Wirelss Information Network Group

at the

Worcester Polytechnic Institute

Activity Report

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PREFACE

The Electrical Engineering Department at the Worcester Polytech has a long tradition in radio communications. Perhaps our most prominent alumni in the radio communication industry is Atwater Kent, one of the pioneers in the radio communication industry. The Electrical Engineering Department building is named after him: the Atwater Kent Laboratory. This building, originally build in 1906, is the first building in the U.S. which was used to host an Electrical Engineering Department.

Currently, a group of our faculty and graduate students have shown considerable interest in various aspects of Wireless Information Networks. The uniqueness of our group lies in the ability to investigate all issues related to wireless indoor communications. Unmatched by any other research group, in the past few years we have contributed in basic research in channel modeling and simulation, spread spectrum communications, adaptive equalization, multiple access methods, network architectures and wireless optical communications. Our group has performed numerous measurements at the Worcester Polytech campus and in particular the Atwater Kent Laboratories. As a result, it is an ideal place for performance evaluation of the new systems. Currently, we intend to expand our group to study multi-media wireless networks. The research work of our group was initially supported by GTE Laboratories and, recently, the main part was supported by the National Science Foundation with some contributions from the Raytheon Company, HP and TI. We are intending to increase our industry sponsored research activities.

PROJECTS

- o Frequency domain meaurement and modeling indoor radio propagations
- o Time domain measurement and modeling of the indoor radio propagations
- o Simulation of the indoor radio propagations
- o Spread spectrum for wireless offices
- o Adaptive equalization of the indoor radio channel
- o Multiple access techniques for local wireless networks
- o Performance evaluation of wireless office information networks
- o Speech and image coding for wireless local communciations
- o Optical wireless indoor networks

FACILITIES

The lab. is equipped with time and frequency domain measurement systems. The main component of the frequency domain measurement system is a network analyzer (HP 8753B) which outputs a swept frequency signal and analyzes the received signal. The network analyzer is capable to measure upto 3GHz and it can be updated to perform measurements upto 6GHz. The signal generated by the network analyzer is used as the input to a 45 *dB* transmitter RF amplifier. The output of the RF power amplifier is propagated by a dipole antenna. The signal from the receiver dipole antenna is passed through an attenuator and a series of amplifiers with a gain of 60 *dB*. The output of the amplifiers is returned to the network analyzer to determine the frequency response of the channel. The measured data is then read and stored by the PC controller for further analysis. The network analyzer is equipped with the Fourier transform board which provides the time domain response of the channel.

The time domain measurements are based on a fast digital scope (Tektronix 11402) with 600 MHz bandwidth. A carrier frequency of around 1 GHz is modulated by a train of narrow pulses providing 5nsec resolution for the received signal (the HP8082A pulse generator can generate pulses upto 2nsec width). The pulses are repeated every 500 ns. The modulated carrier is input to the 45 *dB* amplifier and the output is transmitted with a quarter-wave dipole antenna. The stationary receiver also uses a similar antenna to capture the radio signal. This is followed by a step attenuator and a low-noise high gain ($\approx 60dB$) amplifier chain. The signal is then demodulated using an envelope detector whose output is displayed on a digital storage oscilloscope coupled to a AT&T 6300 PC with a GPIB instrument bus.

In addition, analog and digital spectrum analyzers covering the frequency range of 0-110MHz are available, as well as function generators, frequency synthesizers, analog and digital scopes, as well as standard laboratory instruments. A high quality shielded room for low-level, noise free measurements is also available. Recently, Texas Instruments has donated about 100,000 dollars equipment for DSP design which are used by the members of the group for speech and image coding projects.

RECENT PUBLICATIONS

General Tutorials:

K. Pahlavan," Wireless Intra-Office Networks", Invited paper, ACM Trans. on Office Inf. Sys., July 1988.

K. Pahlavan,"Wireless Communication for Office Information Networks", IEEE Comm. Mag., June 1985.

K. Pahlavan,"Wireless Data Communication Techniques for Indoor Applications", Proceedings of IEEE Int. Conf. of Comm.,Chicago, June 1985 .

K. Pahlavan, "Modeling and Computer Simulation of the Indoor Radio Channel", International Conference on Control and Modeling, University of Teheran, Iran, July 1990.

K. Pahlavan, ".Wireless Indoor Communication Networks", A tutorial course, IEEE Workshop on Mobile and Cordless Telephone Communications", Kings College, University of London, England, Sep. 1989.

K. Pahlavan, "Wireless LANs for Offices and Manufacturing Environments", Simon Fraser University and University of Victoria, British Columbia, Canada, July 1989.

K. Pahlavan," Wireless Local Area Networks", Illinois Institute of Technology, Chicago, March. 1989.

K. Pahlavan, " Wireless Distribution Technology: Transmission Techniques", National Communication Forum, Chicago, Sept. 1988.

K. Pahlavan, " Wireless LANs for Offices and Manufacturing Floors", Eastern Telecommunication Forum, Apr. 1988.

K. Pahlavan," Intera-Office Wireless Data Networks", IEEE Communication Theory Workshop, Florida, Apr. 1987.

M. Marcus, P. Ferert, and K. Pahlavan, The Wireless Office, MIT Communication Forum, Sep. 1985.

Channel Characterization

Frequency Domain Channel Modeling and Simulation

S. J. Howard and K. Pahlavan, "Autoregressive Modeling of Wideband Indoor Radio Propagation", submitted to the IEEE Trans. on Comm. (also presented in the IEEE GLOBECOM'90).

K. Pahlavan and S. J. Howard, "Statistical AR Models for the Frequency Selective Indoor Radio Channels", IEE Elect. Let. July 19, 1990.

S. J. Howard and K. Pahlavan, "Autoregressive Modeling of the Indoor Radio Channel", IEE Elect. Let., June 7, 1990.

S. J. Howard and K. Pahlavan,"Measurement and Analysis of the Indoor Radio Channel in the Frequency Domain", IEEE Trans. on Instrumentation and Measurements, Oct. 1990.

S. Howard and K. Pahlavan,"Doppler Spread Measurements of the Indoor Radio Channel", IEE Elec. let, Jan. 19, 1990.

K. Pahlavan and S. J. Howard, "Frequency Domain Measurements of the Indoor Radio Channel", IEE Electronics Letters, Nov. 23, 1989.

S.J. Howard and K. Pahlavan,"Autoregressive Modeling of Wideband Indoor Radio Propagation", Proceedings of the IEEE Globecom, San

Diego, Dec. 1990.

Time Domain Modeling and Simulations

R. Ganesh and K. Pahlavan, "Modeling of the Indoor Radio Channel", submitted for publication in IEE Proceedings (also presented in GLOBECOM'89).

R. Ganesh and K. Pahlavan,"Effects of Local Traffic and Local Movements on the Multipath Characteristics of the Indoor Radio Channel", IEE Electronics Let., June 7, 1990.

R. Ganesh and K. Pahlavan, "On the Arrival of the Paths in Multipath Fading Indoor Radio Channels", IEE, Electronic Letters, June 1989, pp763-765.

K. Pahlavan, R. Ganesh, and T. Hotaling, "Multipath Propagation Measurements on Manufacturing Floors at 910MHz", IEE Electronics Letters, Feb. 1989.

R. Ganesh and K. Pahlavan, "On the Modeling of the Fading Multipath Indoor Radio Channels", IEEE Globecom, Dallas, Texas, Dec. 1989.

R. Ganesh and K. Pahlavan, "A Report on Fading Multipath Indoor Radio Channels" IEEE Workshop on Mobile and Cordless Telephone Communications", Kings College, University of London, England, Sep. 1989.

T. Sexton and K. Pahlavan," Effects of Multi-Cluster Delay Spectrum on Wireless Indoor Communications" Proceedings of 1987 Conference on Information Science and Systems, John Hopkins University, Baltimore, MD., March 1987.

Spread Spectrum

K. Pahlavan and J. W. Matthews," Channel Measurement Noise and the Performance of Adaptive Matched Filter Receivers over Fading Multipath Channels", IEEE Trans. on Comm., Nov. 1990.

K. Pahlavan and M. Chase, " Spread Spectrum Multiple Access Performance of Orthogonal Codes for Indoor Radio Communications", IEEE Trans. on Comm., June 1990.

K. Pahlavan, "Spread Spectrum for Wireless Offices" tutorial paper, IEEE Symposium on Spread Spectrum Techniques and Applications, King's College, London, England, Sep. 1990.

M. Chase and K. Pahlavan, "Spread Spectrum Multiple Access Performance of Orthogonal Codes Over Measured Indoor Channels", IEEE Symposium on Spread Spectrum Techniques and Applications, King's College, London, England, Sep. 1990.

M. Chase and K. Pahlavan,"Spread Spectrum Multiple Access Performance of Orthogonal Codes in Fading Multipath Channels", IEEE MILCOM, Oct. 1988.

K. Pahlavan," Spread Spectrum for Wireless Local Networks", Proceedings of IEEE PCCC, Feb. 1987.

K. Pahlavan, RF Spread Spectrum for Wireless Local Networks, GTE Laboratories, Tech. Report No. TN-86-507.1, Feb. 1986.

Adaptive Equalization

K. Pahlavan, S. Howard, and T. Sexton,"Adaptive Equalization of Indoor Radio Channel", accepted for publication in the IEEE Trans. on Comm.

S. Howard and K. Pahlavan "Performance of Adaptive Equalization over Measured Indoor Radio Channels", IEE Electronics letters, Sep. 1989.

T. A. Sexton and K. Pahlavan, "Channel Modeling and Adaptive Equalization of Indoor Radio Channels", IEEE Jour. of Sel. Areas in Comm. (JSAC), Jan. 1989.

S. Howard and K. Pahlavan, " Performance of a DFE Modem Evaluated from Measured Indoor Radio Multipath Profiles", Proceedings of the IEEE ICC, Atlanta, GA, June 1990.

P. A. Bello and K. Pahlavan," Adaptive Equalization for Staggered QPSK and QPR Over Frequency Selective Microwave LOS Channels", IEEE Trans. on Communications, May 1984.

S. J. Howard and K. Pahlavan, "Adaptive Equalization of Indoor Radio channels for High Speed Wireless LANs", Proceedings of the twenty third Annual Conference on Information Science and System, John Hopkins University, Maryland, March 1989.

T. A. Sexton and K. Pahlavan, "Delay Densities and Adaptive Equalization of Indoor Radio Channels", IEEE MILCOM, Oct. 1988.

T. A. Sexton, "Channel Modeling and Adaptive Equalization of Indoor Radio Channels", Ph.D. Thesis, Due to Aug. 1989. Journaled Articles

Network Architectures and Multiple Access

K. Zhang and K. Pahlavan, " Relation Between Transmission and Throughput of the Slotted ALOHA Local Packet Radio Networks" accepted for publication in the IEEE Trans. on Comm.

K. Zhang and K. Pahlavan, "CSMA Local Radio Networks with BPSK Modulation in Rayleigh fading Channels", IEE Elect. Let., Sep. 27th, 1990.

K. Zhang and K. Pahlavan,"An Integrated Voice-Data System for Wireless Local Area Networks", IEEE Trans. on V.T., April 1990.

K. Zhang, K. Pahlavan, and R. Ganesh, "Slotted AHOLA Networks with PSK Modulation in Rayleigh-Fading Channels", IEE Electronics Letters, March 1989.

K. Zhang and K. Pahlavan,"A New Approach for the Analysis of the Slotted ALOHA Packet Radio Networks", Proceedings of the IEEE ICC, Atanta, GA, June 1990.

K. Zhang and K. Pahlavn, "An Integrated Voice/Data System for Mobile Indoor Radio Networks Using Multiple Transmission Rate", IEEE Globecom, Dallas, Texas, Dec. 1989.

K. Zhang and K. Pahlavan, "A Radio System for Integrated Voice/Data Local Networks" IEEE Workshop on Mobile and Cordless Telephone Communications", Kings College, University of London, England, Sep. 1989.

K. Zhang and K. Pahlavan, "An Integrated Voive/Data System for Wireless Local Area Networks" Proceedings of the Twenty-Second Annual Conference on Information Sciences and Systems, Princeton University, Princeton, NJ, March 1988.

K. Zhang, Wireless Local Networks for Integrated Voice/Data Services, Ph.D. Dissertation, EE Dept., WPI, June 1990.

R. Ganesh, "Multiple Accessing in Local Area ALOHA Networks in Presence of Capture", M.S. thesis, WPI, June 1987.

R. Ganesh and K. Pahlavan," Effects of Retransmission and Capture for Local Area ALOHA Systems", Proceedings of 1987 Conference on Information Science and Systems, John Hopkins University, Baltimore, MD., March 1987.

Other Related Publications

K. Pahlavan " Nonlinear Quantization and Multi-Level/Phase Modulation and Coding", IEEE Trans. on Comm., Jan. 1991.

K. Pahlavan and J. L. Holsinger,"Voice-Band Data Communication, A Historical Review: 1919-1988", invited paper, IEEE Comm. Soc. Mag., Jan. 1988.

K. Pahlavan, " Comparison Between the Performance of QPSK, SQPSK, QPR, and SQPR Systems Over Microwave LOS Channels" IEEE Trans. on Communications, March 1985.

K. Pahlavan and J.L. Holsinger, QAM Trellis-Coded Signal Structure, U.S. Patent, Apr. 21, 1987.

J. L. Holsinger and K. Pahlavan," A Historical Overview of Voice-Band Data Communications", Proceedings of IEEE Int. Conf. in Comm., Seattle, WA, June 1987.

K. Pahlavan and J. L. Holsinger," Expanded Trellis Code Modulation for Voice-Band Data Communications", Proceedings of IEEE Int. Conf. Of Comm., June 1987.

K. Pahlavan and J. L. Holsinger, "A Method to Counteract the Effects of PCM Systems on the Performance of Ultra High Speed Voice-band Modems", Proceedings of IEEE ICC, Ontario, Canada, June 1986.

K. Pahlavan, " Nonlinear Quantization and Data Communication", Proceedings of IEEE ICASSP, Tokyo, Japan, April 1986.

K. Pahlavan and J. L. Holsinger,"Signal Constellation for Voice-band Data Communication Over Channels with Non-uniform Quantization", Proceedings of IEEE Phoenix Conf. on Computers and Communications, March 1986.

K. Pahlavan,"A Review of Wireless In-House Data Communication Systems", Proceedings of IEEE Computer Communication Symposium, Washington D.C., Dec. 1984.

K. Pahlavan and J. L. Holsinger," A Model for the Effects of PCM Compandors on the Performance of High Speed Modems", IEEE Globecom, New Orleans, Dec 1985.

K. Pahlavan, Signal Processing in Telecommunications, (chapter 22 of handbook of signal processing, edited by Chen), Marcel Dekker Inc., 1988.

J.L. Holsinger, C. Jotikasthira and K. Pahlavan, Signal Structure for Data Communication, U.S. Patent, No. 4,660,213, Apr. 21, 1987.

K. Pahlavan and J. L. Holsinger, QAM Trellis Coded Signal Structures , U.S. Patent, No. 4,660,214, Apr. 21, 1987.

K. Pahlavan,Optimum Signal Space Design in the Presence of Compandors ,Tech. Memo, INFINET Inc., Feb. 1984.

K. Pahlavan, Viterbi Algorithm and High Speed Modems, Tech. Memo., June 1984.

K. Pahlavan and J.L. Holsinger , Comparative Evaluation of Very High Speed Modems, Tech. Memo, Oct. 1984.

Grad. students and their projects

1. M. Chase, Spread Spectrum Multiple Access for Indoor Radio Channels. He is currently working in Kodak Inc., Waltham, MA (he is expected to complete his Ph.D. requirements by June 1991).
2. T. A. Sexton, Adaptive Equalization of Indoor Radio Channels. He is currently working at Motorola Inc, Schaumberg, IL (completed his Ph.D. requirements on Aug. 1989).
3. R. Ganesh, Multipath Channel Characterization for Indoor Radio Channels. R. Ganesh was a Research Assistant supported by NSF (he will complete his Ph.D. requirements by June 1991). He is currently an instructor at WPI.
4. K. Zhang, Integrated Voice Data for Wireless Indoor Radio Networks. He was a Research Assistant supported by NSF (completes his Ph.D. requirements in June 1990). He is currently with Motorola Inc.- Cellular Division, Arlington Heights, IL.
5. S. J. Howard, Characterization of the Indoor Radio Propagations in Frequency Domain. He was a Raytheon fellow (completes his Ph.D. requirements by the June 1991). He is currently with Raytheon Equipment Division, Marlboro, MA.
6. A. Falsafi, Spread Spectrum for Indoor Applications. He is currently with the Digital Equipment Corporation, MA (he has started his Ph.D. program).
7. Paul Fay, Channel Simulation for Indoor Radio Channel, M.S. candidate started recently.
8. Y. Q. Wang, Wireless Netwroks, Ph.D. candidate started recently.
9. S. Wang, Implementation and Analysis of Wireless Optical Indoor Networks. He was originally supported by the Government of China and this year he is full-time M.S. student.

Samples of undergrad. projects

1. S. Smith, T. Hotaling, and G. Jouret, RF Spread Spectrum Implementation of Wireless Terminals, June 1987 (initiated by GTE Laboratories).
2. J. Clark, B. McCullen, and P. Paglia, and A. Rosantone, Infrared Wireless Terminals, June 1987 (initiated by BTE laboratories).
3. D. Brissette, E. Pauer, and D. Willard, Implementation of Wireless Modem Using TMS-320, June 1988 (initiated by Tech-Man Int.).
4. W. Noel, W. Iannacci, and J. Peidavosy, Local Area Network (LAN) Using Wireless Infrared Transmission, June 1988.
5. B. Silvester and B. Hare, Simulation of the Indoor Radio Channel, expected to complete by June 1991 (supported by NSF).

The Institute of
Electrical and Electronics Engineers
Incorporated

United Kingdom and
Republic of Ireland Section

CALL FOR PAPERS

International Symposium on Personal, Indoor and Mobile Radio Communications

King's College - University of London
23rd-24th September 1991

The Symposium is being organized by the COM/SP Chapter of the UK & RI section of IEEE. Papers describing research, development and new concepts are invited for technical sessions. The following topics are suggested but not limited to:

- *state-of-the-art future technology*
- *experiments, trials and services*
- *performance studies*
- *user considerations*
- *coding and modulation techniques*
- *spread spectrum techniques*
- *signal processing applications*
- *antennas and RF subsystems*
- *equalization and diversity techniques*
- *multiple access techniques*
- *propagation study results*
- *novel network architectures*
- *land-mobile satellite communications*

Those wishing to offer a contribution should submit three copies of the full typescripts of not more than 5 A4 papers before 1st April 1991 to:

Europe & Middle East Submissions
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The IEEE Workshop on Wireless Local Area Networks

at the

Worcester Polytechnic Institute

Worcester, MA

May 9–10, 1991

The workshop is sponsored by the Wireless Information Networks Group at WPI, the IEEE Communications Society and WINDATA Inc., Northboro, MA. It is organized to follow the IEEE 802.11 standardization meeting for Wireless Access Methods and Physical Layer Specifications, for local and wide area networks.

PROGRAM

May 9 : Tutorial: Wireless Office Information Networks

Principles of radio channel modeling and digital communications over fading multipath channels as applied to indoor radio environments. Data rate limitations. Adaptive equalization and diversity combining techniques. Spread spectrum systems for wireless offices. Potentials for wireless optical systems.

May 10 : Invited Lectures:

- LANs: past and future
- FCC Regulations
- View of portable and mobile community
- Indoor radio channel characteristics
- Spread spectrum
- Adaptive antenna arrays
- Adaptive equalization
- User's panel

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