Guest Editorial
Underwater Wireless Communication Networks

The oceans, covering two thirds of the Earth's surface, represent one of the last frontiers for exploration and science. Apart from playing a key role in international commerce and fishing, oceans contain information about climate and the history of our planet, as well as yet-to-be-explored energy resources and forms of life. Ocean exploration has been recognized as a key step towards a fuller understanding and sustaining of life on Earth through the development of ocean-observation systems.

Wireless information transmission through the ocean is one of the enabling technologies for the development of these future ocean-observation systems, whose applications include gathering of scientific data, pollution control, climate monitoring, detection of objects on the ocean floor, and transmission of images from remote sites. Wireless signal transmission underwater is also crucial for surveillance and military applications, as well as control of the autonomous vehicles which will serve as mobile nodes in future information networks of distributed underwater sensors.

Wireless communications underwater are usually established using acoustic waves although both radio and optical techniques may be used for applications that specialize to very short distances. Acoustic communications are governed by three factors: limited bandwidth, time-varying multipath propagation, and low speed of sound underwater. Together, these factors result in a communication channel of poor quality and high latency, and pose challenges very different from terrestrial wireless networking. This is driving the design of new communication algorithms and network protocols across all layers of the system architecture.

Underwater acoustic techniques have been studied and used for many years. Despite their long history, advanced communication systems based on underwater acoustic signaling are still actively being studied. Because of the challenging propagation environment and the limited understanding of the phenomena involved, many problems remain to be solved for these systems to provide reliable communications and predictable performance. In addition, networking aspects of underwater communication systems, unexplored until recently, have started to attract significant interest, and present a fertile and promising research area.

This special issue has as its main purpose to present recent contributions in the area of underwater wireless communications and networking, and to provide a view of the field's state-of-the-art today. The contributions span underwater propagation, channel modeling, physical-layer transmission, and network protocol design, considering a range of approaches, from mathematical modeling to simulation and ocean-based experiments.

In "Underwater Wireless Optical Communication Channel Modeling and Performance Evaluation using Vector Radiative Transfer Theory," Jaruwatanadilok models the impact of light absorption and scattering on the delay and angle spread and polarization of received signals. This analysis leads to an optical communications system performance analysis that highlights the impact of system design trade-offs such as the receiver field of view.

In "A Discrete-Time Channel Simulator Driven by Measured Scattering Functions," Van Walree, Jenserud and Smedsrud address one of the major hurdles to rapid progress in underwater acoustic communications research, i.e., the difficulty in realistically simulating the propagation of communications signals through complex ocean environments. Their technique is based upon creating realizations of the time-varying channel impulse response whose scattering function matches that measured during field experiments in an environment of interest.

In "Detection, Synchronization, and Doppler Scale Estimation with Multicarrier Waveforms in Underwater Acoustic Communication," Mason, Berger, Zhou, and Willett propose a novel method for detection, synchronization, and Doppler scale estimation in underwater acoustic communications. The technique uses OFDM waveforms and its performance is demonstrated using both simulated signals as well as data collected in the field.

In "Iterative Carrier Frequency Offset and Channel Estimation for Underwater Acoustic OFDM Systems," Kang and Iltis present a practical low-density parity-check (LDPC) coded OFDM system for underwater acoustic channels with sparse multipath and attendant Doppler effects.

In "Multiband OFDM for Covert Acoustic Communications," Leus and Van Walree propose a technique for achieving low-rate, long range acoustic communications at a very low SNR. The technique, which is based upon multiband OFDM signaling, also utilizes a Basis Expansion Model representation to track channel fluctuations at the receiver. The performance of the approach is demonstrated using field data.

Hwang and Schniter, in the paper "Efficient Multicarrier Communication for Highly Spread Underwater Acoustic Channels," propose a method for communication over underwater acoustic channels that exhibit large delay and Doppler spreads. The authors propose a coded pulse-shaped multi-carrier scheme that allows a small amount of controlled inter-carrier interference, which is mitigated in a near-optimal manner using a soft noncoherent equalizer with low complexity.

In "Nonbinary LDPC Coding for Multicarrier Underwater Acoustic Communication," Huang, Zhou, and Willett present

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methods of constructing nonbinary LDPC codes that achieve excellent performance and can be encoded in linear time. The codes improve communications system performance in fading channels and help realize a reduction in the transmitted signal's peak to average power ratio thus addressing a drawback of multicarrier techniques. The performance of the resulting coded communications system is demonstrated using both simulation results and field data.

Mirza and Schurgers examine a novel localization method for a distributed sampling system based on a network of drifting sensors. Their paper develops a distributed, energy-aware scheme that localizes the sensors, off-line, after the completed sampling mission with minimal communication cost for each sensor. A factor-graph based optimization scheme is applied to determine the drifting sensor positions using the sensor collected data.

Network coding strategies for underwater communication networks are developed in the paper by Lucani, Medard and Stojanovic. The authors first develop a simple model for the attenuation in underwater acoustic channels that is amenable to analysis, then, a network coding based lower bound for transmission power in underwater acoustic networks is developed using the aforementioned approximation. The performance of several previously proposed network coding schemes is evaluated for underwater acoustic channels and compared to this bound.

The paper by Parrish, Tracy, Roy and Arabshahi addresses the integrated system design of an underwater network, highlighting the interplay between key characteristics of the acoustic propagation medium and its impact on the choice of link layer parameters. The paper combines capacity considerations with the design of a medium-access (MAC) protocol specifically designed to work with existing hardware, providing numerical evaluation of the system performance by simulation.

The paper by Syed, Ye and Heidemann introduces T-Lohi, a new class of distributed and energy-efficient MAC protocols that employs a new tone-based contention resolution mechanism that exploits space-time uncertainty and high latency to detect collisions and count contenders, as well as a low-power wake-up receiver to significantly reduce energy consumption. T-Lohi is compared with other solutions, and a thorough performance evaluation is reported, showing the benefits of the proposed scheme.

Another view of MAC protocols can be seen in the paper "RIPT: A Receiver-Initiated Reservation-Based Protocol for Underwater Acoustic Networks." This paper, by Chirdchoo, Soh, and Chua, amortizes the cost of coordination over long-delay channels by organizing transmissions in long packet trains, and coordinating transmissions from neighbors at the receiver.

In the work by Zorzi, Baldo, Casari and Harris, the implications of acoustic underwater channel characteristics (attenuation, noise, long propagation delays, and distance-dependent bandwidth) and of underwater acoustic modems (energy consumption for different communication modes) on protocol design are studied. A new energy-efficient routing protocol for underwater sensor networks is designed and compared to other commonly employed routing strategies. The authors also provide extensions to ns2 to encompass underwater acoustic channels, an underwater MAC protocol and the new routing algorithm.

We believe that these papers highlight some of best recent ideas in the field of underwater communications and networking, and can provide an excellent starting point for researchers who want to contribute to this emerging field.

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Urbashi Mitra received the B.S. and the M.S. degrees from the University of California at Berkeley in 1987 and 1989 respectively, both in Electrical Engineering and Computer Science. From 1989 until 1990 she worked as a Member of Technical Staff at Bellcore in Red Bank, NJ. In 1994, she received her Ph.D. from Princeton University in Electrical Engineering. From 1994 to 2000, Dr. Mitra was a member of the faculty of the Department of Electrical Engineering at The Ohio State University, Columbus, Ohio. In 2001, she joined the Department of Electrical Engineering at the University of Southern California, Los Angeles, where she is currently a Professor. Dr. Mitra is currently an Associate Editor for the IEEE Transactions on Information Theory and the Journal of Oceanic Engineering. She was an Associate Editor for the IEEE Transactions on Communications from 1996 to 2001. Dr. Mitra served two terms as a member of the IEEE Information Theory Society's Board of Governors (2002-2007). She is the recipient of: USC Mellon Mentoring Award (2008), IEEE Fellow (2007), Texas Instruments Visiting Professor (Fall 2002, Rice University), 2001 Okawa Foundation Award, 2000 Lumley Award for Research (OSU College of Engineering), 1997 MacQuigg Award for Teaching (OSU College of Engineering), 1996 National Science Foundation (NSF) CAREER Award, 1994 NSF International Postdoctoral Fellowship, 1998 Lockheed Leadership Fellowship, 1987 California Microelectronics Fellowship. She has co-chaired the IEEE Communication Theory Symposium at ICC 2003 in Anchorage, AK and the the first ACM Workshop on Underwater Networks at Mobicom 2006, Los Angeles, CA. Dr. Mitra was the tutorials Chair for IEEE ISIT 2007 in Nice, France and the Finance Chair for IEEE ICASSP 2008 in Las Vegas, NV. Dr. Mitra has held visiting appointments at: the Eurecom Institute, Rice University and Stanford University. She served as co-Director of the Communication Sciences Institute at the University of Southern California from 2004-2007.

James Preisig (S'79,M'92,SM'07) received the B.S. degree in electrical engineering from the United States Coast Guard Academy in 1980, the S.M. and E.E. degrees in electrical engineering from the Massachusetts Institute of Technology in 1988, and the Ph.D. degree in electrical and ocean engineering from the Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Program in Oceanography and Oceanographic Engineering in 1992. He was a Postdoctoral Investigator at WHOI from 1992 to 1994 and a Visiting Assistant Professor at Northeastern University from 1994 to 1997. Since July 1997, he has been on the scientific staff of the Department of Applied Ocean Physics and Engineering at WHOI and is currently an Associate Scientist with Tenure. He is the recipient of the 1999 ONR Ocean Acoustics Young Faculty Award and is a member of the Acoustical Society of America's Underwater Acoustics and Signal Processing Technical Committees. Dr. Preisig is also an associate editor of the IEEE Journal of Oceanic Engineering and served as a member of the IEEE Sensor Array and Multichannel Signal Processing Technical Committee from 1998 to 2004. Dr. Preisig's research interests are in the areas of adaptive signal processing, system identification, underwater acoustic propagation modeling, underwater acoustic communications, and numerical optimization.

Milica Stojanovic graduated from the University of Belgrade, Serbia, in 1988, and received the M.S. and Ph.D. degrees in electrical engineering from Northeastern University, Boston, MA, in 1991 and 1993. After a number of years with the Massachusetts Institute of Technology, where she was a Principal Scientist, in 2008 she joined the faculty of Electrical and Computer Engineering Department at Northeastern University. She is also a Guest Investigator at the Woods Hole Oceanographic Institution. Her research interests include digital communications theory, statistical signal processing and wireless networks, and their applications to mobile radio and underwater acoustic communication systems. Milica served as an Associate Editor for Communciations for the IEEE Vehicular Technology Transactions (2001-2007) and is currently an Associate Editor for the IEEE Journal of Oceanic Engineering.

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