

## CANADA RESEARCH CHAIR

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### CHAIRHOLDER PROFILES

#### **Norman C. Beaulieu**

iCORE - Canada Research Chair in  
Broadband Wireless Communications  
University of Alberta  
Tier 1 - January 1, 2001



**Research Involves:** Expanding the capacity and quality of service of wireless communication systems

**Research Relevance:** Ensuring the ability of communications networks to meet growing demands for wireless services and enabling new multimedia services

### KEEPING UP WITH THE WIRELESS REVOLUTION

The proliferation of wireless telecommunications devices has put an enormous strain on the physical capabilities of this new technology. The number of cellular phone users has leapt from a mere 25,000 in 1984, to some 16 million a decade later. There were 30 million cordless phones in use across North America in 1992, a number that has since doubled. And global PCS services that were bringing in \$2 billion in 1996, are estimated to have revenues of about \$12 billion in 2001.

Norman Beaulieu is at the forefront of researchers responsible for ensuring that the capability of this technology will be able to keep pace with the demands of these dramatically expanding business and consumer markets.

Beaulieu specializes in the most fundamental aspects of the science of broadband wireless communications. He has also applied these theoretical insights to solving some of the most practical problems in the design of communications systems. And he has been successful. Beaulieu has overturned many of the traditional methods for handling this technology, revealing them to be too expensive and inaccurate to be retained.

This work won Beaulieu the honour of being elected as a fellow of the Institute of Electrical and Electronics Engineers at a relatively early stage in his career. He recently became the only Canadian Editor-in-Chief that the organization's influential research journal has ever had.

Beaulieu has made seminal contributions in several distinct aspects of the field, giving him a wide perspective on strategies for overcoming the current limitations of wireless telecommunications. He suggests that no single improvement will be as effective as several complementary improvements that address different features of the problem. As a recipient of a Canada Research Chair, he intends to investigate several such improvements, dealing with how interference is handled, how signals are processed, and the ability to predict in advance how much data will be travelling over a particular channel.

# NOTICE OF APPOINTMENTS

## IEEE FELLOW

Dr Beaulieu was elected an IEEE Fellow on January 1, 1999, with the citation:

For contributions to the analysis and modeling of wireless data and digital communication systems.

## STEACIE

Norman Beaulieu was awarded the NSERC E.W.R. Steacie Memorial Fellowship in 1999, the first electrical engineer to be so honoured in fifteen years, with the citation:

Norman Beaulieu is a world authority in wireless communication theory who has discovered ingenious mathematical approaches to predict in advance how well new wireless and digital communications systems will perform. His methods are of keen interest to those who design cell phone networks, for example, who need to know if such problems as channel fading and data loss will affect users. In January, he was elected Fellow of the Institute

of Electrical and Electronics Engineers (IEEE).

## IEEE TRANSACTIONS

Norman C. Beaulieu was appointed Editor-in-Chief of the IEEE *Transactions on Communications* in January 2000.

*Transactions on Communications* is the flagship publication of the IEEE Communications Society, which has over 45,000 members. Regarded as "the source" for break through communications theories and practical applications, this world-renowned, scholarly journal covers all aspects of physical-layer communications. At present, there are over 80 Area Editors and Editors on the editorial staff who process over 900 submitted manuscripts per year. The journal has over 9000 subscribers.

Dr Beaulieu is the first individual in Canada to be appointed editor-in-chief of this journal.

## FELLOWSHIP IN THE ROYAL SOCIETY OF CANADA

Dr Norman C Beaulieu was elected to the ranks of the Royal Society of Canada in 2002.

Fellowship in the Royal Society of Canada is considered Canada's most prestigious academic accolade to which scholars and scientists aspire. "These distinguished individuals have accomplished work of truly outstanding quality," said Howard Alper, President of the Royal Society of Canada. "They add enormous value to the extraordinary resource of talent and experience that constitutes the Society."

The citations for the awards describe Dr Beaulieu as "a scientific leader in the analysis and modeling of wireless communications systems. He has discovered ingenious mathematical solutions and models for a wide range of digital communications components and applications. International researchers have widely used his methods, models and results."

# WIRELESS COMMUNICATIONS LABORATORY

iCORE Chair  
Electrical and Computer Engineering  
University of Alberta

*Dr Norman C. Beaulieu is iCORE Chair of the Wireless Communications Laboratory. Two other researchers already at the University of Alberta are part of the research team - Dr Witold Krzymieñ and Dr Ivan Fair - both of the department of electrical and computer engineering. iCORE has committed \$700,000 for five years for a total of \$3.5 million to establish this research team.*

## EXECUTIVE SUMMARY

Professor Norman C. Beaulieu was awarded the first iCORE Research 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 Wireless Communications Laboratory. Assistant Professor Xiaodai Dong and Associate Professor Chinthananda Tellambura joined the team in February 2002 and July 2002, respectively.

The Laboratory has collaborations with researchers at other institutions, with industry and with the iCORE High-Capacity Digital Communications (HCDC) Laboratory. There are research collaborations with partners in New Jersey, Massachusetts, Missouri, Italy and Ontario.

Dr Beaulieu has brought \$715,405 of other (not from iCORE) research funding to the research program. As co-investigator, Dr Beaulieu has secured an additional \$200,000 in research grants.

Dr Beaulieu's team had a total of 92 journal and conference papers published or accepted during the reporting period, a remarkable number. In addition, one Report of An Invention was filed with the University of Alberta Industry Liaison Office.

The iCORE Chair has made strong contributions to the training of highly qualified personnel. One PhD thesis and two MSc theses were completed under his supervision in the reporting period. One PhD qualifying examination was held. In addition, five PhD thesis proposals and two MSc thesis proposals were completed. Currently, Dr Beaulieu is supervising six MSc candidates, ten PhD candidates and three postdoctoral fellows (PDFs) at the University of Alberta. In addition, he is supervising two PhD candidates at Queen's University.

Dr Beaulieu received distinguished recognition by being elected a Fellow of the Royal Society of Canada, and by being appointed to the Executive Committee of the Royal Society. In addition, Dr Beaulieu continued to serve in the reporting period as editor-in-chief of the *IEEE Transactions on Communications*.

The iCORE Wireless Communications Laboratory sponsored ten external invited speakers and twenty-three internal speakers in two seminar series.

In consequence of the achievements, awards, recognition and growth of the first thirty-one months, the 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 GOALS AND OBJECTIVES

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 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

## RESEARCH PROJECTS

The research conducted in the iCORE Wireless Communications Laboratory is multifaceted; some topics under investigation are listed in the Research Team section below.

Dr Beaulieu's research and editorial activity led to his election as a Fellow of the Royal Society of Canada (FRSC) where he was one of eight of the 62 new Fellows of the Royal Society chosen to be profiled in its media release. In addition, he was invited to serve as Invited Distinguished Speaker at an international conference, and invited to write the introduction to the classic reprint of the paper "Linear Diversity Combining Techniques" by D. G. Brennan.

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

made in the transmission system components and the transmission system designs. 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 overall goal of the proposed research is higher capacity in broadband wireless communication systems at lower cost. The primary thrust of this research is investigation into fundamental properties, limitations,

(multiple-input multiple-output) antenna techniques. The work includes physical link layer issues such as adaptive modulation and coding, space-time coding, multiple access interference cancellation and long range channel state prediction, as well as medium access control (MAC) and radio resource management questions, such as



**IN 2002, DR BEAULIEU'S RESEARCH AND EDITORIAL ACTIVITY LED TO HIS ELECTION AS A FELLOW OF THE ROYAL SOCIETY OF CANADA (FRSC).**

hybrid ARQ (automatic repeat request) and packet transmission scheduling algorithms. Dr Krzymieñ has done collaborative research with Nortel Networks and Ericsson Wireless Communications. His professional service to the communications research community includes being an Associate Editor for the IEEE *Transactions on Communications*, a member of the Editorial Board of

and improvements in broadband wireless systems. A secondary thrust is the application of the research results to present and future systems. This two-pronged approach is consistent with the Chair's belief that strong fundamental research is vital to the understanding and improvement of technically challenging systems, while application of the fundamental research results is an important step in creating economic advantages for the supporting community.

*Wireless Personal Communications - An International Journal* (Kluwer), the Area Editor for Digital Communications / Signal Processing of the *International Journal on Wireless & Optical Communications* (World Scientific), and a member of Technical Program Committees for five international conferences. He also served as Session Chair for

several major international conferences. Professor Krzymieñ is the principal investigator on an NSERC Strategic Grant "Enabling Technologies for Future High Throughput Packet Data Access" awarded in October 2002 for five years at \$200,000 per year. The grant's team includes iCORE professors Beaulieu, Fair, Schlegel and Tellambura.

Professor Krzymieñ's current

research activity encompasses the following main projects:

- “Enabling Technologies for Future High Throughput Packet Data Access,” an NSERC Strategic Grant supported project
- “Techniques for Efficient Digital Wireless Multiple Access,” an NSERC Individual Research Grant project
- “Space-Time Processing and Coding for Wideband CDMA and Future Wireless Access,” a TRILabs supported project
- “Multiple-Access Interference Cancellation for Efficient CDMA Wireless Communications,” a TRILabs supported project
- “High Bit Rate Packet Data Wireless Access on Single and Multi-Carrier Forward Links,” a TRILabs supported project
- “Advanced Receivers for Adaptive MIMO and Multi-Carrier Packet Data Access Systems,” a TRILabs supported project

Dr Fair and his graduate students are investigating efficient channel coding techniques for wireless communication systems. The three main thrusts of their work supported through the iCORE Wireless Communications Laboratory include development of efficient turbo decoding techniques, new codes for MIMO systems, and coding techniques to reduce the peak-to-average power ratio in OFDM systems.

As associate chair for undergraduate studies and acting director of computer engineering

in the department of electrical and computer engineering (ECE) at the University of Alberta, Dr Fair has also played an active role in the evolution of the ECE curriculum and programs. Dr Fair was recently appointed an Associate Editor for *IEEE Communications Letters*, and continues to serve on program committees of a number of conferences and as a reviewer for several technical journals.

Research projects lead by Dr Fair that are currently being supported by the iCORE Wireless Laboratory 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.

Professor Xiaodai Dong joined the department and iCORE Wireless Communications Laboratory in February 2002. Professor Dong serves as an associate editor for modulation and signal design of the *IEEE Transactions on Communications*, and a member of the Technical Program Committee for the 2003 IEEE International Conference on Communications (ICC'2003). She provides extensive paper review services to a number of journals and conferences.

Professor Dong's research activities focus on the development of theory and applications that are essential to enabling high capacity broadband wireless communications systems. Specific interests include communication

theory, adaptive modulation and coding, fading channels, multiple antenna systems, multi-carrier communications and ultra-wideband technology. To achieve this goal, research projects focusing on highly effective channel estimation schemes, link adaptation technologies, and ultra-wideband communication transceiver designs are currently under investigation.

Dr C. Tellambura is associate professor and iCORE research associate in the department of electrical and computer engineering, University of Alberta. He was recruited from Monash University in Victoria, Australia and joined the iCORE Wireless Communications Laboratory in July 2002. Dr Tellambura is known internationally for his work in communication theory and wireless systems. He is serving as associate editor for multicarrier systems of the *IEEE Transactions on Communications* and associate editor of the *IEEE Transactions on Wireless Communications*.

Dr Tellambura's research aims to develop coding techniques that will reduce the fluctuations of an OFDM signal amplitude and will reduce interference in OFDM systems. Some of the potential applications and significance of this research are:

- digital subscriber loops, which use existing telephone lines to carry very high-speed data, use multicarrier modulation. High peaks can contribute to out-of-band interference and this may also couple to adjacent subscriber lines causing unacceptable interference;

- if OFDM is to be used for mobile telephony, the Doppler spread caused by the movement of the mobile creates a fundamental limit to performance. Improved coding techniques can alleviate this;
- other applications include wireless local area networks, digital video broadcasting, digital audio

broadcasting and wireless access for mobile satellite services and wireless data networks. New coding techniques and transmit-diversity for OFDM will enhance performance benefits. Some topics currently under investigation are:

- peak reduction in OFDM;
- interference cancellation in OFDM;

- hybrid selection/maximal ratio diversity over correlated fading channels;
- novel suboptimal diversity combining receivers;
- a new representation for the characteristic function of a lognormal random variable;
- adaptive modulation for OFDM;
- space-time codes over correlated fading channels.

## RESEARCH TEAM

The laboratory consists of a team of professors, graduate students and postdoctoral fellows with two office support staff, three summer research assistants, two research engineers and one computer systems specialist.

TEAM LEADER	AWARDS
Norman Beaulieu	<ul style="list-style-type: none"> <li>• Fellow of the Royal Society of Canada</li> <li>• Appointment to Executive Committee of the Royal Society of Canada</li> <li>• NSERC E.W.R. Steacie Memorial Fellow</li> <li>• IEEE Fellow</li> <li>• Canada Research Chair in Broadband Wireless Communications</li> <li>• Fellow of Engineering Institute of Canada (EIC)</li> </ul>
RESEARCH TEAM	TITLE
Witold Krzymieñ Ivan Fair Chinthananda Tellambura Xiaodai Dong	Professor, Fellow of the Engineering Institute of Canada (EIC) Associate Professor Associate Professor Assistant Professor
OTHER TEAM MEMBERS	RESEARCH TOPIC
Qiong Xie Robert Hang	Cellular Network Coverage VHDL Design

PDF - DR BEAULIEU	TOPIC
Julian Cheng M. Oussama Damen Seung Joon Lee	Exact Performance Analysis of DS-CDMA in Nakagami Fading Space-Time Codes and Bandwidth Efficient Pulse Shaping Multirate DS-CDMA for Multimedia Applications

SUPPORT STAFF	POSITION
Mark Wells	Editorial Assistant to the Editor-in-Chief of the <i>IEEE Transactions on Communications</i>
Sharon Walker	Administration
Walt Howard	Computer Systems Specialist

PHD - DR BEAULIEU	TOPIC	AWARDS
Kevin Altman	Symbol Synchronization in Small Signal-to-Interference Ratio Environments	NSERC PGS-B, iCORE Graduate Student Scholarship
Kareem Baddour	Autoregressive Simulation Methods for MIMO systems	NSERC PGS-B, Industry Canada Fessenden Postgraduate Scholarship
Yunfei Chen	Fading Channel State and Model Parameter Estimation	Alberta Ingenuity Scholarship
Julian Cheng	Exact Performance Analysis of DS-CDMA	NSERC PGS-B, NSERC Postdoctoral Fellowship
Ethan Davis	Signal Classification and Modulation Identification	NSERC PGS-B, Nortel Grant
Sasan Haghani	Capacity of Fading Wireless Channels	Alberta Ingenuity Scholarship
Bo Hu	Performance Analysis of Ultra-Wideband Systems	Alberta Ingenuity Scholarship
Pavel Loskot	Hybrid Maximal Ratio/S+N Selection Diversity	
Amir Rabiei	Non-Coherent Maximum Likelihood Estimation	

Kathiravetpillai Sivansan	Receiver Designs for Multiuser Detection	
Peng Tan	Interference Cancellation in OFDM	Alberta Ingenuity Scholarship
Bohdan Tomiuk	Channel Estimation Error in Maximal Ratio Diversity Combining	NSERC PGS-A
David Young	Novel Fading Models based on Physical Channels	
Xiaodi Zhang	Performance Analysis of H-S/MRC Systems	

<b>MSC CANDIDATE - DR BEAULIEU</b>	<b>TOPIC</b>	<b>AWARDS</b>
Lingzhi Cao	Pilot Symbol Assisted 16-QAM for High Capacity Wireless Systems	
Xiaofei Dong	Higher-Order Statistical Behaviour of Fading Channels	
Sasan Haghani	Hybrid Selection/Maximal Ratio Diversity for Two-Dimensional Signalling	
Jeremiah Hu	Tractable Models for Phase Distributions in Signal Fading	NSERC PGS-A, WH Johns Grad Fellowship, iCORE Graduate Student Scholarship
Wenyu Li	Optimal Pilot Symbol Assisted Modulation	
Faruq Rajwani	Novel Closed-Form Approximations to Lognormal Sum Distributions	NSERC PGS-A, WH Johns Grad Fellowship
Qiong Xie	Minimax Approximation to Lognormal Sum Distributions	
Tim Poon	Optimal Receiver Designs for Co-Channel Interference Environments	NSERC PGS-A, iCORE Graduate Student Scholarship, WH Johns Grad Fellowship



PHD CANDIDATE – DR KRZYMIEN	TOPIC	AWARDS
Jia Liu	Interference Cancellation Algorithms for Layered Space-time Wireless Links	TRLabs Scholarship
Shreeram Sigdel	Efficient Receiver Algorithms for Multiple-Input Multiple-Output (MIMO) Wireless Links Employing Adaptive Multi-Carrier Transmission	TRLabs Scholarship
Geoffrey Messier	Techniques for Improved CDMA Forward Link Performance in Realistic Propagation Environments	PGS-A, iCORE Graduate Student Scholarship, TRLabs Scholarship
David Mazzaresse	High Throughput Downlink Cellular Packet Data Access with Multiple Antennas and Multi-user Diversity	TRLabs Scholarship, FS Chia Scholarship
Robert Novak	Adaptive Multi-carrier Systems for High Bit Rate Downlink Wireless Packet Data Access	TRLabs Scholarship
Kay Wee Ang	Improved Hybrid Subtractive Interference Cancellation Schemes	

MSC CANDIDATES – DR KRZYMIEN	TOPIC	AWARDS
Shuying Shen	Long Term Prediction of Small Scale Fading and Multi-user Interference in Single-carrier Single-antenna Packet Data Access Systems	NSERC PGS-A, iCORE Graduate Student Scholarship, TRLabs Scholarship
Robert Elliott	Transmission Scheduling Algorithms for CDMA Packet Data Access Evolution	

PDF - DR FAIR	TOPIC	AWARDS
Yan Xin	PAPR Reduction in OFDM	Alberta Ingenuity Scholarship

PHD CANDIDATES - DR FAIR	TOPIC	AWARDS
Fengqin Zhai	Integration of Error Control and Constrained Sequence Codes	CWTA (Canadian Wireless Telecommunications Assn) Scholarship
Ge Li <i>(Co-supervised with Dr Krzymieñ)</i>	Low Density Parity Check (LDPC) Codes for MIMO Wireless Systems	TRLabs Scholarship
Chunlong Bai <i>(Co-supervised with Dr Krzymieñ)</i>	Hybrid Automatic Repeat Request (ARQ) Coding Schemes for Adaptive High Throughput Wireless Data Links Employing Multiple-input Multiple-output (MIMO) Antenna Systems	Alberta Ingenuity Scholarship, TRLabs Scholarship

MSC CANDIDATES - DR FAIR	TOPIC
Aaron Hughes	Integration of Error Control and Constrained Sequence Codes

SUMMER STUDENTS - DR FAIR	TOPIC	AWARDS
Vincent Sieben	Development of Convolutional Codes with Additional Spectrum Control	NSERC Undergraduate Award

PHD CANDIDATES - DR DONG	TOPIC
Mohsen Eslami	Link Adaptation for Multiple Antenna Systems

MSC CANDIDATES - DR DONG	TOPIC
Alfred Lee	Receiver Design of Ultra-Wideband Communication Systems
Lei Xiao	Highly Effective Channel Estimation for Wireless Fading Channels

PHD CANDIDATE - DR TELLAMBURA	TOPIC
Luqing Wang	Reduction of High Peaks of OFDM Signals

MSC CANDIDATE - DR TELLAMBURA	TOPIC
Yunxia Chen	Performance of Diversity Systems in Correlated Fading Channels

SUMMER STUDENT - DR TELLAMBURA	TOPIC
Rees Machtemes	3rd and 4th Generation Wireless Systems

## COLLABORATIONS

### Research Collaboration

Dr Beaulieu's national and international research collaborations include:

1. Wireless Systems Research Department, AT&T Labs - Research, Middletown, New Jersey, US (Moe Win, Jack H. Winters); Shannon Laboratories, AT&T Labs - Research, Florham Park, New Jersey, US (Benjamin F. Logan); Department of Statistics, Rutgers University, Piscataway, New Jersey, US (Lawrence A. Shepp): Research on hybrid selection/maximal ratio diversity combining digital receivers.

2. Electrical Engineering Department, University of L'Aquila, L'Aquila, Italy (Fortunato Santucci and Marco Pratesi): Research on new mathematical modeling of sums of lognormal random variables and applications to outage in slow frequency hopped time division multiple access (TDMA) spread spectrum (FHSS) cellular systems.

3. 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.

4. 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.

5. Department of Electrical Engineering, University of Missouri, Columbia, Missouri, US (Chengshan Xiao): Research on higher-order statistics of fading channel simulators and research on novel channel models and simulation techniques for line-of-sight fading channels.

Dr Krzymieñ and his students collaborate with the Institute for Communication Technology, German Aerospace Centre (DLR), Oberpfaffenhofen, Germany. The collaboration involves joint work in the area of spread-spectrum multi-carrier systems. The prime contact is Dr Stefan Kaiser. A visiting postdoctoral researcher from DLR, Dr Erik Haas, joined the group from May to August 2003. His visit was funded by DLR.

Professor Tellambura's research collaborations include:

1. Electrical Engineering Department, Virginia Tech, US (A. Annamalai): Research on diversity systems and their performance in wireless environments. Joint research results will be published in a forthcoming book as well.
2. Electrical Engineering Department, University of Bergen, Norway (M. Parker): Research on peak power reduction for OFDM systems.

#### Other Collaborations

Dr Beaulieu continued to serve in the reporting period as editor-in-chief of the IEEE *Transactions on Communications*. Professor Beaulieu also served on the editorial board of the *Proceedings of the IEEE* and as associate editor for communication theory of the IEEE *Communications Letters*. Complementing his research journal activities, the iCORE Chair has been active in research conference organization. A highlight of this activity is the hosting of the International Association of Science and Technology for Development (IASTED) Wireless and Optical Conference (WOC 2002), held in Banff, Alberta in July 2002. The

conference attracted 204 registrants from 24 countries including major participation from Canada, the United States and Korea. Under the leadership of the iCORE Chair, the WOC 2002 Conference grew 264 percent in submissions, 262 percent in registrations and 234 percent in the number of paper presentations over the WOC 2001 conference. Other research conference organization activity includes service on the Technical Program Committee of the conference WIRELESS 2002 and service on the Technical Program Committee of the Global Telecommunications Conference GLOBECOM 2003, service on the Technical Program Committee of the International Telecommunications Symposium ITS 2002, service on the Prize Paper Committee of ITS 2002 and service as Session Chair for the International Conference on Telecommunications ICT'2003 and the IEEE International Symposium on Advances in Wireless Communications.

Dr Beaulieu served on key panels during the reporting period, including: the IEEE Vehicular Technology Society Fellow Evaluation Committee, the British Columbia Advanced Systems Institute research funding proposal review panel, the NSERC Circle Forum, an NSERC Workshop on Highly Qualified Personnel (HQP), the College of Reviewers of the Canada Research Chairs Program and an NSERC Industrial Research Chair Proposal Site Visit Committee.

#### Collaboration with Industry

Dr Beaulieu continued as Director of the Corporation of Eleven Engineering Incorporated,

Edmonton, Alberta in the reporting period. He has been actively involved in technology and product planning as well as in the recruitment of highly qualified personnel.

Dr Krzymieñ's industry collaborations include:

1. Spatial Processing Technology Group, Harlow Laboratories, Nortel Networks, Harlow, UK. Prime contact: Dr Chris Ward. The Harlow group is an industrial partner on an NSERC Strategic Grant. The collaboration primarily entails the spatial processing aspects of the strategic project, but also includes link adaptation and multi-carrier transmission techniques.
2. CDMA Systems Performance Evaluation Group, Nortel Networks, Richardson, Texas, US. Prime contact: Dr David Paranchych. The collaboration is focused on shorter-term evolution of 3rd generation cellular systems enabling high throughput packet data access, and primarily involves design and evaluation of scheduling algorithms for best-effort packet data.
3. Ericsson Wireless Communications, San Diego, California, US and Boulder, Colorado, US. Prime contact: Dr Anthony Soong. Collaboration involves exchange of technical information concerning design and performance evaluation of high throughput single-carrier wireless packet data systems employing adaptive transmission techniques.

### Collaboration with High-Capacity Digital Communications (HCDC) Laboratory

The iCORE Wireless Communications Laboratory has given funding to the iCORE High-Capacity Digital Communications (HCDC) to provide a portion of the salary for a VHDL Design engineer, Robert Hang, for the HCDC lab. Projects include:

- designing and simulating a multi-channel frequency tracking algorithm for a MIMO receiver;
- designing and simulating a timing synchronization algorithm for a MIMO receiver;
- implementing a MIMO receiver design in VHDL for use in the FPGA development board of the HCDC MIMO testbed;

- assisting in a demonstration of the HCDC MIMO system to a potential industrial partner (L3 Communications, Inc.);
- planning the design of the next phase of the MIMO project: the development of a joint packet communication testbed.

The HCDC MIMO team will be presenting research papers based on measurements obtained with the HCDC MIMO testbed at two IEEE conferences this summer and L3 Communications is now an industrial partner on the HCDC MIMO team.

Professor Beaulieu is providing scientific input to the MIMO project. In particular, he is collaborating with Professor Schlegel and a PDF on theoretical solutions to the determination of the capacity of MIMO systems.

### iCORE Wireless Communications Laboratory Seminars

The iCORE Wireless Communications Laboratory has sponsored ten research seminars by invited external speakers from Utah, Waterloo, Kingston, Minnesota, Sydney (Nova Scotia), Turkey, California, Tokyo, Victoria (British Columbia) and France. In addition to providing the usual forum for scientific exchange, the seminar series was designed to introduce the speakers to the University of Alberta and iCORE.

### Graduate Students' Seminar Series

The iCORE Chair's graduate students requested that the Laboratory agree to, and sponsor, a seminar series to be organized and presented by the graduate students. This seminar series has been very well attended by graduate students and faculty from the entire department. In the reporting period, 23 seminars were sponsored.

## FUNDING

### New Funds Acquired this year as Prime Investigator

In addition to iCORE funding of \$700,000, the Chair received an Alberta Ingenuity Fund Institutional Establishment Grant of \$180,000 over two years, an NSERC Research Grant in Wireless Communications and Digital Transmission for \$66,000 per year, and an NSERC E.W.R. Steacie Memorial Fellowship for \$90,000, accompanied by a Research Grant Supplement for \$144,405. In addition, Dr Beaulieu received \$200,000 per year for his Canada Research Chair (CRC) in Broadband Wireless Communications Systems, with an infrastructure grant of \$125,000 from the Canadian Foundation for Innovation (CFI).

### New Funds Acquired this year as Co-Investigator

An NSERC Strategic Grant was awarded in October 2002 in the amount of \$200,000 per year for five years. The award, entitled "Enabling Technologies for Future High Throughput Packet Data Access," provides funding for principal investigator Dr Krzymieñ and co-investigators Drs Beaulieu, Fair, Schlegel, and Tellambura.

### Other

Dr Tellambura received an NSERC Discovery Grant of \$28,000 per year, titled "Orthogonal Frequency Division Multiplexing for Wireless Communications," for the period June 2002 to March 2006.

Dr Dong received an NSERC Discovery Grant titled "Highly Spectral Efficient Wireless Communication Systems," at a funding level of \$22,850 per year for the period April 2003 to March 2007.

## INTELLECTUAL PROPERTY

### Activity this year, including revenue

Dr Beaulieu has filed a University of Alberta Report of an Invention: “Threaded Algebraic Space-Time Signal Constellations and Codes and Threaded Algebraic Space-Time Code Construction Methodology.”

Dr Krzymieñ was granted two patents this year:

1. Q. Shen, W.A. Krzymieñ, “Closed-loop power control scheme for wireless communication systems,” US Patent No. 6 529 709 (granted 4 March 2003; assigned to TRILabs).
2. W.A. Krzymieñ, S. Sun, “Spread spectrum time-division multiple access communication scheme,” US Patent No. 6 493 334 (granted 10 Dec 2002; assigned to TRILabs).

### Patents Received or Created over Lifetime

1. N.C. Beaulieu, “Methods, Systems and Devices for Generating Pulse Shapes,” US and Canadian Patent Application, filed March 28, 2002.
2. A. Jalali, W.A. Krzymieñ, P. Mermelstein, “A medium access control scheme for data transmission on code division multiple access wireless systems,” US Patent No. 5,828,662 (granted 27 October 1998; assigned to Nortel).
3. G.G. Messier, W.A. Krzymieñ, “Channel code decoding for the CDMA forward link,” US (10/260,226; filed 27 September 2002) and Canadian (2,405,322; filed 26 September 2002) patent applications (assigned to TRILabs).
4. W.A. Krzymieñ, S. Sun, “Spread spectrum time-division multiple access communication scheme,” Canadian patent application (no. 2,272,875; filed 26 May 1999, assigned to TRILabs).
5. Q. Shen, W.A. Krzymieñ, “Power control scheme,” a Canadian patent application (no. 2,183,139; filed 12 August 1996, assigned to TRILabs).

### Potential for Future Commercial Activity

The iCORE Chair and his graduate students and PDFs are conducting research on a number of topics that are of great relevance to practical wireless systems. There is potential for intellectual property arising in work on space-time coding, orthogonal frequency division multiplexing (OFDM) and diversity receiver designs.

Professor Krzymieñ’s research activity spans the full range from design and evaluation of novel wireless systems based on the foundation of communications theory to their potential commercial applications, facilitated through his active industrial contacts. The general direction of that activity, best characterized under the general heading of “Enabling Technologies for Future High Throughput Packet Data Access” is of high interest to his industrial partners. In addition to his iCORE affiliation, Professor Krzymieñ is also very strongly linked with the activities of TRILabs, with which he has been closely affiliated since 1986. The TRILabs affiliation further facilitates effective contacts with numerous industrial and other commercial partners, and hence enhances the prospects for commercialization of his research results.

## PUBLICATIONS

### Refereed Journal Publications

1. G. Takahara, F. Alajaji, N.C. Beaulieu, and H. Kuan, "Constellation Mappings for Two-Dimensional Signalling of Non-Uniform Sources," *IEEE Transactions on Communications*, vol. 51, Mar. 2003, pp. 400-408.
2. N.C. Beaulieu, "Introduction to 'Linear Diversity Combining Techniques'," Invited Paper, *Proceedings of the IEEE*, vol. 91, Feb. 2003, pp. 328-330.
3. D.P. Weins, J. Cheng, and N.C. Beaulieu, "A Class of Method of Moments Estimators for the Two-Parameter Gamma Family," *Pakistan Journal of Statistics*, vol. 19(1), 2003, pp. 129-141.
4. D.J. Young and N.C. Beaulieu, "Power Margin Quality Measures for Correlated Random Variates Derived From the Normal Distribution," *IEEE Transactions on Information Theory*, vol. 49, Jan. 2003, pp. 241-252.
5. S. Haghani and N. C. Beaulieu, "Symbol Error Probability of Low-Order Orthogonal Signalings in Rayleigh Fading with General Diversity Combining," *IEEE Communications Letters*, vol. 6, Dec. 2002, pp. 520-522.
6. C. Xiao, Y.R. Zheng, and N.C. Beaulieu, "Second-Order Statistical Properties of the WSS Jakes' Fading Channel Simulator," *IEEE Transactions on Communications*, vol. 50, June 2002, pp. 888-891.
7. J. Cheng and N.C. Beaulieu, "Generalized Moment Estimators for the Nakagami Fading Parameter," *IEEE Communications Letters*, vol. 6, Apr. 2002, pp. 144-146.
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2. M.O. Damen and N.C. Beaulieu, "On Diagonal Algebraic Space-Time Block Codes," to appear as a full paper in *IEEE Transactions on Communications*.
3. M.O. Damen, N.C. Beaulieu, and J.-C. Belfiore, "Bandwidth Efficient Linear Modulations for Multiple Antenna Transmission," to appear as a full paper in *IEEE Transactions on Information Theory*.
4. M.O. Damen, H. El Gamal, and N.C. Beaulieu, "Linear TAST Constellations: Fundamental Limits and Near Optimal Constructions," accepted for publication as a full paper in *IEEE Transactions on Information Theory*.
5. E. Davis, N.C. Beaulieu, and M. Rollins, "A MAP Blind Bit-Rate Detector for Variable Gain Multiple Access Systems," to appear in *IEEE Transactions on Communications*.
6. C.C. Tan and N.C. Beaulieu, "Transmission Properties of Conjugate-Root Pulses," accepted pending revisions for publication in *IEEE Transactions on Communications*.
7. X. Dong and N.C. Beaulieu, "New Analytical Probability of Error Expressions for Classes of Orthogonal Signals in Rayleigh Fading," to appear in *IEEE Transactions on Communications*.
8. X. Dong and N.C. Beaulieu, "Level Crossing Rate and Fade Duration of MRC and EGC Diversity in Ricean Fading," to appear in *IEEE Transactions on Communications*, May 2003.
9. M.Z. Win, N.C. Beaulieu, L.A. Shepp, B.F. Logan, and J.H. Winters, "On the SNR Penalty of MPSK with Hybrid Selection/Maximal Ratio Combining over LLD Rayleigh Fading Channels," to appear as a full paper in *IEEE Transactions on Communications*.
10. J. Cheng and N.C. Beaulieu, "Precise Error Rate Analysis of Bandwidth Efficient BPSK in Nakagami Fading and Cochannel Interference," accepted pending revisions for publication as a full paper in *IEEE Transactions on Communications*.
11. N.C. Beaulieu and C. Cheng, "Efficient Nakagami-m Fading Channel Simulation," accepted pending revisions for publication as a full paper in *IEEE Transactions on Vehicular Technology*.
12. N.C. Beaulieu and M.L. Merani, "Generation of Multiple Rayleigh Fading Envelope Sequences with Specified Cross-Correlations," accepted pending revisions for publication in *European Transactions on Telecommunications*.
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15. H. El Gamal and M. O. Damen, "Universal space-time coding," *IEEE Trans. Inform. Theory*, vol. 49, May 2003.
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18. S. Loyka, C. Tellambura, A. Kouki, A. Annamalai, and F. Gagnon, "Comments on New method of performance analysis for diversity reception with correlated Rayleigh-fading channels," to appear in *IEEE Transactions on Vehicular Technology*.
19. A. Annamalai and C. Tellambura, "MGF-based mathematical framework for analysis of generalized selection diversity systems in wireless channels," to appear in *IEEE Transactions on Vehicular Technology*.



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1. S. Haghani, N.C. Beaulieu, and M.Z. Win, "Bounds to the Error Probability of Hybrid Diversity Two-Dimensional Signalling," IEEE GLOBECOM, Taipei, Nov. 17-21, 2002, pp. 1408-1414.
2. K.E. Baddour and N.C. Beaulieu, "Robust Doppler Spread Estimation in Nonisotropic Scattering Environments," IEEE Vehicular Technology Conference: VTC2002-Fall, Vancouver, Canada, Sept. 24-28, 2002 pp. 2459-2464.
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4. S. Haghani, N.C. Beaulieu, and M.Z. Win, "The Penalty of Hybrid Diversity with LLD Rayleigh Fading," IEEE International Symposium on Advances in Wireless Communications: VTC'02-Fall, Victoria, Canada, Sept. 23-24, 2002, pp. 87-88.
5. N.C. Beaulieu, "Modelling and Simulation of Wireless Channels," SIU Signal Processing and Communications Conference: SIU 2002, Pamukkale, Denizli, Turkey, June 13, 2002, p. 3. Invited Distinguished Speaker Seminar.
6. M.O. Damen and N.C. Beaulieu, "Concatenated Block Error Control Codes and Bandwidth Efficient Algebraic Space-Time Codes," Proc. 3G Wireless: 3Gwireless'2002, San Francisco, May 28-31, 2002, pp. 181-186.
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15. K.W. Ang and W.A. Krzymieñ, "Performance of the multi-stage variable group hybrid interference cancellation scheme with timing and phase errors," in the Proc. 2002 IEEE Semi-Annual Vehicular Technology Conference (VTC2002-Spring), Jeju, Korea, April 2003, paper S08C\_04, 5 IEEE formatted pages.
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37. Luqing Wang and C. Tellambura, "A Novel PAR reduction Technique for OFDM systems Using Adaptive Mapping," to appear in the 15th International Conference on Wireless Communications, Calgary, Alberta, Canada, July 7-9, 2003.
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44. A. Jayalath and C. Tellambura, "A Blind Detection Algorithm for PTS," IEEE International Symposium on advances in wireless communications, Victoria, BC, Canada, Sep. 2002, pp. 125-126.
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### Published Abstracts

1. M.Z. Win, N.C. Beaulieu, L.A. Shepp, B.F. Logan and J.H. Winters, "On the SNR Penalty of MPSK with Hybrid Selection/Maximal Ratio Combining over LLD Rayleigh Fading Channels," *IEEE Transactions on Communications*, vol. 51, Mar. 2003, pp. 517-518.
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