Photo by King Chung Huang
Student Developer, University of Calgary Learning Commons

EXPERIMENTAL LABORATORY FOR INTERNET SYSTEMS AND APPLICATIONS (ELISA)

ELISA Principal investigators

Carey Williamson
Professor, University of Calgary

Rick Bunt
Associate Vice-President, Info & Comm Technology,
University of Saskatchewan

Derek Eager
Professor, University of Saskatchewan

The Experimental Laboratory for Internet Systems and Applications (ELISA) is a state-of-the-art laboratory for researching Internet systems. It will be used to build the components of the "next-generation Internet" and alleviate the limitations that are appearing on today's Internet. The research facility is a geographically distributed Internet testbed, with workstations, laptops, PDAs, wireless access points, routers, and specialized network measurement equipment that can be flexibly configured for "hands-on" Internet experiments and network performance studies. One endpoint of the laboratory is housed in the Department of Computer Science at the University of Saskatchewan. The other endpoint is part of the Broadband Wireless Networks Laboratory in the Information and Communications Technology building at the University of Calgary.

Phase One of the ELISA project is now complete, with initial equipment at the two endpoints installed.

DR CAREY WILLIAMSON

BROADBAND WIRELESS NETWORKS, PROTOCOLS, APPLICATIONS AND PERFORMANCE

iCORE Professor and Telus - iCORE Industrial Chair
Computer Science
University of Calgary

Dr Carey Williamson is an iCORE Professor in Broadband Wireless Networks, Protocols, Applications, and Performance. iCORE has committed $350,000 per year for five years, for a total of $1.75 million dollars for this program at the University of Calgary. Dr Williamson also holds an iCORE-Telus Industrial Research Chair in the area of Wireless Internet Traffic Modeling at the University of Calgary, for which he receives $100,000 per year from both Telus and iCORE for two years or more if matched with NSERC funding.

EXECUTIVE SUMMARY

Dr Carey Williamson leads a team of seven graduate students and five research staff, with interests in wireless networks, Internet technologies, and network performance. Much of the research is experimental in nature, with an applied focus on industrially relevant network and protocol performance issues. The general goals of the research program are to identify and research solutions to problems and bottlenecks in the design and operation of protocols in wireless/web-based communication systems, and to research larger-scale deployment of wireless Internet/web infrastructure. Intellectual property rights have been negotiated for research projects on network monitoring software and wireless Web servers.

Wireless web servers are required where short-lived, sometimes ad-hoc wireless networks are implemented, in situations such as sporting events, disaster recovery sites, press conferences, conventions, trade shows, or entertainment applications such as media streaming, home networking, or multi-player gaming. The research focuses on the transaction rate and end-to-end throughput achievable in an ad-hoc wireless network, and the impact of the number of clients, web object size, persistent connections, transmit power, and wireless channel error rate.

The team has also conducted an industrial research project, focused on developing a network monitoring tool for measuring Internet traffic on the backbone link in SaskTel's provincial network, to characterize the web traffic generated by residential customers on the network and to provide recommendations for enhancing the effectiveness of SaskTel's existing web caching infrastructure. A new research front, to be addressed in the coming months, involves the characterization of peer-to-peer (P2P) file-sharing traffic.

The research group continues to work on CATNIP (Context-Aware Transport/Network Internet Protocol), which was designed to reduce the delay for web page downloads by indicating which web packets are crucial in the user-perceived response time. The interaction between CATNIP, DiffServ, and RED (Random Early Detection) is currently being studied, using a comprehensive set of additional experiments.

Additional experiments will be facilitated in late 2003 now that construction of Phase 1 of the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA) has been completed.

The research team acquired additional resources in September 2002, when Dr Williamson received $100,000 per year in funding from each of Telus Mobility and iCORE for an Industrial Research Chair in Wireless Internet Traffic Modeling. The initial stage of the project involved the assignment of a dedicated research team member, and the application for an NSERC Industrial Research Chair (IRC), one of the conditions of the award.

In addition to the above projects, Dr Williamson received an undergraduate teaching award, and was involved in the authoring or co-authoring of 16 research papers (two journal, six conference, and eight submitted).

RESEARCH GOALS AND OBJECTIVES

Two of the most exciting and fastest-growing Internet technologies in recent years 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 principle of layering: Web users do not need to know the details of the underlying communication protocols in order to use network applications. Wireless technologies have revolutionalized the way people think about networks, by offering users freedom from the constraints of physical wires. These technologies are available today, in laptop or handheld form, at relatively modest cost. Mobile users are interested in exploiting the full functionality of the technology at their fingertips, as wireless networks bring closer the "anything, anytime, anywhere" promise of mobile networking.

The research program focuses on unifying wireless technologies and the Web, exploiting the full benefits of each. Necessarily, the research program is applied in nature, with a strong focus on experimental computer systems performance research.

The general goals of the research program, as stated in the original proposal to iCORE, are:

- to identify performance problems and bottlenecks in the design and operation of protocols in wireless/Web-based communications systems;
- to propose and evaluate creative solutions to these performance problems;
- to promote larger-scale deployment of wireless Internet/Web infrastructure at the University of Calgary.

RESEARCH PROJECTS

This section describes selected projects underway in the research group in 2002-2003. The number of projects discussed is limited, for space reasons. The chosen projects are intended to reflect the variety of the network performance research carried out in the group, and complement the larger set of projects described in last year's annual report.

Wireless Web Servers

A natural step in the wireless Internet evolution is the convergence of technologies to form the "wireless Web": the wireless classroom, the wireless campus, the wireless office, and the wireless home. In fact, the same technology that allows Web clients to be mobile (i.e., wireless network interfaces) also enables the deployment of wireless Web servers.

While the market for mobile Web servers may not be obvious, they can play a useful role in short-lived networks. A short-lived network is created spontaneously, in an ad hoc fashion, at a particular location in response to some event (scheduled or unscheduled). The network operates for some short time period (typically minutes to hours), before being disassembled, moved, and reconstituted elsewhere.

A NATURAL STEP IN THE WIRELESS INTERNET EVOLUTION IS THE CONVERGENCE OF TECHNOLOGIES TO FORM THE "WIRELESS WEB."

There are several distinguishing characteristics of a short-lived network. Often, the location of the needed network is not known a priori. There may not be any existing network infrastructure, either wired or wireless, at the needed location. In addition, the time at which the network is needed may not be known. Deployment may need to be spontaneous, with unknown (but often bounded) operating duration. The number of users for the network is typically small (perhaps tens to hundreds), bandwidth requirements are moderate, and the geographic coverage area for the network is limited. More importantly, there is often a need for either data collection or data dissemination at the site of the network. In most cases, the data access requirement is for a "closed" set of specialized content, rather than general Internet content. Examples of

deployment scenarios for short-lived networks are sporting events, disaster recovery sites, press conferences, conventions and trade shows, and classroom area networks. The potential for entertainment applications (e.g., media streaming, home networking, multi-player gaming) is also high. In many of these contexts, an ad hoc wireless network (with a wireless Web server as an information repository) provides a suitable solution.

In this project to date, the team has explored the feasibility of wireless Web server deployment in the context of classroom area networks. While the measurement experience to date with wireless Web servers in the "legacy classroom" environment has been modest (i.e., one graduate class with 13 students), the experiments in the Wireless Internet Performance Laboratory at the University of Calgary have more rigorously determined an upper bound on the practical achievable performance. In particular, the research was focused on the performance capabilities of an Apache Web server running on a laptop computer with an IEEE 802.11b wireless LAN interface. The team studied in-room and in-building Web performance for a small number of Web client machines, also with wireless network interfaces. All mobile computers are configured to operate in ad hoc mode, since no existing network infrastructure is assumed. The clients download content from the wireless Web server. A wireless network analyzer collects and analyzes traces from the experiments, with traffic analysis spanning from the Medium Access Control (MAC) layer to HTTP at the application layer.

The experiments focused on the HTTP transaction rate and end-to-end throughput achievable in an ad hoc wireless network environment, and the impacts of factors such as number of clients, Web object size, persistent connections, transmit power, and wireless channel error rate. In general, the experimental results indicate that off-the-shelf hardware and software for wireless Web servers can provide tolerable user-level Web performance. However, the wireless bottleneck, network efficiency problems, and server power consumption issues may limit the performance and robustness of wireless Web servers in short-lived networks, at least with current technology.

This work has been carried out primarily by research associate Guangwei Bai and MSc student Kenny Oladosu. Technical assistance, when needed, has been provided by Martin Arlitt, Nayden Markatchev, and Tianbo Kuang.

Ongoing work targets the deployment of wireless Web servers at indoor University of Calgary home sporting events (e.g., volleyball, basketball) next winter. 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 single project unifies many of the topics on which the graduate students and research staff are currently working. An intellectual property agreement for the Wireless Web Servers project was signed with UTI at the University of Calgary this past year.

A paper describing research results to date has been submitted for possible external publication. It is still in the review process.

Web Traffic Characterization

In this past year, the team did a six-month industrial research contract with SaskTel (Saskatchewan Telecommunications) in Regina. SaskTel is the primary telecommunications provider in the Province of Saskatchewan, and one of many Internet Service Providers in the province as well. The objectives of the project were:

- to develop a network monitoring tool for measuring Internet traffic on the 1 Gbps backbone link in SaskTel's provincial network;
- to characterize the Web traffic generated by residential customers on SaskTel's network;
- to provide recommendations for enhancing the effectiveness of SaskTel's existing Web caching infrastructure

This project was carri.ed out primarily by Martin Arlitt, a senior research associate on the iCORE research team. He was assisted by colleague Rob Simmonds in the development, testing, and debugging of the multi-threaded network monitoring software.

Since the project work was carried out under a non-

disclosure agreement, the results of the project cannot be included here. However, the project was still extremely valuable, for three reasons. First, the lab maintained intellectual property rights to the network monitoring software that was developed for this project. The team is currently using the very same software in a (voluntary) project with Information Technologies at the University of Calgary, to help characterize campus-wide Internet traffic. With this software, the team is well prepared to do similar projects with any other telco or ISP that expresses interest in our tool. Second, the SaskTel network provided a very challenging environment for the testing and debugging of the network monitoring software. Several anomalies were noted (for example, improperly encapsulated IP packets, TCP port number collisions at Web caching proxies), so the software had to be fixed to detect and handle these properly. As a result, the software tool is more robust now than it would have been if developed only within our pristine test environment. Third, the proprietary data sets that were collected provided a current snapshot of "typical" Internet usage. The biggest surprise was the sheer volume and variety of peer-to-peer (P2P) file-sharing traffic seen on the network.

The latter observation has launched a new research front on peer-to-peer networking issues. Team member Martin Arlitt attended a CANARIE Networking Workshop in Ottawa this past year to learn more about P2P, and will play a lead role in our ongoing research on this topic.

CATNIP TCP

One of the experimental protocols developed in the research group last year was called CATNIP (Context-Aware Transport/Network Internet Protocol). The CATNIP protocol provides a "smarter" way for a Web server to send Web pages to a Web client, by indicating which TCP packets are the crucial ones that affect the user-perceived response time for Web page downloads. Network simulation and network emulation experiments with CATNIP TCP demonstrated its effectiveness in reducing both the mean and the variance of delays for Web page downloads.

The primary challenge tackled this year was to find the "path of least resistance" for possible deployment of CATNIP TCP on the Internet. In its original version, CATNIP TCP requires a one-bit "packet priority" field in a reserved portion of the TCP packet header. Needless to say, this is an obstacle to its deployment on the Internet because of the need to modify all the routers to interpret this bit properly.

The compromise approach proposed is to leverage DiffServ (Differentiated Services), a stateless paradigm for providing Quality of Service (QoS) on today's Internet. The DiffServ traffic classes are supported by many of today's router vendors.

The CATNIP DiffServ(CATNIP-DS) project was undertaken by team member Qian Wu, with some initial assistance from TeleSim team member Roger Curry. Qian has developed a scheme for mapping CATNIP packet priorities into DiffServ "codepoints" at the network edge. The approach then relies on network routers supporting DiffServ to make use of this codepoint information when handling packets.

Experiments to date have been carried out with network simulation, using ns-2. Simulation results have actually been quite disappointing, showing little or no benefits for CATNIP TCP on DiffServ. One reason is RED (Random Early Detection), a probabilistic packet discard algorithm used for active queue management in DiffServ routers. The probabilistic nature of RED is likely nullifying the effectiveness of intelligent packet marking at the edges of the network. The team is currently developing a much more comprehensive set of simulation experiments to fully understand this phenomenon, before moving on to network emulation and live Internet experiments with CATNIP-DS.

RESEARCH TEAM

The research team consists of five full-time research staff, and seven graduate students (one of whom is co-supervised).

TEAM LEADER	AWARDS
Carey Williamson	Teaching Excellence-Honorable Mention

OTHER TEAM MEMBERS	TITLE/TOPIC
Martin Arlitt	Web Performance, Network Traffic Measurement, Workload Characterization
Guangwei Bai	Internet Traffic Modeling, Wireless Web Measurement
Tianbo Kuang	Wireless Traffic Measurement, Media Streaming
Qian Wu	Network Simulation, TCP/IP
Nayden Markatchev	Network Simulation, Media Streaming, Mobile Computing

MSC CANDIDATES	TOPIC	AWARDS
Mingwei Gong	Request Scheduling in Internet Web Servers	
Abhinav Gupta	Location-Aware Ad Hoc Routing	Alberta Ingenuity, iCORE Graduate Student Scholarship
Andreas Hirt	Wireless Network Security	NSERC PGS-B, iCORE Graduate Student Scholarship
Gwen Houtzager	Optimizing Web Proxy Cache Placement	NSERC PGS-B, iCORE Graduate Student Scholarship
Yujian (Peter) Li	Modeling Web/TCP Transfer Time	
Kehinde (Kenny) Oladosu	Wireless Web Server Performance	
Fang (Shelly) Xiao	Fairness Issues for Wireless TCP	

COLLABORATIONS

At the University of Calgary, the research team continues to interact with the TeleSim research group coordinated by Rob Simmonds and Brian Unger. Collaboration with Rob Simmonds was crucial for a joint paper on Web server benchmarking using the IP-TNE (Internet Protocol Traffic and Network Emulator) for parallel WAN emulation. Collaboration with PhD candidate Cam Kiddle has resulted in a co-authored paper (Kiddle, Simmonds, Williamson, Unger) on fluid-flow approaches to network simulation.

Also at the University of Calgary, the chair has volunteered to assist with a CFI proposal to upgrade the general campus networking infrastructure and increase the deployment of wireless infrastructure on campus. Information Technologies is the lead on this application.

COLLABORATION WITH INDUSTRY

Telus Mobility

In Summer 2002, the team submitted a brief research proposal to iCORE regarding a possible industrial research chair on Wireless Internet Traffic Modeling, to be jointly funded by iCORE, NSERC, and Telus Mobility. In Fall 2002, funding was awarded from Telus Mobility ($100,000 per year, for two years), with matching funds from iCORE ($100,000 per year, for two years).

The conditions of the award indicated that an application for an NSERC Industrial Research Chair (IRC) should be submitted within the first year of the award, to obtain additional matching funds and to extend the chair position to five years. Over the past six months, the team has been preparing an NSERC/Telus/iCORE Industrial Research Chair application to be submitted to NSERC. The bulk of the research proposal is finished, though the budget section and the university portion of the proposal are still in a state of flux. The full proposal should be submitted to NSERC in Summer 2003.

Two meetings with Telus Mobility took place during the past quarter. On an interim basis, research team member Qian Wu has been assigned to the "Wireless Network Capacity Planning" part of this project until a suitable new research associate can be recruited. Preliminary simulation results are expected in Summer 2003.

SaskTel

In this past year, the team did a six-month industrial research contract with SaskTel in Regina. The collaborative research project on Web Traffic Measurement was completed in December 2002, with the final report submitted in January 2003.

Sun Microsystems

On behalf of Dr Dennis Salahub (VP Research) and the University of Calgary, Professor Ron Johnston (Department of Electrical and Computer Engineering) Carey Williamson drafted a proposal for a Sun Microsystems Center of Excellence (COE) on Wireless Internet Technologies, to be situated in the ICT building at the University of Calgary. A meeting was held on campus with Sun representatives in 2002, but as yet no further information is known about the status of this proposal.

Intel

The local Intel representative Monty Ghitter was engaged to discuss a possible research project related to wireless Internet technologies. A project proposal was developed and submitted to Intel, with feedback anticipated in April 2003.

TRLabs

Several meetings have been held with John McRory at TRLabs regarding mutual research interests, including being a part of their upcoming CFI proposal on Home Networking Technologies, joining TRLabs as an adjunct scientist in spring 2003, and having a TRLabs-sponsored graduate student (or two) in September 2003. The chair will offer a tutorial (Wireless Internet: Protocols and Performance) at the TRLabs Wireless 2003 conference in July.

MULTIDISCIPLINE OR MULTI-INSTITUTIONAL PARTNERSHIPS

Primary multi-institutional partnership is with respect to the CFI-funded Experimental Laboratory for Internet Systems and Applications (ELISA), being constructed jointly between the University of Calgary and the University of Saskatchewan. While the official decision regarding the matching funds from the Province of Saskatchewan is still pending (anticipated in April 2003), the University of Saskatchewan has advanced "bridge funding" for Phase 1 of the ELISA lab on an interim basis.

Significant progress was made

this year on the ELISA lab at the University of Calgary. First, the renovations for the ELISA server room in ICT 718A are now complete. These plans, coordinated by Brian Scowcroft, involved extra wiring (electrical power, network connections), plumbing (air conditioning), and equipment protection (Universal Power Supply, emergency shutoff). Second, network connectivity for the lab has been arranged. The network connection for the lab is a 1 Gbps Ethernet (copper) to the campus router. From there, Netera will provide the external connectivity to CA*net 4, and thus to the University of Saskatchewan. Third, the interim funding from the University of Saskatchewan was used to purchase some initial equipment for the ELISA lab. This equipment included laptops, wireless access points, rack-mounted PCs, a router/switch, and a data storage server. This equipment arrived in March, and is now operational in the lab.

Completion of the ELISA lab is expected in Fall 2003, once the Province of Saskatchewan matching monies are secured (anticipated April 2003) and all CFI funds released.

FUNDING

The initial iCORE research program budget assumes $350,000 per year from iCORE for five years. These funds are complemented by support from the university (faculty positions, startup funds, graduate student support, lab space, in-kind contributions), research grants (NSERC, CFI), external scholarship support (NSERC, Alberta Ingenuity, iCORE), and industrial support. The total budget in the initial proposal averages $750,000 per year.

New Funds Acquired This Year as Prime Investigator

In September 2002, funding was awarded from Telus Mobility for an Industrial Research Chair in Wireless Internet Traffic Modeling. This funding ($100,000 per year for two years) was matched by iCORE, bringing the total to $200,000 per year for two years. An application for an NSERC Industrial Research Chair is in preparation, to further complement this funding (an additional $100,000 per year) and extend it to five years.

The SaskTel research project generated $30,000 in external contract revenue, of which 30 percent was retained by the university for research overhead.

The chair's individual NSERC research grant was up for renewal this year, and was renewed in March 2003. The new Discovery Grant amount is $33,000 per year, for four years.

The Province of Alberta matching funds for the ELISA CFI lab were received this year. The amount awarded by ASRIP was $605,000. These funds are awaiting the go-ahead from the Province of Saskatchewan, and must be spent by the end of March 2004.

New Funds Acquired This Year as Co-Investigator

While the CFI award for the ELISA lab was officially announced in January 2002, the CFI award ($1.2 million) shows in this year's budget, to be consistent with the original iCORE proposal. The co-investigators on the CFI proposal are Derek Eager and Rick Bunt from the University of Saskatchewan. The University of Saskatchewan is the lead institution on this proposal, because the iCORE Chair was the principal investigator, writing most of the proposal prior to his move to the University of Calgary.

INTELLECTUAL PROPERTY

A primary research theme this year has been on wireless Web servers, to evaluate their feasibility and performance. We contacted Richard May from InnoCentres and Geoff Moon from UTI regarding this innovation at a very early stage of the research, to evaluate commercial potential and protect intellectual property (IP) rights. The IP agreements clearly state that iCORE funding was the primary enabler behind this research idea.
UTI has completed the "due diligence" process with respect to this IP, and Richard May has had preliminary discussions with several parties regarding commercial potential for the idea. No revenue has accrued from this IP yet.

The other intellectual property item of interest is the network monitoring software developed by Rob Simmonds and Martin Arlitt for the SaskTel project. In many respects, this software is similar to the public-domain tool tcpdump, though our tool has been carefully designed and implemented for one Gbps Ethernet environments.

Three particular innovations in this software tool are the multi-threaded architecture developed by Simmonds (allowing the software to run effectively on a dual-processor network monitoring machine, reading packets at one Gbps) the customized statistical summaries developed by Arlitt (allowing it to run for long periods of time, while summarizing traffic for Web, peer-to-peer, and other networking applications), and the HTTP parsing code developed by Arlitt and Simmonds (allowing it to parse HTTP/1.0 and HTTP/1.1 headers in TCP packet payloads, revealing information about request sizes, response sizes, browser types, persistent connections, and Web object cacheability).

The tool also supports the capture of packet headers or full packet payloads, just like tcpdump. This software has been shared with SaskTel on a non-exclusive basis for their ongoing use. We have retained intellectual property rights for this software, allowing further development and use for our own research purposes.

PUBLICATIONS

Refereed Journal Publications

1. C. Williamson, R. Simmonds, and M. Arlitt, "A Case Study of Web Server Benchmarking Using Parallel WAN Emulation," *Performance Evaluation*, vol. 49, no.1-4, Sept. 2002, pp. 111-127.
2. M. Busari and C. Williamson, "ProWGen: A Synthetic Workload Generation Tool for Simulation Evaluation of Web Proxy Caches," *Computer Networks*, vol. 38, no.6, June 2002, pp. 779-794.

Conferences

1. C. Kiddle, R. Simmonds, C. Williamson, and B. Unger, "Hybrid Packet/Fluid Flow Network Simulation," 17th ACM International Workshop on Parallel and Distributed Simulation (PADS), San Diego, CA, June 2003, pp.143-152.
2. G. Bai and C. Williamson, "Workload Characterization in Web Caching Hierarchies," Proc. IEEE/ACM Intl. Symp. Modeling, Analysis, and Simulation of Computer and Telecommunications Systems (MASCOTS), Fort Worth, TX, Oct. 2002, pp. 13-22.
3. N. Markatchev and C. Williamson, "WebTraff: A GUI for Web Proxy Cache Workload Modeling and Analysis," Proc. IEEE/ACM MASCOTS Conference, Fort Worth, TX, Oct. 2002, pp.356-363.
4. T. Kuang and C. Williamson, "A Measurement Study of RealMedia Audio/Video streaming Traffic," Proc. SPIE ITCOM 2002, Boston, MA, July 2002, pp. 68-79.

5. T. Kuang and C. Williamson, "RealMedia Streaming Performance on an IEEE 802.11b Wireless LAN," Proc. IASTED Wireless and Optical Communications Conference (WOC 2002), Banff, AB, July 2002, pp. 306-311.
6. G. Bai and C. Williamson, "Time-Domain Analysis of Web Cache Filter Effects," Proc. SCS Intl. Symp. Perf. Eval. of Comp. and Telecomm. Systems (SPECTS'02), San Diego, CA, July 2002, pp. 195-205.
7. C. Williamson and Q. Wu, "Context-Aware TCP/IP," Proc. ACM SIGMETRICS Conference, Marina del Rey, CA, June 2002, pp. 262-263. (abstract only)
8. R. Simmonds, C. Williamson, M. Arlitt, R. Bradford, and B. Unger, "Web Server Benchmarking Using Parallel WAN Emulation," Proc. ACM SIGMETRICS Conference, Marina del Rey, CA, June 2002, pp. 286-287. (abstract only)

Photo by King Chung Huang
Student Developer, University of Calgary Learning Commons

Nayden Markatchev and Carey Williamson stand behind the Calgary endpoint equipment for ELISA.