small Signal-to-Interference Ratio Environments	NSERC Postgraduate Scholarship iCORE Graduate Student Scholarship
Kareem Baddour	Autoregressive Simulation Methods for MIMO systems	
Yunfei Chen	Wireless Channel State and Model Parameter Estimation	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Ethan Davis	Signal Classification and Modulation Identification	
Sasan Haghani	Capacity of Fading Wireless Channels	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Bo Hu	Performance Analysis and Design of Ultra-Wide Bandwidth Systems	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Pavel Loskot	Efficient Semi-Analytical and Simulation Methods for Wireless System Performance Assessment	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Amir Masoud Rabiei	Multiuser Detection and Power Control	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Kathiravetpillai Sivanesan	Receiver Designs for Multiuser Detection	
Peng Tan	Novel Receivers for Orthogonal Frequency-Division Multiplexing Communications Systems	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
David Young	A Novel Increased Data Rate Multiuser Transmission Scheme	
Xiaodi Zhang	Performance analysis of H-S/MRC systems	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship

Beaulieu: MSc Students

	TOPIC	AWARDS
Lingzhi Cao	Pilot Symbol Assisted 16-QAM for High Capacity Wireless Systems	
Jeremiah Hu	Optimal Diversity Combining in Non-Gaussian Environments	NSERC PGS-A Scholarship Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
		Walter H. Johns Graduate Studies Scholarship Alberta Learning Graduate Student Scholarship
Wenyu Li	Optimal Pilot Symbol Assisted Modulation	
Tim Poon	Optimal Multiuser Receiver Designs for Co-Channel Interference Environments	NSERC Postgraduate Scholarship iCORE Graduate Student Scholarship Association of Universities and Colleges of Canada International Space Scholarship
		ASTech Foundation Leaders of Tomorrow Award Edmonton Sir Winston Churchill Scholarship
Faruq Rajwani	Novel Closed-Form Approximations to Lognormal Sum Distributions	iCORE Graduate Student Scholarship NSERC Postgraduate Scholarship
		Walter H. Johns Graduate Studies Scholarship Alberta Learning Graduate Scholarship

Beaulieu: Other Team Members

	POSITION	ROLE
Lingzhi Cao	Research Engineer	Conduct preliminary research on high-risk ideas and contribute to the management of the iWCL.
Chris Jones	System Administrator	Provide computer support to Dr Beaulieu and all team members associated with the iWCL.
Sharon Walker	Administrative Assistant	Provide administrative and secretarial assistance to Dr Beaulieu and all team members associated with the iWCL.
Sandra Abello	Administrative Assistant	Provide administrative and secretarial assistance to Dr Beaulieu and all team members associated with the iWCL.

Krzymień: Postdoctoral Fellows

	ROLE/TOPIC	AWARDS
Dr Bartosz Mielczarek	Alberta Ingenuity Fellow/ Techniques for High Throughput Wireless Packet Data Access	
Dr Erik Haas	Visiting Scientist from the German Aerospace Centre (funded by the German side) / Advanced Algorithms for OFDM Signal Detection	

Krzymień: PhD Students

	ROLE/TOPIC	AWARDS
Robert Elliott	TRLabs PhD Student, NSERC Canada Graduate Scholar, Alberta Ingenuity Scholar/Scheduling Algorithms for High Throughput Multiple Antenna Wireless Packet Data Systems	TRLabs Fellowship NSERC Canada Graduate Scholarship iCORE Graduate Student Scholarship
Kevin Jacobson	TRLabs PhD Student, NSERC Scholar/Relay Networks for 4th Generation Cellular Systems	TRLabs Fellowship NSERC PGS B Scholarship iCORE Graduate Student Scholarship Walter H. Johns Graduate Studies Scholarship
Chunlong Bai	TRLabs PhD Student and Alberta Ingenuity Scholar (co-supervised with Dr I.J. Fair)/Hybrid ARQ Protocols Optimized for Adaptive Multi-Carrier MIMO Wireless Packet Data Systems	Alberta Ingenuity Fund Full-time Studentship TRLabs Fellowship TRLabs Scholarship iCORE Graduate Student Scholarship
Jia Liu	TRLabs PhD Student/ Non-Linear Transmitter Pre-Processing Algorithms for Layered MIMO Multi-User Wireless Systems	TRLabs Scholarship
Shreeram Sigdel	TRLabs PhD Student/ Efficient Receiver Algorithms for Multiple-Input Multiple-Output (MIMO) Wireless Systems Employing Adaptive Multi-Carrier Transmission	TRLabs Scholarship
Geoffrey Messier	TRLabs PhD Student/ Techniques for Improved CDMA Forward Link Performance	TRLabs Scholarship
Ge Li	TRLabs PhD Student (co-supervised with Dr I.J. Fair)/Low Density Parity Check (LDPC) Codes for MIMO Wireless Systems	TRLabs Scholarship
David Mazzarese	TRLabs PhD Student and Rohit Sharma Scholar/High Throughput Downlink Cellular Packet Data Access with Multiple Antennas and Multi-User Diversity	TRLabs Scholarship

	ROLE/TOPIC	AWARDS
Kay Wee Ang	Part-time PhD student; employed by the Institute for Infocomm Research, Singapore/Improved Hybrid Subtractive Interference Cancellation Schemes (part time; employed by the Institute for Infocomm Research, Singapore)	
James Z. Yang	Provisional PhD Candidate/ Receiver Processing Algorithms for Layered MIMO Systems	

Krzymieñ: MSc Students

	ROLE/TOPIC	AWARDS
Yu Fu	MSc student, (co-supervised with Dr C. Tellambura)/Intercarrier Interference Reduction in MIMO OFDM Systems	

Krzymieñ: Other Team Members

	ROLE/TOPIC	AWARDS
Robert Hang	Research Associate/ Algorithms for Layered MIMO Systems	

Fair: Postdoctoral Fellows

	ROLE/TOPIC	AWARDS
Dr Yan Xin	Postdoctoral Fellow/PAPR reduction in OFDM systems	Alberta Ingenuity Fund Ingenuity Fellowship

Fair: PhD Students

	ROLE/TOPIC	AWARDS
Fengqin Zhai	PhD Student/Integration of error control and constrained sequence codes	
Ge Li	PhD Student (Co-supervised with Dr Krzymieñ)/Low density parity check (LDPC) codes for MIMO wireless systems	TRLabs Scholarship
Chunlong Bai	PhD Student (Co-supervised with Dr Krzymieñ)/Hybrid automatic repeat request (ARQ) coding schemes for adaptive high throughput wireless data links employing multiple-input multiple-output (MIMO) antenna systems	Alberta Ingenuity Fund Full-time Studentship (renewal) TRLabs Fellowship iCORE Graduate Student Scholarship

Fair: MSc Students

	ROLE/TOPIC	AWARDS
Aaron Hughes	MSc Student/Integration of error control and constrained sequence codes	TRLabs Scholarship
Ali Alavi	MSc Student (Co-supervised with Dr Tellambura)/ Techniques for peak-to-average power ratio reduction in OFDM systems	
Marco Castellon	MSc Student (Co-supervised with Dr Elliot)/ Development of power efficient turbo decoder	

Tellambura: Postdoctoral Fellows

	ROLE/TOPIC	AWARDS
Dr Wen Chen	PDF/Coding for OFDM	

Tellambura: PhD Students

	ROLE/TOPIC	AWARDS
Dung Ngoc Dao	PhD Student/Space division multiple access methods	
Saeed Fouladi Fard	PhD Student / Nonlinear decoding methods for CDMA	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship Tuition Scholarship, University of Alberta
Alireza Ghaderipoor	PhD Student/Space-time Coding and Decoding Techniques	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship
Laleh Najafizadeh	PhD Student/Channel estimation techniques	Alberta Ingenuity Fund Full-time Studentship iCORE Graduate Student Scholarship Delta Kappa Gamma World Fellowship
Yue Wu	PhD Student/Space-time coding techniques	Tuition Scholarship, University of Alberta
Luqing Wang	PhD Student/Reduction of High Peaks of OFDM Signals	

Tellambura: MSc Students

	ROLE/TOPIC	AWARDS
Ali Alavi	MSc Student/Decoding algorithms for Golay sequences	
Yunxia Chen	MSc Student/Performance of Diversity Systems in Correlated Fading Channels	
Yu Fu	MSc Student/Interference Cancellation for OFDM	

Tellambura: Other Team Members

	ROLE/TOPIC	AWARDS
Rees Machtemes	Summer student May to August, 2003/ 3rd and 4th Generation Wireless System Proposals	

Fapojuwa: PhD Students

	ROLE/TOPIC	AWARDS
Xiao Liu	PhD Student/Security mechanisms in wireless local area networks	TRLabs Scholarship NSERC Graduate Scholarship
Helen Lampow-Maundy	PhD Student (part-time)/ WLAN and Cellular Inter-networking	
Mohamed Shehata	PhD Student (Co-supervised with Dr Eberlein)/A Semi-formal framework for requirements engineering	

Fapojuwa: MSc Students

	ROLE/TOPIC	AWARDS
Justin Agbakwuru	MSc Student (Co-supervised with Dr Ulieru)/Scheduling protocol for Bluetooth based WPANs	
Uzo Nzurum	MSc Student/Radio Resource Management Protocols for Wireless IP networks	
Mudit Seth	MSc Student/Adaptive QoS Techniques for CDMA2000 networks	iCORE Graduate Student Scholarship
Ian Lee	MSc Student/ Multimedia traffic modeling in wireless networks	
Rob Sizeland	MSc Student (Co-supervised with Dr Davies)/Quality of Service in IEEE802.11 wireless LANs	NSERC Industrial Scholarship TRLabs Scholarship
Travis Stevens	MSc Student /Quality of Service in Mobile ad hoc networks	NSERC Industrial Scholarship TRLabs Scholarship
Oscar Salazar	MSc Student (Co-supervised with Dr Sesay)/Quality of Service routing in mobile ad hoc networks	TRLabs Scholarship

	ROLE/TOPIC	AWARDS
Yagi Uhuegbulem	MSc Student (Co-supervised with Dr Sesay)/Performance analysis of IEEE802.11 WLANs with exposed nodes	TRLabs Scholarship
Rajeev Babbar	MSc Student (Co-supervised with Dr Far)/Application of software agents to resource management in wireless networks	
Kevin Luo	MSc Student /Packet Scheduling mechanisms in wireless IP networks	

Dong: PhD Students

	ROLE/TOPIC	AWARDS
Mohsen Eslami	PhD Student/High speed ultra-wideband technology	Graduate Tuition Scholarship, University of Alberta (2003) Graduate Research Scholarship, University of Alberta (2003)
Zhengang Chen	PhD Student/Adaptive transmission techniques for multiple antenna wireless networks	Graduate Tuition Scholarship, University of Alberta (2003-2004) Graduate Research Scholarship, University of Alberta (2003-2004)
Yue Wang	PhD Student/Ultra-wideband channel measurements and modeling	Graduate Tuition Scholarship, University of Alberta (2003-2004) Graduate Research Scholarship, University of Alberta (2003-2004)

Dong: MSc Students

	ROLE/TOPIC	AWARDS
Lei Xiao	MSc Student/Effective Channel Estimation for Wireless Fading Channels	IEEE Student Travel Grant (2004) Graduate Tuition Scholarship, University of Alberta (2002-2003) Graduate Research Scholarship, University of Alberta (2002-2003)
Alfred Lee	MSc Student/Transceiver Design of Ultra-Wideband Communication Systems	

COLLABORATIONS

BEAULIEU: COLLABORATIONS

INSTITUTION	NATURE OF COLLABORATION
PROVINCIAL	
iCORE High Capacity Digital Communications Laboratory, University of Alberta	Development and testing of a multiple-input, multiple-output MIMO testbed.
Department of Mathematical and Statistical Sciences, University of Alberta (Douglas R. Wiens):	Research on fading channel amplitude distribution parameter estimation and order statistics
NATIONAL	
Department of Mathematics and Statistics, Queen's University, Kingston, Ontario, Canada (Fady Alajaji, Glen Takahara, and Hongyan Kuai)	Research on signal constellation mappings for non-uniform sources
INTERNATIONAL	
Samsung Electronics, Korea.	4th Generation (4G) Wireless
Wireless Systems Research Department, AT&T Labs – Research, Middletown, New Jersey, USA (Moe Win, Jack H. Winter); Shannon Laboratories, AT&T Labs – Research, Florham Park, New Jersey, U.S.A. (Benjamin F. Logan); Department of Statistics, Rutgers University, Piscataway, New Jersey, U.S.A. (Lawrence A. Shepp):	Research on hybrid selection/maximal ratio diversity combining digital receivers. This collaboration has resulted in two journal papers and four conference papers.
Department of Engineering Science, University of Modena, Modena, Italy (Maria Luisa Merani)	Research on efficient generation of cross-correlated fading amplitude sequences for simulation of correlated branch diversity systems. This collaboration has resulted in one journal paper and one conference paper.
Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts, U.S.A. (H.T. Kung and V. Tarokh); Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, Berkeley, California, USA (D. Tse); Department of Electrical and Computer Engineering, University of Illinois, Urbana-Champaign, Urbana, Illinois, U.S.A. (P.R. Kumar); School of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana, U.S.A. (M.D. Zoltowski); Department of Electrical and Computer Engineering, University of Maryland, College Park, Maryland, U.S.A. (K.J.R. Liu):.	Research in space-time processing for ad-hoc mobile wireless networks. This collaboration has resulted in joint funding applications valued at over $9M Canadian, and the formation of an International Network of Excellence. The only Canadian researcher invited to join this Network of Excellence is N.C. Beaulieu.
INDUSTRIAL	
iCORE Chair	Has continued as Director of the Corporation of Eleven Engineering Incorporated, Edmonton, Alberta in the reporting period. He has been involved in technology and product planning as well as in the recruitment of highly qualified personnel.

KRZYMIEŃ COLLABORATIONS
TRLabs-Calgary
Collaborative links with Simon Fraser University (Dr. Paul Ho), U of Waterloo (Dr. W. Zhuang), PROMPT-Quebec (Dr. C. Despins)
Institute for Communication Technology, German Aerospace Centre (DLR), Oberpfaffenhofen, Germany
Spatial Processing Technology Group, Harlow Laboratories, Nortel Networks, Harlow, UK
CDMA Systems Performance Evaluation Group, Nortel Networks, Richardson, TX, USA
Ericsson Wireless Communications, San Diego, CA and Boulder, CO
TELLAMBURA COLLABORATIONS
Electrical Engineering Department, Virginia Tech, USA
Electrical Engineering Department, University of Bergen, Norway
FAPOJUWA COLLABORATIONS
General Dynamics Canada
Telus Mobility

INTELLECTUAL PROPERTY

PATENTS	TITLE/NAME	STATUS
G.G. Messier, W.A. Krzymień	"Scheduling of wireless packet data transmissions"	US Patent Application No. 10/669,151 filed 23 September, 2003, assigned to TRLabs

FUNDING

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