An Overview of the Center for Wireless Information Network Studies at Worcester Polytechnic Institute, MA, USA

Kaveh Pahlavan, Director and Founder, CWINS
Professor, Electrical and Computer Engineering Department, WPI
kaveh@ece.wpi.edu
www.cwins.wpi.edu

The Center for Wireless Information Network Studies (CWINS) is a well renowned compact wireless research laboratory with a successful history of research alliances with other industrial and academic groups. The center has performed research for government agencies and has close ties with the world-leading organizations in the wireless industry. The core competence of the center is in indoor radio channel propagation measurement modeling and in the development of testbeds and tools for design and performance monitoring of wireless indoor networks. For over a decade, by publishing an international periodical journal, organizing several workshops and participating in organizing a yearly international conference, the center has contributed significantly to information exchange among important sectors of the wireless industry.

History

The research program in wireless information networks at WPI was established in 1985 as the first research program of this sort in the United States. In 1986, the program was awarded the first NSF grant in modern wireless communications to start pioneering work on channel modeling, transmission and multiple access methods for wireless indoor networks. In 1989 and 1990, the center participated in founding the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) and the IEEE International Symposium on Spread Spectrum Techniques and Applications (ISSSTA) in the UK. In 1991, the center organized the first IEEE Workshop on Wireless LANs, which was held at WPI. In 1992, the center organized the Third IEEE PIMRC in Boston. In 1994, the center initiated the International Journal on Wireless Information Networks, the first journal in this field. In 1995, Prof. Pahlavan and Dr. Levesque published "Wireless Information Networks", John Wiley and Sons, the first graduate level textbook in wireless networks. During 1996-98, the Wireless LAN Research Laboratory was formed under CWINS to serve as an industrial research alliance in answer to the growing interest in wireless LAN technology. In 1996, Prof. Pahlavan was elected Fellow of the IEEE for his contributions in wireless office information networks. In 1997, the center expanded the scope of research to perform pioneering research for indoor and short-range goelocation applications for the Small Unit Operation Situation Awareness System program under DARPA. Also in 1997, the center initiated a long-term active collaboration with the University of Oulu, Nokia, and several other leading wireless companies in Finland.

Research Objectives and Directions

The main objective of the center is to perform basic research in broadband wireless local access. The pioneering research work in indoor radio propagation measurements and modeling and developing experimental testbeds and performance evaluation facilities for comparative studies of evolving wireless indoor networks is now finding its way into applications for wireless home networking. The center strikes a balance between basic and applied research by maintaining contacts with national and international research organizations as well as leaders in the commercial industry.

Projects

The projects conducted at CWINS are focused on two main areas of research: radio propagation and modem design for physical layer, and traffic engineering and performance monitoring of broadband indoor wireless networks.

Radio propagation measurement and modeling at CWINS started in 1986 with the development of a wideband indoor radio channel measurement system and time domain modeling of wideband indoor radio propagation. Shortly after that, the center introduced frequency domain modeling using a network analyzer that since then has become a popular method for indoor radio propagation measurement. These efforts were funded by NSF, HP and Raytheon. Later, the center developed a spread spectrum channel sounder for GTE Laboratories for performance monitoring of urban cellular systems. More recently, time-space channel measurement characteristics of indoor radio propagation have been studied at the center for smart antenna and indoor geolocation applications. In the early 1990s a first 2-D ray-tracing program for radio

propagation prediction in indoor areas was developed and calibrated using the results of measurements obtained in the earlier research. This program was extended to 3-D ray-tracing for microcellular applications in 1993. Results of these efforts have been used by NYNEX Science and Technology, GTE Laboratories, ERS, and more recently by DARPA's SUO/SAS project and United Technology Research Center. In 1996 the center developed an indoor deployment tool for wireless LANs for the WLRL, a consortium of five industrial partners. In 1994, CWINS started a real-time channel simulation for indoor propagation program using its own proprietary prototype. This year, the center has received an award from DoD to purchase the most advanced commercially available real-time channel simulation hardware platform that will be used to simulate all channel measurements and modeling efforts of the previous years. The latest contribution of the center to the research community is the recognition of the fact that the exiting channel models developed for telecommunication applications are not suitable for performance evaluation of geolocation systems operating in multipath environments. Through a research program initiated by the DARPA's SUO/SAS program and later supported by Nokia, the Finnish Airforce, and TEKES, the center has launched a program for the measurement and modeling of the indoor radio channel for geolocation applications.

Starting in 1986, CWINS performed theoretical studies of wireless network access methods, capture effects, voice and data integration, and performance of WLANs. In 1993, with the support of NYNEX, a benchmark software tool was developed to provide real-time performance monitoring such as throughput and time data of CDPD networks. In 1995, the center was awarded a grant from NSF to deploy and evaluate the performance of an experimental wireless LAN tested. This unique subnet wireless LAN testbed was designed to examine a variety of technologies for point-to-point inter-LAN bridges as well as different technologies used for mobile laptop applications. This led to an experimental performance evaluation of WLANs where throughput, delay and other characteristics were measured taking into account the effects of walls, floors, and number of users. In 1996 with the support of WLRL, the CDPD benchmark tool was augmented to be used for WLANs. Using this tool and HP Open View, HP Protocol Analyzer, empirical data was collected and modeled. This enabled the center to lay a foundation for wireless traffic engineering. In 1997, the center started a long-term collaboration with the University of Oulu, Nokia and other Finnish companies. The first project called Wireless LANs for UMTS (WiLU) had a goal to evaluate inter-technology handoff requirements for the third generation pan-European standard UMTS. The work focused on developing handoff algorithms between WLANs and GPRS. In 1999, a second project called Wireless Indoor Geolocation and IP traffic analysis (WINGIP) had two main objectives. The first objective was to investigate and model the performance of voice applications over existing WLANs and IP networks. A measurement system for voice oriented applications was designed and used with the NSF WLAN testbed to collect data, and a complete OPNET simulation was created and checked against measurements. The second objective was to investigate the feasibility and performance of including geolocation services over fourth generation wireless networks, in particular using OFDM in HIPERLAN2. In 1999, the center started investigating the area of home networking, with particular interest in the Bluetooth, HomeRF, IEEE 802.11, a and b, IEEE 802.15 Wireless Personal Area Networks (WPAN), and other wireless home networking initiatives.

Research Staff

The center is a compact and highly selective organization, the staff of the center includes two full-time, three part-time, several contributing faculty members and 5-10 graduate and undergraduate students. The founder and director of CWINS is Kaveh Pahlavan, Professor of Electrical and Computer Engineering and Computer Science, WPI, and International Professor of Electrical Engineering, University of Oulu, Finland. Dr. Jacques Beneat is a full-time research scientist at CWINS, mainly involved in radio propagation measurements and modeling and real-time channel simulation. Dr. Allen Levesque, is a Research Professor in wireless communication systems, Dr. James Mathews is a consultant in radio design, Craig Mathais of Farpoint Group, is a consultant in commercial aspects of Wireless LANs. A number of ECE and CS department faculty members at WPI have participated in CWINS projects.

Sample list of publications

1. K. Pahlavan, et. al. "Handoff in Hybrid Mobile Data Networks", IEEE Personal Communication Magazine, April 2000 (invited paper).

2. K. Pahlavan, P. Krishnamurthy, and J. Beneat, "Wideband Radio Propagation Modeling for In-

door Geolocation Applications", IEEE Communications Magazine, April 1998 (invited paper).

3. K. Pahlavan, A. Zahedi, and P. Krishnamurthy, "Wideband Local Access: WLAN and WATM", IEEE Communications Magazine, Special Series on Wireless ATM, November 1997 (invited paper).

4. A. Falsafi, K. Pahlavan, and G. Yang, "Transmission Techniques for Wireless LANs", IEEE Journal on Selected Areas in Communications, November 1996 (invited paper).

5. K. Pahlavan, T. H. Probert, and M. E. Chase, "Trends in Local Wireless Networks", IEEE Communications Magazine, March 1995 (invited paper).

6. K. Pahlavan and A. Levesque, "Wireless Data Communication", IEEE Proceedings, September 1994 (invited paper).

7. K. Pahlavan, S. Howard, and T. Sexton, "Adaptive Equalization of Indoor Radio Channel", IEEE Transactions on Communications, January 1993.

8. S. J. Howard and K. Pahlavan, "Autoregressive Modeling of Wideband Indoor Radio Propagation", IEEE Transactions on Communications, September 1992.

9. K. Zhang and K. Pahlavan, "An Integrated Voice-Data System for Wireless Local Area Networks", IEEE Transactions on Vehicular Technology, April 1990.

10. K. Pahlavan, "Wireless Office Information Networks", IEEE Communications Magazine, June 1985 (A modified version of this paper was published in the ACM Transactions on Office Information Systems, July 1988. It was also published as the opening paper in "Advances in Local and Metropolitan Area Networks", edited by William Stalling, IEEE Press, 1994).

Facilities

The center has several radio channel measurement systems suitable for indoor telecommunications, smart antenna and geolocation applications over a broad range of frequencies. The center has extensive ray-tracing capabilities suitable for indoor, urban and tunnel applications. The center is augmenting its real-time channel simulation capabilities to be suitable for indoor and urban telecommunication, smart antenna and geolocation applications.

The center has a complete experimental wireless LAN sub-network with router, switch, access points, wireless inter-building bridges, and laptops with wireless adapter cards. It has proprietary and commercial wireless network application monitoring tools suitable for wireless traffic engineering and voice over IP studies.

There are extensive computer facilities in the CWINS laboratory, the ECE department, and WPI. WPI is a member of the Internet 2 Consortium.

Sponsoring organizations

The center has received support from government agencies such as the National Science Foundation and DARPA, from the local industry such as GTE Laboratories, TASC/Litton, Bell Atlantic Mobile, BBN, Sierra Comm, Raytheon Company, DEC, and Alta Group of Cadence, and from national industry such as Savi Technologies (CA), Apple Computers (CA), Radio LAN (CA), Hewlett-Packard (CA), Motorola (IL), Texas Instruments (TX), and United Technologies Research Center (CN). It has received support from international agencies and industry such as Nokia (FI), Elektrobit (FI), Sonera (FI), TEKES (FI), Finnish Air Force (FI), NTT (JAPAN), and Jolt (ISRAEL). The companies that sponsored the WLRL alliance were Aironet, Cushcraft, Harris Semiconductors, Persoft, and DEC. The center has also provided corporate consulting and training to several national and international companies.

Statement on Impact

The research at the CWINS has resulted in more than 150 technical papers, several book chapters and the text book *Wireless Information Networks*, the first comprehensive text book published on modern WIN systems. The research has resulted in over a dozen Ph. D. dissertations, numerous M.Sc. and extended undergraduate senior projects. The students who complete their graduate degrees learn multi-disciplinary skills and teamwork practices in a fast-paced information technology hungry environment that permits them to move quickly and productively into the competitive workplace. CWINS has enjoyed great success in placement of its graduates in start-up companies, academia, and corporations active in the expansion of wireless information networks (such as Qualcomm, Nokia, David Sarnoff Labs, Bellcore, Motorola, GTE Laboratories, Rockwell International, PCSI, Raytheon, etc.).