Guest Editorial Special Section on Ultra-Wideband Wireless Communications—A New Horizon

ULTRA-WIDEBAND (UWB) transmission has recently received significant attention in both academia and industry for applications in wireless communications. UWB technology has many benefits, including high-data rate, availability of low-cost transceivers, low-transmit power, and low interference. It operates with emission levels that are commensurate with common digital devices such as laptops, palm pilots, and pocket calculators. The approval of UWB technology made by the Federal Communications Commission (FCC) of the United States in 2002 reserves the unlicensed frequency band between 3.1 to 10.6 GHz (7.5 GHz) for indoor UWB wireless communication systems. Industrial standards such as IEEE 802.15.3a (high-data rate) and IEEE 802.15.4a (very low-data rate) have been introduced based on UWB technology. On the other hand, the Department of Defense (DoD) UWB systems are different from commercial systems in that jamming is a significant concern. Although R&D efforts in recent years have demonstrated that UWB radio is a promising solution for high-rate short-range, and moderate-range wireless communications and ranging, further extensive investigation, experimentation, and development are necessary towards developing effective and efficient UWB communication systems. In particular, UWB technology has found a new application for lower-data rate moderate-range wireless communications, illustrated by IEEE 802.15.4a and DoD systems with joint communication and ranging capabilities unique to UWB technology. Unlike the indoor environment in 802.15.3a (WPAN), the new environments for sensors, IEEE 802.15.4a, and DoD systems will be very different, ranging from dense foliage to dense urban obstructions. The application of UWB radio to low-cost, low-power sensors has promise. The centimeter accuracy in ranging and communications provides unique solutions to applications, including logistics, security applications, medical applications, control of home appliances, search-and-rescue, family communications and supervision of children, and military applications.

Fundamental techniques and concepts of UWB radio have been included in many books. Some special issues in technical journals also collect scattered research papers. There seems to be a gap between the basic books and advanced special issues. In particular, with the rapid growth of UWB technology, we need a special session that systematically reviews the state-of-the-art and reports the latest development in some areas unique to UWB radio. We are fortunate to have eleven experts to realize our vision. This special session will be very timely and valuable for future development of UWB. It will thus be unique from the vehicular technology point of view, emphasizing both short-range and moderate-range applications such as WPAN and sensors and *ad hoc* networks since previous books and special issues mainly deal with the short-range high-date rate WPAN.

The eleven papers range from propagation, system concepts, timing acquisition, system implementation, and networking. In the first paper, Molisch systematically reviews the state-of-the-art of statistical UWB channel models emphasizing IEEE standard body efforts in 802.15.3a and 802.15.4a. Following the review, Qiu, Zhou, and Liu presents a new deterministic physics-based model for high-rise building environment where longer ranges can be modeled. The simple closed form is instrumental to future system concepts. Due to the rich multipath caused by the extreme wide bandwidth, the optimum concept of reception using the RAKE receiver structure is infeasible for some low cost applications. To reduce complexity, transmitted reference, an old concept, has received renewed attention. Chao and Scholtz derive optimal receiver structures for an ultra-wideband transmitted reference (UWB TR) system in multipath environments. Timing acquisition is a particularly acute problem faced by UWB systems. We have three papers systematically addressing this unique issue. Aedudodla, Vijayakumaran, and Wong address the significance of the acquisition problem in UWB systems and the ways to efficiently tackle it. A survey of the current approaches to UWB signal acquisition and challenges and issues are also given in this paper. The paper by Suwansantisuk, Win, and Shepp investigates important properties of acquisition receivers that employ commonly used serial-search strategies. In particular, they focus on the properties of the mean acquisition time (MAT) for wide bandwidth signals in dense multipath channels. Timing with dirty templates (TDT) is a recently proposed acquisition algorithm with attractive features. Starting with performance analysis of TDT, the paper of Farahmand, Luo, and Giannakis goes on to considerably broaden its scope by developing novel tracking loops and detectors following naturally the TDT operation.

After dealing with propagation, system concepts, and timing acquisitions, we have five papers dealing with implementations and networking. Three papers cover the key implementation issues including analog-to-digital (A/D) conversion and transceiver architectures. Two papers address the key networking issues, multiple access and medium access control. In the paper of Hoyos and Sadler, the authors consider A/D conversion. The framework presented here for A/D conversion is motivated by the sampling of an input signal in domains which may lead to significantly less demanding A/D conversion characteristics; lower sampling rates and lower bit resolution requirements. In

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the paper by O'Donnell, and Brodersen, the authors present the system architecture, modeling and design constraints for an integrated, CMOS, impulse ultra-wideband transceiver targeting very low power consumption on the order of a milli-Watt. Noncoherent receiver for low-data rate, low-cost applications sensor networks has received increasing attention in the UWB community. The architecture and performances of a noncoherent low-complexity UWB impulse radio (IR) transceiver architecture is presented in the paper by Stoica, Rabbachin, Tiuraniemi, and Oppermann. The UWB-IR transmitter is based on a delay locked loop (DLL) and UWB monocycle pulse generator. The UWB-IR receiver is based on a noncoherent, energy detection-based approach. Popular multiple access schemes for asynchronous users that access the channel at randomly or pseudo-randomly chosen time instances are ALOHA and time hopping-pulse position modulation (TH-PPM). To cope with the randomness of the respective signals can be challenging for a receiver. In the paper by Weisenhorn and Hirt, an alternative and deterministic multiple-access scheme is proposed that can eliminate some of these drawbacks. The principle of this multiple access scheme is that each user transmits with an individual pulse-rate or packet-rate, while the duty cycle of the user signals is kept very low. In UWB wireless networks, medium access control (MAC) is essential to coordinate the access among competing devices. The paper by Shen, Zhuang, Jiang, and Cai presents a comprehensive overview of UWB MAC development on four important aspects: multiple access, overhead reduction, resource allocation, and quality of service (QoS) provisioning, and identifies some future research issues. It is shown that the unique UWB characteristics (such as large bandwidth, low-transmission power, pulse transmission, precise positioning capability, and long-acquisition time) not only pose significant challenges but also offer great opportunities in efficient UWB MAC design.

Finally, we would like to express our sincere thanks to Dr. Tan Wong, the Editor-in-Chief of IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, for his support and help in bringing forward this special session.

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He is currently an Associate Professor in the Department of Electrical and Computer Engineering, Center for Manufacturing Research, Tennessee Technological University, Cookeville. His current interest is in wireless communication and networking systems, in particular ultra-wideband (UWB). He was Founder-CEO and President of Wiscom Technologies, Inc., manufacturing and marketing WCDMA chipsets. Wiscom was sold to Intel in 2003. Prior to Wiscom, he worked for GTE Labs, Inc. (now Verizon), Waltham, MA, and Bell Labs, Lucent, Whippany, NJ. He has worked in wireless communications, radio propagation, digital signal processing, EM-scattering, composite absorbing materials, RF microelectronics, UWB, underwater acoustics, and fiber optics. He holds over 10 U.S. patents pending in WCDMA and authored over 40 technical papers and 4 book chapters. He contributed to 3GPP and IEEE standards bodies, and delivered invited seminars to institutions including Princeton University and the U.S. Army Research Lab.

Dr. Qiu serves as Associate Editor, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, *International Journal of Sensor Networks (Inderscience)*, and *Wireless Communication and Mobile Computing* (New York: Wiley). He is a Guest Book Editor for *Ultra-Wideband (UWB) Wireless Communications* (New York: Wiley, 2005), and three special issues on UWB in the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, and *Dynamics of Continuous, Discrete and Impulse Systems Series B: Applications & Algorithms*. He serves as a Member of TPC for GLOBE-COM, WCNC, and MILCOM. In addition, he served on the advisory board of the New Jersey Center for Wireless Telecommunications (NJCWT).

Robert A. Scholtz (S'56–M'59–SM'73–F'80–LF'02) was born in Lebanon, OH, on January 26, 1936. He is a Distinguished Alumnus of the University of Cincinnati, where, as a Sheffield Scholar, he received the degree in electrical engineer in 1958. He was a Hughes Masters and Doctoral Fellow while receiving the M.S. and Ph.D. degrees in electrical engineering from USC in 1960 and Stanford University Palo Alto, CA, in 1964, respectively.

Working on missile radar signal processing problems, he remained part-time at Hughes Aircraft Co. until 1978. In 1963, he joined the faculty of the University of Southern California, where he is now the Fred H. Cole Professor of Engineering. From 1984 through 1989, he served as Director of USC's Communication Sciences Institute, and from 1994 to 2000, he was Chairman of the Electrical Engineering Systems Department. In 1996, as part of the Integrated Media Systems Center effort, he formed the Ultrawideband Radio Laboratory (UltRa Lab) to provide facilities for the design and test of impulse radio systems and other novel high-bandwidth high-data rate wireless mobile communication links. He has consulted for numerous companies and various government agencies. His research interests include communication theory, synchronization, signal design, coding, adaptive processing, and pseudo-noise generation, and their application to communications, and radar systems. He has coauthored three books, *Spread Spectrum Communications, Spread Spectrum Communications Handbook* with M. K. Simon, J. K. Omura, and B. K. Levitt, and *Basic Concepts in Information Theory and Coding* with S. W. Golomb and R. E. Peile.

Dr. Scholtz was elected to the grade of Fellow in the IEEE in 1980, for contributions to the theory and design of synchronizable codes for communications and radar systems. He has received many prizes for his research, including the Donald Fink Prize (IEEE), the Leonard G. Abraham Prize Paper Award (IEEE Communications Society), the 1992 Senior Award (IEEE Signal Processing Society), the Ellersick Award (IEEE Military Communications Conference), the Military Communications Conference Award for Technical Achievement, the S. A. Schelkunoff Transactions Prize Paper Award (IEEE Antennas and Propagation Society), and the IWUWBS Best Paper Award (International Workshop on Ultrawideband Systems). In 2004, he delivered the Plenary Address to the joint meeting of IEEE Conference on Ultra Wideband Systems and Technologies and the International Workshop on Ultra Wideband Systems. Dr. Scholtz and Dr. Moe Win are the recipients of the 2006 Eric E. Sumner Award from the IEEE "for pioneering contributions to ultra-wide band communications science and technology." He has been an active member of the IEEE for many years, manning several organizational posts, including Finance Chairman for the 1977 National Telecommunications Conference, Program Chairman for the 1981 International Symposium on Information Theory, and Board of Governors positions for the Information Theory Group and the Communications Society. He has been General Chairman of six workshops in the area of communications, including most recently two ultra-wideband radio workshops.

Xuemin (Sherman) Shen (SM'02) received the B.Sc. degree from Dalian Maritime University, Liaoning, China, in 1982 and the M.Sc. and Ph.D. degrees from Rutgers University, NJ, in 1987 and 1990, respectively all in electrical engineering.

From September 1990 to September 1993, he was first with the Howard University, Washington, DC, and then the University of Alberta, Edmonton, Canada. Since October 1993, he has been with the Department of Electrical and Computer Engineering, University of Waterloo, Canada, where he is a Professor and the Associate Chair for Graduate Studies. His research focuses on mobility and resource management in interconnected wireless/wireline networks, UWB wireless communications systems, wireless security, and ad hoc and sensor networks. He is a coauthor of two books, and has published more than 200 papers and book chapters in wireless communications and networks, control and filtering.

Dr. Shen was the Technical Program Co-Chair for IEEE Globecom'03 Symposium on Next Generation Networks and Internet, ISPAN'04, IEEE Broadnet'05, QShine'05, and is the Special Track Chair of 2005 IFIP Networking Conference. He serves as the Associate Editor for IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS; IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY; *ACM/Wireless Networks*; *Computer Networks; Dynamics of Continuous, Discrete and Impulsive -Series B: Applications and Algorithms*; *Wireless Communications and Mobile Computing* (Wiley); and *International Journal of Computers and Applications*. He also serves as Guest Editor for IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, IEEE WIRELESS COMMUNICATIONS, and IEEE COMMUNICATIONS MAGAZINE. He received the Premier's Research Excellence Award (PREA) from the Province of Ontario, Canada, for demonstrated excellence of scientific and academic contributions in 2003, and the Distinguished Performance Award from the Faculty of Engineering, University of Waterloo, for outstanding contribution in teaching, scholarship and service in 2002. He is a registered Professional Engineer of Ontario, Canada.