

2005 Research Report

CAREY WILLIAMSON**APRIL 2004 - MARCH 2005**

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A man with glasses is looking at a computer monitor. The monitor displays a world map with various colors representing different regions. The text is overlaid on the image.

BROADBAND WIRELESS NETWORKS, PROTOCOLS, APPLICATIONS, AND PERFORMANCE

WIRELESS INTERNET TRAFFIC MODELLING

Two exciting Internet technologies are the World Wide Web and wireless networks. The Web has made the Internet available to the masses, through its TCP/IP protocol stack and the information-hiding principle of layering. Wireless technologies have revolutionized the way people think about networks, by offering users freedom from the constraints of physical wires.

CAREY WILLIAMSON

iCORE Professor

Department of Computer Science, University of Calgary

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Dr Carey Williamson has been an iCORE Professor in the Department of Computer Science at the University of Calgary, specializing in Broadband Wireless Networks, Protocols, Applications, and Performance since July 1, 2001. He also holds an NSERC/iCORE/TELUS Mobility Industrial Research Chair (IRC) in Wireless Internet Traffic Modeling.

Combined, Dr Williamson leads a research team of 16 people with interests in wireless networks, Internet technologies, and network performance, with an applied focus on industrially-relevant network and protocol performance issues.

EXECUTIVE SUMMARY

This document summarizes research activities for the reporting year of April 1, 2004 to March 31, 2005. The highlights of this reporting year include:

- Leading an active research team that currently consists of 2 faculty members, 6 research staff, and 8 graduate students (4 PhD, 4 MSc)
- Collectively producing 17 research publications (6 journal, 9 conference, 2 book chapters), with 14 more papers (4 journal, 10 conference) currently submitted and under review
- Supervising 5 graduate students to successful completion of their MSc programs
- Acquiring the equipment for the CFI-funded ELISA laboratory
- Extensive service contributions at department, university, national, and international levels

RESEARCH PROGRAM OVERVIEW

This research program combines wireless technologies and the Web, to maximize the value of each. The applied research portion has a strong focus on experimental computer systems performance research, applying techniques such as empirical measurement, computer simulation, and analytical modeling to assess the performance of Internet systems.

The general goals of the research program are:

- To identify protocol performance problems in wireless Web communication systems;
- To propose and evaluate creative solutions to these performance problems; and
- To promote deployment of wireless Web infrastructure at the University of Calgary

RESEARCH PROJECTS

This section describes selected projects underway in our research group in 2004-2005. The chosen projects reflect the variety of network performance research carried out in the group, and complement the larger set of projects discussed in reports from previous years.

Wireless Media Streaming

We are continuing our research on wireless media servers and the portable networks paradigm. The portable network paradigm refers to the deployment and use of Web servers and multimedia servers in a wireless ad hoc networking environment, without requiring any pre-existing network infrastructure. Four research publications have resulted from this work to date.

The main emphasis in this past year has been on wireless media streaming and included a live field trial of a wireless media server with a French cinematography class. Eight concurrent unicast stored video streams were successfully delivered to students using laptops in the wireless ad hoc classroom network.

This project unifies many of the topics on which graduate students and research staff are currently working. The challenges include not just Web content delivery, but also request scheduling, wireless media streaming, quality of service, TCP protocol performance, caching, security, and ad hoc routing. This project also provides a natural linkage to a new faculty member, whose specialty is multimedia content delivery systems on the wired Internet. Wireless access networks change many of the assumptions on which multicast streaming systems are based.

The “Bad Apple” Phenomenon

Our experiments with video streaming applications in wireless LANs identified an interesting observation that we call the “bad apple” phenomenon: when one user in the Wireless LAN (WLAN) has poor or intermittent wireless connectivity, this client can disrupt the media streaming quality for all other users in the WLAN. In other words, one “bad apple spoils the batch.” Further research demonstrated that the phenomenon arises because of interactions that occur between protocols when using a shared wireless channel, a FIFO queue, and multiple stations with differing wireless channel quality.

In essence, this problem is a transient manifestation of Head Of Line (HOL) blocking, at the Medium Access Control (MAC) layer. All pending packets in the

queue are blocked while the front packet undergoes retransmissions. The effective service rate of the queue diminishes. Since the media server continues to generate packets for the streaming clients, the queue fills and overflows, and packets from all clients are subject to loss. When the “bad apple” reconnects, the service rate of the WLAN queue returns to normal, and the backlog dissipates. The result of this phenomenon is that guaranteeing Quality of Service (QoS) for wireless video streaming is impossible. Performance in the WLAN will degenerate to that of the client with the worst wireless connectivity.

Our research is studying solutions to this fundamental problem, which pervades all IEEE 802.11 technologies, including IEEE 802.11e. We have three solutions in mind. The simplest is to disable MAC-layer retransmissions. However, this has the undesirable side effect of making the WLAN unreliable for all users. The second solution is to use multiple queues for service classes, and to do dynamic adaptation of transmission rates and retry limits. The third solution is to use multi-rate multi-channel MAC protocols, as described in the next section.

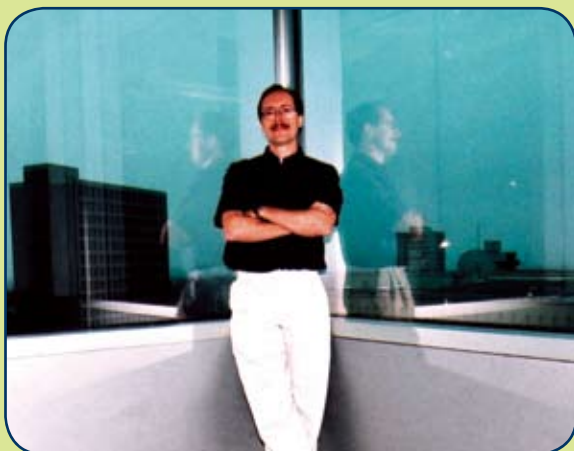
Multi-Rate Multi-Channel MAC Protocols

Dynamic transmission rate selection is widely used in IEEE 802.11b WLANs to combat adverse wireless channel conditions. However, overall system throughput suffers when stations with different transmission rates share the same physical channel. This phenomenon is another manifestation of the “bad apple” problem, though it is not quite as severe as in the video streaming case.

In our recent work, we are proposing and evaluating a multi-rate multi-channel MAC protocol to solve this problem. This approach assumes a multi-radio WLAN environment. Our approach uses different transmission channels to isolate high-rate stations from low-rate stations. Simulation is used to evaluate the performance of the proposed protocol, assuming four channels and four transmission rates (1, 2, 5.5, and 11 Mbps). Our simulation results show throughput improvements of up to 450 percent compared to the IEEE 802.11b MAC protocol. Our simulations have considered up to 30 hosts, in both static and mobile scenarios. We have also studied static versus dynamic rate assignment strategies for the channels. In all cases, our new MRMC protocol looks promising. To that end, two papers have been written describing this work and are under submission at this time.

Anonymous Network Communication

Anonymous communication is important for certain network applications. For example, sender anonymity



Carey Williamson

is required for applications such as e-voting and e-counseling for victims of abuse, while receiver anonymity may be needed to protect freedom of speech when publishing certain documents on the Web.

There have been several systems proposed for providing anonymous network communication. For example, Mixes provide anonymity by re-routing a message through a series of intermediate nodes, using layered encryption to hide the contents of a message from hop to hop. Broadcasting approaches send each encrypted message to everyone, though only the intended receiver has the key required to decrypt the message. Our team has spent the past two years designing, implementing, and evaluating an anonymous communication scheme. The design of our anonymous communication scheme is based on the Buses protocol from the literature. Buses provide strong mutual anonymity without the overhead incurred by mixes and broadcasting. The Buses protocol uses the metaphor of a city bus with a scheduled route through the network. The bus hides a message's route through the network just like a public transit bus hides a passenger's route through a city.

We have implemented and evaluated this modified Buses protocol in a Linux cluster environment. Several modifications to the original Buses protocol were necessary to protect against replay attacks, to

make the protocol scalable, and to make it practical for implementation. To the best of our knowledge, we have created the first practical implementation of any Buses protocol in the literature.

This work is exciting and significant. Our measurement results show that our protocol is a promising alternative for providing strong anonymity with manageable overhead. The potential impact of this work on Internet-based communication is huge.

Two research papers have been prepared related to this work. Both papers have been submitted for possible publication, and are still in the review process. Extending the protocol to wireless ad hoc network environments is the primary challenge for this research.

OBJECTIVES FOR THE NEXT YEAR

The objectives for the next year are to build and maintain a sustainable network measurement infrastructure in the ELISA lab to support our research, to build and evaluate a stadium-scale prototype for wireless video streaming, and to conduct a capacity planning simulation study for TELUS Mobility using our custom-designed traffic models for cellular data networks. These projects will hopefully continue as the Chair undertakes the iCORE renewal process in Fall 2005.

Carey Williamson
and some research
team members
at the 2005 Banff
Informatics Summit



RESEARCH TEAM MEMBERS

My research team currently consists of two faculty members, six full-time research staff and eight graduate students (three of whom are co-supervised).

There were several changes in my research staff this year:

- Tianbo Kuang. Tianbo resigned in August 2004 in order to take a new job at Intel in Calgary. Tianbo was a valuable employee for the last three years, doing a lot of research on wireless network measurement, video streaming, and multi-channel MAC protocols. He and I co-authored five research papers in the last three years.
- Guangwei Bai: Guangwei’s position with my research group also came to an end in August 2004. Guangwei and I co-authored eight research publications in the last three years, including the work on wireless Web servers and the modeling of Web cache filter effects. Guangwei is still exploring employment options in the Calgary area.
- Nayden Markatchev: Nayden became a full-time graduate student in January 2005, and had to relinquish the ELISA lab manager role that he has handled admirably for the past three years. Nayden was admitted to the MSc program, and has chosen to work with Dr Rob Simmonds on Grid Computing.

Team Members

FACULTY TEAM NAME	ROLE/TOPIC	AWARDS/SPECIAL INFO
Carey Williamson	Team Leader, Wireless Internet	NSERC/iCORE/TELUS Mobility IRC
Anirban Mahanti	Assistant Professor	Multimedia Systems
POSTDOCTORIAL FELLOWS		
Yujing Wu	Wireless, CDMA	Telus Mobility
PHD STUDENTS		
Xiaozhen (Jean) Cao	Wireless Streaming	NSERC IPS, TRLabs Fellowship
Mingwei Gong	Wireless Scheduling	Passed candidacy January 2005
Andreas Hirt (co-supervised)	Anonymous Communication	NSERC CGS and AB Ingenuity
Nadim Parvez (co-supervised)	TCP Modeling	Started January 2005
MSC STUDENTS		
Sean Boyden (co-supervised)	Video Streaming	Province of Alberta Scholarship
Abhinav Gupta	Ad Hoc Routing	AB Ingenuity, finished August 2004
Andreas Hirt (co-supervised)	Network Anonymity NSERC PGS	Finished July 2004
Gwen Houtzager	Web Proxy Caching	NSERC PGS, finished Jan 2005
Alok Madhukar	P2P Traffic Analysis	TRLabs Scholarship
Aniket Mahanti	Web Proxies	NSERC PGS
Dan Munteanu	Network Processors	Finished August 2004
Ian Wormsbecker	Multi-Channel MAC	Heritage Scholarship
Fang (Shelly) Xiao	WLAN Fairness Issues	Finished August 2004

OTHER RESEARCH TEAM MEMBERS

Martin Arlitt	Network Traffic Measurement	HPLabs, Grid Research Centre
Guangwei Bai	Traffic Modeling	Ended August 2004
Emir Halepovic	Network Traffic Analysis	NSERC CGS for Sept 2005
Gwen Houtzager	Network/System Admin	Started January 2005
Tianbo Kuang	Wireless Protocols	Ended August 2004
Nayden Markatchev	Network/System Admin	Ended December 2004
Hongxia Sun	CDMA, Cellular	TELUS Mobility project
Qian Wu	Network Simulation	Multi-channel MAC

COLLABORATIONS

INSTITUTIONAL AND PROVINCIAL

WIRELESS PILLAR, WESTGRID

At the University of Calgary, my research team and I interact with the TeleSim research group coordinated by Rob Simmonds and Brian Unger. We attend weekly meetings as part of TeleSim, exploring mutual interests in parallel/distributed simulation, high performance computing, and grid computing. I am also a participant in Netera and WestGrid.

I attended the annual general meeting of Centre for Information Security and Cryptography (CISAC), organized by iCORE Chair Hugh Williams. I have registered with CISAC as an affiliated researcher.

I have attended several strategic planning meetings of the so-called "Wireless Pillar" group at the University of Calgary. This group is fostering multi-disciplinary collaboration on wireless research initiatives at the U of C. Several other iCORE researchers (for example, Graham Jullien, Gérard Lachapelle, Jim Haslett) are part of this group, as is CRC Chairholder Michal Okoniewski.

NATIONAL

U OF C, U OF S, CFI, NSERC

My main multi-institutional partnership involves the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA), shared by the University of Calgary and the University of Saskatchewan. The bulk of the equipment for the CFI-funded ELISA lab arrived this year. The purchase process was on hold for the last 2 years pending completion of the inter-institutional agreement between the University of Calgary and the University of Saskatchewan.

Research Services completed the inter-institutional agreement in November 2004, after 28 months of negotiations. Purchase orders were issued in December 2004. The ordered equipment has now arrived, with most of it installed and operational at the University of Calgary.

Payment for the equipment has not yet been processed. An additional one-year extension has been sought and received so that my ASRIP account does not expire prior to project completion. The project end date is now March 31, 2006.

The ELISA project is now eligible to apply for CFI Institutional Operating Funds (IOF). The University of Saskatchewan is forwarding the application to CFI, requesting approximately \$270K to be shared equally between the two universities. These funds will provide salary and benefits for a full-time lab administrator at each site for three years.

While not a research collaboration in the usual sense, I also served on two national committees for agencies that provide grants to researchers. About two months of my time were devoted to reviewing NSERC grants for NSERC GSC-330 (Computer and Information Science). I reviewed 69 Discovery Grants and 9 Equipment (RTI) Grants, totalling about 1600 pages. I also attended the six-day NSERC GSC meeting in Ottawa in February. This was my first year of a three-year term on this committee. While there is immense academic value in this volunteer service, the time and energy required for this work are substantial. I also serve on the national College of Reviewers for CFI grant applications. I reviewed about five grant proposals this year.



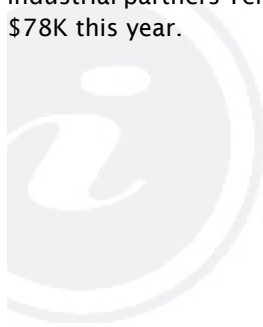
INTERNATIONAL
SIGMETRICS 2005, WWW 2007
<p>My international collaborations focus on upcoming research conferences:</p> <p>The first involves hosting the 2005 ACM SIGMETRICS Conference. Derek Eager (University of Saskatchewan) and I are sharing duties as General Chairs for this conference, which is the premier annual international conference on computer systems performance evaluation. Approximately 150 conference attendees are expected for the conference on June 6-10, 2005. We have selected Banff as the location, with the Banff Park Lodge as the conference hotel. I have applied for and received an iCORE ISPR grant (\$10K) to help provide financial support for hosting this prestigious conference.</p> <p>A second activity relates to the World Wide Web (WWW) Conference, which will be hosted in Banff in May 2007. Activities related to WWW 2007, for which I am General Chair, are picking up. I have become a member of the International World Wide Web Conference Committee (IW3C2) executive, as required by the IW3C2. I will be attending an IW3C2 executive committee meeting at WWW 2005 in Japan in May to report on our planning activities for the 2007 conference. With assistance from Carole Carlton at iCORE, we have chosen EventPlan as the Professional Conference Organizer (PCO) for WWW 2007. We are currently negotiating the contract with the Fairmont Banff Springs Hotel. Again, I have applied for and received an iCORE ISPR grant (\$10K) to help bootstrap the planning for this large (1000-person) conference.</p>
INDUSTRY
TELUS MOBILITY
<p>My primary industrial collaboration has been with TELUS Mobility in Toronto, as part of my NSERC/TELUS/iCORE Industrial Research Chair in Wireless Internet Traffic Modeling.</p> <p>Hongxia Sun, Yujing Wu, and I visited TELUS Mobility in Toronto in August 2004. We provided Michael Wu with an update on our research progress, and we obtained a CD-ROM of measurement data from the TELUS Mobility network.</p> <p>A significant portion of my research time this past year was spent on network traffic analysis work for TELUS Mobility. Research team member Hongxia Sun and I did most of this work, with some assistance from Yujing Wu and Emir Halepovic. A 40-page final report was provided to TELUS Mobility in December 2004 as a deliverable. The contents of this report are confidential to TELUS Mobility and cannot be described here.</p> <p>We had one meeting with TELUS Mobility this past quarter as well. Michael Wu and Paul Wang visited the University of Calgary on March 17, 2005. They met with me and my research team (Hongxia Sun, Yujing Wu, and Emir Halepovic) to review the project status and next steps for 2005.</p>
TRLABS
<p>A second example of industrial research collaborations is my participation as an Adjunct Scientist at TRILabs Calgary. I regularly attend research staff meetings at TRILabs, and gave a presentation there in December 2004 on multi-channel MAC protocols.</p> <p>Two of my graduate students are funded in part by TRILabs, as part of a new initiative on Home Networking Technologies. PhD student Jean Cao has an NSERC Industrial Postgraduate Scholarship (IPS) with TRILabs as the industrial partner. They supplement her IPS award with a TRILabs Fellowship. She is working on wireless video streaming. MSc student Alok Madhukar holds a TRILabs Scholarship. He is working on Peer-to-Peer traffic classification techniques that can be used by Internet Service Providers in wired or wireless networks.</p>

INTELLECTUAL PROPERTY

The UTI office is currently handling five of our Intellectual Property disclosures from the last few years. These disclosures include Wireless Web Servers, Bidirectional Multi-Channel MAC Protocols, Multi-Rate Multi-Channel MAC Protocols, Hybrid SRPT Scheduling Policies, and Anonymous Network Communication Protocols. To the best of my knowledge, no patents, licenses, or revenue have yet arisen from these disclosures, though several companies have expressed interest in certain aspects of our work. Ian Bell is in regular contact with me on the status of these disclosures.

FUNDING

Carey Williamson's research in his wireless lab is funded by an iCORE Professorship and an iCORE Industrial Chair. This year he has received contributions from CFI (\$405K), NSERC (~\$218K), ASRA (~\$202K) and his industrial partners Telus Mobility and TRILabs (\$143K combined). The University of Calgary has also provided \$78K this year.



PUBLICATIONS

REFEREED JOURNAL PUBLICATIONS

M. Arlitt and C. Williamson, "An Analysis of TCP Reset Behaviour on the Internet", *ACM SIGCOMM Computer Communication Review*, Special Issue on the Internet's Vital Statistics, Vol. 35, No. 1, pp. 37-44, January 2005.

A. Mahanti, D. Eager, and M. Vernon, "Improving Multirate Congestion Control Using TCP Vegas Throughput Equations", *Computer Networks*, Vol. 48, No. 2, pp. 113-136, 2005.

G. Bai and C. Williamson, "Time-Domain Analysis of Web Cache Filter Effects (Extended Version)", *Performance Evaluation*, Vol. 58, No. 2-3, pp. 285-317, December 2004.

J. Rolia, X. Zhum, M. Arlitt, and A. Andrzejak, "Statistical Service Assurances for Applications in Utility Grid Environments", *Performance Evaluation*, Vol. 58, No. 2-3, December 2004.

A. Mahanti and D. Eager, "Adaptive Data Parallel Computing on Workstation Clusters", *Journal of Parallel and Distributed Computing*, Vol. 64, No. 11, pp. 1241-1255, November 2004.

T. Kuang and C. Williamson, "Hierarchical Analysis of RealMedia Streaming Traffic on an IEEE 802.11b Wireless LAN", *Computer Communications*, Vol. 27, pp. 538-548, 2004.

REFEREED CONFERENCE PROCEEDINGS

X. Cao, G. Bai, and C. Williamson, "Media Streaming Performance in a Portable Wireless Classroom Network", *Proceedings of IASTED European Conference on Internet Multimedia Systems and Applications (EuroIMSA)*, Grindelwald, Switzerland, pp. 246-252, February 2005.

A. Omotayo and C. Williamson, "Multi-layer Analysis of Web Browsing Performance for Wireless PDAs", *Proceedings of IEEE International Workshop on Wireless Local Networks (WLN)*, Tampa, FL, pp. 660-667, November 2004.

T. Kuang and C. Williamson, "A Bidirectional Multi-channel MAC Protocol for Improving TCP Performance on Multihop Wireless Ad Hoc Networks", *Proceedings of ACM/IEEE International Workshop on the Modeling and Simulation of Wireless and Mobile Systems (MSWiM)*, Venice, Italy, pp. 301-310, October 2004.

A. Gupta, I. Wormsbecker, and C. Williamson, "Experimental Evaluation of TCP Performance in Multi-hop Wireless Ad Hoc Networks", *Proceedings of IEEE/ACM International Symposium on the Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS)*, Volendam, Netherlands, pp. 3-11, October 2004.

Y. Li and C. Williamson, "A Hysteresis Model for Web/TCP Transfer Latency", *Proceedings of IEEE/ACM MASCOTS*, Volendam, Netherlands, pp. 167-174, October 2004.

M. Gong and C. Williamson, "Simulation Evaluation of Hybrid SRPT Scheduling Policies", *Proceedings of IEEE/ACM MASCOTS*, Volendam, Netherlands, pp. 355-363, October 2004.

G. Bai and C. Williamson, "The Effects of Mobility on Wireless Media Streaming Performance", *Proceedings of Wireless Networks and Emerging Technologies (WNET)*, Banff, AB, pp. 596-601, July 2004.

C. Williamson and N. Kamaluddeen, "Network Measurements of a Wireless Classroom Network", *Proceedings of the 16th International Conference on Wireless Communications (Wireless 2004)*, Calgary, AB, pp. 561-570, July 2004.

G. Bai, K. Oladosu, and C. Williamson "Performance Issues for Wireless Web Servers", *Proceedings of the International Workshop on Mobile and Wireless Ad Hoc Networking (MWAN)*, Las Vegas, NV, pp. 59-65, June 2004.

BOOKS AND CHAPTERS

A. Williams, M. Arlitt, C. Williamson, and K. Barker, "Web Workload Characterization: Ten Years Later", to appear as a book chapter in *Web Content Delivery*, 2005. Invited.

C. Williamson, "Wireless Web Performance Issues", to appear as a book chapter in *Web Content Delivery*, 2005.

SPECIAL/INVITED PRESENTATIONS

C. Williamson, "Portable Networks", Distinguished Lecture Series, Department of Computer Science, University of Victoria, October 29, 2004. Invited.

C. Williamson and M. Gong, "Simulation Evaluation of Hybrid SRPT Scheduling Policies", Workshop on Multi-Server Scheduling, Carnegie Mellon University, Pittsburgh, PA, USA, April 19, 2004. Invited.

