Introduction to the Issue on Performance Limits of Ultra-Wideband Systems

ULTRA-WIDEBAND (UWB) systems are now emerging across a variety of commercial and military applications, including communications, radar, geolocation, and medical. First generation commercial wireless UWB products are anticipated to be widely deployed soon. However, many fundamental issues for UWB systems still remain largely open. These include waveform design, aspects of channel modeling and indoor propagation, range-rate tradeoffs, transceiver architectures and complexity-performance tradeoffs, equalization, acquisition and robustness to jitter, multi-user interference and modeling, optimal use of combined analog and digital mixed-signal processing, the role of UWB in networks, radar through barriers, as well as overlay issues that include coexistence and sensitivity of UWB systems to narrow band interference. Despite the progress in UWB technology, there is still considerable uncertainty over the parameters of what will constitute successful UWB designs and deployment. This situation can at least in part be attributed to a lack of full understanding, and insufficient exploration, of the performance limits and dimensions of UWB, and other applications that may be possible, but not yet envisioned.

With evolution of device and architecture technology, combined digital and analog signal processing techniques bring tremendous promise and will play a more and more dominant role, resulting in significant system performance improvements. Studies of performance limits will help to realistically bound the space of applications. These concurrent and interwoven aspects are crucial towards uncovering the mysteries of UWB. Although analytical study and extensive performance measurements of different UWB systems in various wireless propagation scenarios have been reported, it is imperative to explore and investigate realizable features that this technology can ultimately deliver, combining theory and applications, to further help resolve open issues.

This special issue brings together contributions from signal processing, communications, and related communities, with particular focus on signal processing capabilities in UWB systems, system performance studies, and fundamental limitations of UWB systems. The fifteen papers in this issue reflect the continuing emphasis on UWB communication systems, and also include ranging and related applications.

UWB channel modeling and associated issues, such as sparse channel estimation, continue to provide new insights, models, and algorithms. The first four papers address aspects of UWB channels. The first paper, ''Prediction and Modeling for the Time Evolving Ultra-Wideband Channel,'' by Tsao *et al.*, considers the problem of predicting a time-varying UWB channel, and and evaluates the performance of a prediction algorithm using experimentally collected data. The second paper, ''Capacity of Sparse Multipath Channels in the Ultra-Wideband

Regime,'' by Raghavan *et al.*, considers ergodic capacity of sparse UWB channels when training is employed, and yields implications for signal design. The third paper, ''Multipath Delay Profile Acquisition for Ultra-Wideband PPM Systems,'' by Porrat *et al.*, considers the impact of growth in the number of multipath components and implications for channel estimation. The fourth paper, ''Ultra-Wideband Compressed Sensing: Channel Estimation,'' by Paredes *et al.*, applies recent advances in compressed sensing to UWB channel estimation.

UWB is often thought of in the context of ultra short pulses. The fifth paper, ''Improving the UWB Pulseshaper Design using Non-Constant Upper Bounds in Semidefinite Programming,'' by Berger *et al.*, applies optimization tools to the problem of pulse spectral shaping to achieve a desired power spectral density.

Pulse-based UWB systems have long been employed for radar and related applications. The sixth paper, ''Theoretical Limits for Estimation of Periodic Movements in Pulse Based UWB Systems,'' by Gezici, develops bounds and algorithms for a system that estimates the rate of a periodically moving scatterer, with potential application in medical respiration detectors. The seventh paper, ''Time Delay Estimation Bounds in Convolutive Random Channels,'' by Xu *et al.*, provides mean-square error (Ziv–Zakai) bounds on time delay estimation in UWB channels, including non-line of sight cases where conventional bounding approaches may be inappropriate.

Transmitted reference (TR) transceivers have generated considerable interest as an alternative to conventional channel estimation and equalization schemes. The next three articles address aspects of these systems. The eighth paper, ''A Decorrelating Multiuser Receiver for Transmit-Reference UWB Systems,'' by Dang *et al.*, develops an iterative blind post-processing scheme that enables multiuser operation with an analog TR receiver front end. The ninth paper, ''Performance Analysis of UWB Autocorrelation Receivers over Nakagami-Fading Channels,'' by Pausini *et al.*, provides expressions for error rates of a TR receiver for a class of UWB channel models. The tenth paper, ''Modeling and Mitigation of Narrowband Interference for Transmitted-Reference UWB Systems,'' by Alemseged *et al.*, analyzes the impact of narrow band interferers on a TR receiver, and develops algorithms for interference suppression.

Direct-sequence code division multiple access (DS-CDMA) and multi-carrier orthogonal frequency division multiplex (OFDM) wideband signaling formats have naturally been extended into the UWB regime. The last five papers address aspects of such systems. The eleventh paper, ''Performance of Multiple Antenna DS-CDMA UWB system with Noisy Channel Estimates and Narrow-Band Interference,'' by Nagvanshi *et al.*, develops error-rate expressions for a receiver that exploits multiple antennas to handle multi-user and other interferers. The twelfth paper, ''Signal-to-Interference-Plus-Noise Ratio Analysis for Direct-Sequence

Ultra-Wideband Systems in Generalized Saleh-Valenzuela Channels,'' by Wu *et al.*, develops SINR expressions for multi-access DS RAKE receiver systems that utilize a family of channel models developed primarily for indoor UWB propagation. The thirteenth paper, ''Impact of Channel Estimation on Ultra-Wideband System Design,'' by Sheng *et al.*, analyzes the impact of imperfect channel delay and amplitude estimates on a RAKE receiver employing maximum-ratio combining of the RAKE fingers. The fourteenth paper, ''Energy-Efficient Power Control in Impulse Radio UWB Wireless Networks,'' by Bacci *et al.*, applies game theory to study energy efficient power control in a UWB network employing RAKE receivers. The fifteenth paper, ''Performance Analysis of Multiband OFDM UWB Systems with Imperfect Synchronization and Intersymbol Interference,'' by Lai *et al.*, develops BER analysis for UWB OFDM systems with imperfect timing and frequency estimation, and employs recent IEEE standard UWB channel models.

We believe that exploration of UWB systems and technology will provide new insights into old problems, and enable new and valuable applications to be uncovered, and we hope that the results reported here will provide valuable steps forward. We are grateful to the authors and reviewers for their contributions, and extend our gratitude to the IEEE JSTSP Editor-in-Chief Dr. Lee Swindlehurst for his kind support.

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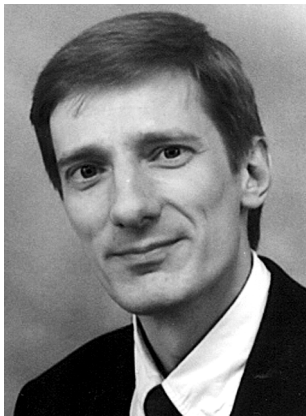
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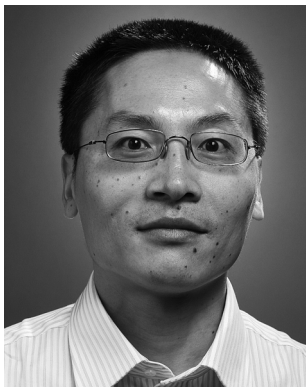
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