Editorial
Underwater Acoustic Communications: Where We Stand and What Is Next?

I. Introduction

UNDERWATER acoustic communications and networking technologies are critical tools for underwater exploration, subsea resource extraction, national defense missions, etc. Their roles are becoming ever more important as nations around the globe turn to the oceans as sustainable sources of food and energy.

The quest for acoustic communications has steadily intensified over the past two decades, addressing key issues of bandwidth efficiency, reliability, and latency, and focusing on adapting to the changing propagation conditions. These features are often at odds, as the nature of acoustic propagation forces tradeoffs on the system designer. For a high data rate, one must trade reliability; for full reliability, one must trade latency. While it is tempting to say that these channel-imposed constraints and tradeoffs are annoying, it is also true that working with the acoustic channel provides unique technical challenges and solutions that are not seen in other areas.

The first bandwidth-efficient acoustic modems, based on phase-synchronized decision-feedback equalization [item 1) in the Appendix], have provided an operational capability that reached as far as the Mariana trench [item 2) in the Appendix], and have initiated a wave of innovative solutions, such as sparse channel estimation [item 3) in the Appendix], turbo equalization [item 4) in the Appendix], and multiantenna transmissions [item 5) in the Appendix]. Alongside with single-carrier systems, research has been active on multicarrier systems, i.e., orthogonal frequency division multiplexing. Innovative solutions on that front have ranged from intercarrier interference equalization [item 6) in the Appendix], [item 7) in the Appendix] to pre-FFT processing and differentially coherent detection [item 8) in the Appendix].

Today, research on the physical layer issues has reached a certain level of maturity. Transmission rates of tens of kilobits per second or higher have been demonstrated in numerous sea trials, a great leap from the few tens of bits per second in the early practice. Demonstrated communication ranges amount to tens of kilometers and beyond. Nonetheless, there are challenging environments where even low data rates at short ranges can be hard to achieve, or the performance can be extremely variable.

As the physical layer technology becomes more robust, new applications emerge, calling for integration of underwater modems into networks of fixed and mobile nodes. This push in turn drives the need for higher layer networking technology including medium access control, localization, route discovery, and reliable multihop communications. The last decade has seen significant growth and interest in underwater network stacks and simulators [items 9)–11) in the Appendix], networking protocols, and at-sea network testbeds [item 12) in the Appendix].

Advances in low-power compact computing technology over the past decade have had a large impact on the design of underwater modems. General-purpose computing platforms and software-defined open-architecture modems [items 11) and 13) in the Appendix] are slowly starting to replace specialized hardware such as digital signal processors (DSPs) and field programmable gate arrays (FPGAs) in many applications, affording flexibility and adaptivity that was previously not possible. These developments pave the way for adaptive systems that utilize feedback from the receiver to tune modulation schemes, error correction codes and protocol parameters dynamically to maintain good performance [items 14)–17) in the Appendix].

The research community is presently exploring new directions for the next generation of underwater wireless technologies and is also searching for a home program to fund the basic research and advance the related technologies. The U.S. National Science Foundation (NSF) Computer and Network Systems, Alexandria, VA, USA, program recognized such needs and commissioned a workshop on underwater wireless communications and networking. The workshop took place in Washington, DC, in March 2018, with 60 participants from academia, industry, and government. The attendees represented international communities in North America, Asia, and Europe that consistently invest in underwater wireless communication research or have significant interests in using the related technology. The goal of the workshop was to develop an application-driven roadmap to spur future research and technological developments. Priorities were identified in four areas: applications, physical layer, networks, and implementation. This editorial provides a brief report on the workshop findings in each of the four areas.

II. Emerging Applications

While significant technological advancements have been made in underwater wireless communication research, the field lacks application-driven attention of terrestrial radio frequency wireless communications. The obvious explanation is the comparatively small market, aside from the channel-imposed

Digital Object Identifier 10.1109/JOE.2018.2883872

limitations in the underwater environment. To further advance the field, there exists a strong need to broaden research participation and attract more users from commercial sectors. This requires the research community to actively expand specific application domains, through close partnerships with diverse disciplines and various industries that have interests in ocean exploration and monitoring. Aside from the traditional domain of national defense and homeland security, new applications are found in offshore oil and gas industry, fisheries, and environmental protection.

Signal processing expertise gained in underwater communications is expected to find applications in other areas as well. For example, in biomedical applications, the need for through-tissue wireless communications presents an opportunity to use acoustic waves as the alternative to electromagnetic (EM) waves. Acoustic waves experience low attenuation in human tissue, and ultrasonic transducers are perceived as safer than high-power EM systems. High data rates, on the order of megabits per second, have been demonstrated, which gives hope to live streaming of high-definition videos in medical diagnosis and surgery [item 18) in the Appendix].

Without a doubt, the increasingly popular underwater autonomous platforms, such as autonomous underwater vehicles (AUVs) and underwater gliders, are driving the needs for underwater acoustic communications in various missions. High data rate wireless communications over short ranges can find use in supporting human-robot interactions. Another example is AUV inspection of underwater structures, which is of interest to shipping and offshore oil and gas industries. Wireless links will enable operations around complex structures or by multiple vehicles.

Fisheries and aquaculture are expected to benefit from acoustic communications in multiple ways. Implanted or externally attached acoustic tags have been used to study fish behaviors and support fisheries management [item 19) in the Appendix]. As various underwater mobile platforms are adopted to inspect farming infrastructures or fish habitats, acoustic communications will be needed to support vehicle navigation and send images or short videos from AUVs in aquaculture applications.

New communication environments, along with the new applications, call for new technological advancements in underwater acoustic communications and networking. The changing Arctic is one of such examples. It represents a still largely unexplored frontier for acoustic communications, except for a limited number of studies [item 20) in the Appendix]. Due to its sensitivity to the global climate, the Arctic Ocean is experiencing significant changes in the upper boundary, i.e., reduced ice-coverage during summer, as well as in its interior. Such changes provide new opportunities to develop natural resources, trade, and global connectivity, which, in turn, calls for new communications, sensing, and navigation technologies [item 21) in the Appendix].

The ice-cover poses great challenges to vehicle navigation and localization, as surfacing for GPS fixes is often impossible. Moreover, the ice ridge or the interior sound-speed profile may create shadow zones for acoustic transmissions. To ensure connectivity, a solution demonstrated in [item 20) in the Appendix] adjusted the vehicle depth to avoid reception dead spots using predictive acoustic models. Clearly, environment-awareness is key to integrated communications, navigation, and networking in such challenging environments.

Fleets of coordinated AUVs support distributed sampling, leading to a range of applications including pursuit of marine life, tracking of fast-evolving plumes, mine detection, etc. A clear need exists for reliable communications and networking among the AUVs, or between the AUVs and their control center for monitoring, command, and human decision making. So far, there are still limited studies in this direction. Field demonstrations are scarce, even with a limited number of AUV nodes. The fundamental issues include how to establish reliable communication links for the mobile underwater network and how to create a flexible, scalable architecture in the dynamic ocean environment.

III. Physical Layer: Signal Processing for Acoustic Communications

Signal processing lessons learned on acoustic channels are many, but two simple guidelines seem to emerge: first, respect the physics of the channel; and second, consider the system aspects carefully before looking for solutions in radio communications. Acoustic systems are inherently broadband, as the bandwidth is not negligible with respect to center frequency, and this fact has a profound impact on signal processing aspects ranging from synchronization to array combining.

The March 2018 NSF Workshop identified a number of specific research topics, with a recurrent theme played by two issues: first, the need for standardized channel models; and second, the design and demonstration of feedback-based acoustic systems.

The importance of statistical channel modeling is evident from the history of international standards on which commercial wireless systems rely for well-defined channel categories. In contrast, our community has not yet succeeded at a concerted effort to standardize typical acoustic channels. Clearly, there is a distinction between deep and shallow water, horizontal and vertical channels, mobile and fixed ones, but every experimental location is different from another, raising doubts as to "what will work where." The community feels that categorization into a reasonable number of *typical* channels could be possible, and that a model could be provided for each category. Granted, such a model will have to have several layers of complexity, starting from the nominal, deterministic characterization of acoustic propagation, and moving on to the random phenomena that include both large-scale and small-scale uncertainties. While nominal propagation models, such as the Bellhop ray-tracer [item 22) in the Appendix], are well established, statistical models are only emerging [items 23)–25) in the Appendix]. These models include the notions of randomly changing link geometry for which repeated ray traces are generated, stochastic replay of recorded channels, or purely stochastic, computer-generated responses, yet with parameters derived from experimental observations. While each method seems to attract its own clientèle, the end goal is that of a unified set of models that could be freely available to students and engineers worldwide, providing a comprehensive testing ground and saving the expense of at-sea deployments. To that end, two trends are foreseen: first, building of a repository of recorded channel responses (potentially under the auspices of IEEE); and second, orchestrating an effort on standardization.

The second issue, namely that of feedback, focuses on the possibility of having the receiver inform the transmitter of current conditions, thus enabling adaptation on the transmit side. Even if performed only in near real time, feedback is essential for the next generation of smart acoustic systems. It can be used in various forms, including adaptive power control, adaptive modulation, adaptive positioning, and directive transmission. Power control alone has been predicted to provide substantial gains that are measured either in power savings or performance improvement obtained with respect to a nonadaptive system [item 16) in the Appendix]. On a finer time scale, adaptive modulation is a topic that has intrigued the community for many years [items 16) and 26) in the Appendix], but still awaits a full-fledged experimental demonstration.

In configuration with transmit arrays, feedback affords an entirely different degree of freedom as it enables directive transmission. So far, experimental work has addressed active time reversal [item 27) in the Appendix] and single-mode excitation [item 28) in the Appendix]. Future efforts are needed to evaluate adaptive transmit arrays for both point-to-point links, where they prevent power from dissipating in space and also provide security, and for multiuser systems, where they hold the promise of spatial division multiplexing. While such systems are actively being considered for the next generation of radio systems [item 29) in the Appendix], adaptive beam pointing for mobile acoustic communications is yet to be demonstrated. Clearly, such demonstrations will require *in situ* experimentation, not just post-processing of recorded signals.

Performance improvement available from a feedback technique, be it adaptive modulation or directive transmission, will be contingent upon the quality of the channel state information that is fed back to the transmitter. Given the temporal and spatial variability of acoustic links, as well as the propagation latency, this next set of challenges will not be an easy one. Nonetheless, we believe that a careful understanding of the physics of propagation, which makes a clear delineation between those channel parameters that admit feedback and those that do not, will lead to achieving substantial gains.

IV. Network Stack: Sharing the Limited Acoustic Bandwidth

Challenges such as long propagation delay, limited bandwidth, spatio-temporal channel variability, and high packet loss render typical terrestrial wireless network protocols ineffective underwater. To deal with these challenges, one cannot simply tune timings and other protocol parameters. Instead, we have to rethink the protocols, and sometimes even the network and network stack architecture. For example, tuning traditional network protocol parameters to deal with propagation delay usually leads to severe performance degradation. On the other hand, delay-aware protocols can exploit spatial multiplexing to increase network throughput [items 30) and 31) in the Appendix]. The last decade of research has shown that a software-defined, information-centric, mobility-aware architecture is the key to addressing large delays and low network efficiency in the underwater domain.

To develop successful underwater networks, application and physical layer constraints have to be understood first. Once we have a clear idea of the application requirements and environmental constraints, application-optimized protocols can be designed, often employing hierarchical or hybrid architectures, combining wired and wireless acoustic, optical and radio links together in a seamless way. Ideas from peer-to-peer networking and centralized cellularlike networking can be combined to develop bandwidth-efficient and robust solutions. If the application demands mobility, we need not only consider the effect of mobility on the network connectivity, but also the possibility that the mobile node's path may be carefully optimized to provide the necessary network connectivity needed by the application [item 32) in the Appendix]. For sensitive applications, we also need to consider security and authentication when designing the network.

Software-defined modems [item 13) in the Appendix] and networking technology, including cross-layer optimization frameworks [items 9) and 10) in the Appendix] and agent-based network stacks [item 11) in the Appendix], provides the necessary tools to implement new underwater networking solutions with reduced programming complexity. As experimentation at sea is expensive and unavailable to many engineers, high fidelity simulation tools are necessary to help bridge the critical gap between network simulations and field experiments. These tools need to be driven by realistic channel models. This reinforces the need for standardized channel modeling. Open sharing of stochastic channel models based on experimental data may also help in addressing this gap (e.g., [item 25) in the Appendix]).

Although much work has gone into developing underwater protocols, there is no common understanding of when to use which network architecture and protocol. The main reason for this is the lack of standardized application scenarios and environmental/channel models to compare networking approaches and protocols fairly. Development of benchmark applications and channel models can go a long way in helping alleviate this problem. Open access to at-sea community testbeds can further improve the situation.

V. Implementation Issues

Implementation defines the process through which the state-of-the-art design is translated into devices and capabilities needed for a specific mission. It is through this process that the academic research is converted into solutions to enable applications in different environments. Many of the implementation efforts have now matured into commercially available modems, e.g., WHOI micromodem, Teledyne Benthos modems, Subnero modems, Evologics modems, Sonardyne modems, etc.

The majority of the current implementations, be it academic prototypes or commercial products, are developed based on proprietary technologies, not supporting interoperability or providing consistency in user experiences. At this time, a single standard, JANUS, is being developed [item 33) in the Appendix] at the NATO Center for Maritime Research and Engineering, La Spezia, Italy, with participation from the community. Outside of this evolving standard, little effort has been devoted to developing a general implementation framework or procedural standards to ensure interoperability of the implementation outcomes. The implementation process consists of four phases: formation of specification based on mission requirements and standards, development of software and hardware, testing and assessment, and training and documentation. Opportunities exist to develop standard practices for each of these phases.

Owing to the increasing adoption and demand for mobile computing and smartphone technology, the last two decades have seen major advances in low-power compact computing technology. Algorithms that once required supercomputers to run can now be implemented on small computing devices with a small form factor and using very little power. Communication techniques and algorithms that were once considered too complex for implementation in underwater modems are now becoming feasible and being revisited. Until recently, practical underwater modems required development of specialized circuitry and highly optimized firmware on FPGAs and DSPs for real-time performance. Today, many modems are implemented on general-purpose computing platforms and graphics processing unit, with only a little penalty in size and power consumption. Software-defined open-architecture modems [items 11) and 13) in the Appendix] are making their way into research testbeds, where flexibility and customizability are key. Such modems are also slowly being adopted in commercial applications where extremely low power operation and long endurance are not critical. The main advantages such modems provide over highly optimized specialized implementations are flexibility and adaptivity. Software-defined modems can upgrade their signal processing as new techniques and standards become available, without having to change the hardware. Software-defined modems enable use of adaptive techniques that utilize feedback from the receiver dynamically for applications that demand performance [items 14) and 15) in the Appendix].

While computing technology has progressed by leaps and bounds, advances in the analog electronics and transducer technology have been much slower. Transducers and matching electronics are cost and size drivers for most underwater modems. There is an opportunity for research in development of smaller, cheaper, and more efficient broadband transducers. The development of such devices can have a large impact on the cost, availability, and adoption of underwater communication technology.

VI. Concluding Remarks

While much has been done in acoustic communications and networking over the past years, exciting new work lies ahead. Unified acoustic channel models, open-source software, affordable and miniaturized hardware, and software-defined networking architectures are foreseen as some of the key elements in the next generation of research practices. Research is needed on both fundamental issues and implementation details. Challenging new directions include reliable communications and networking among fleets of AUVs; integration of sensing, communication, and navigation solutions; and operational demonstrations in challenging and unexplored environments. Reaching these goals will require an increased level of *in situ* experimentation, interdisciplinary partnerships, and broadening of fundamental concepts in acoustic signal processing.

Acknowledgment

This work is a result of the NSF funded workshop on underwater wireless communications and networking in Washington, DC, USA, March 19–20, 2018, under NSF Grant CNS-1730657. The authors would like to thank all the participants for their contributions at the workshop. The workshop details can be accessed at http://uwa.ua.edu.

Aijun Song, *Guest Editor*
Department of Electrical and
Computer Engineering
The University of Alabama
Tuscaloosa, AL 35487 USA

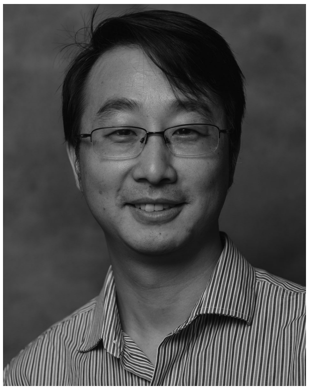
Milica Stojanovic, *Associate Editor*
Northeastern University
Boston, MA 02115 USA

Mandar Chitre, *Editor-in-Chief*
Acoustic Research Laboratory
National University of Singapore
Singapore 119077

Appendix
Related Work

1) M. Stojanovic, J. Catipovic, and J. G. Proakis, “Adaptive multichannel combining and equalization for underwater acoustic communications,” *J. Acoust. Soc. Amer.*, vol. 94, no. 3, pp. 1621–1631, 1993.
2) S. Singh *et al.*, “Acoustic communication performance of the WHOI Micro-Modem in sea trials of the Nereus vehicle to 11,000 m depth,” in *Proc. IEEE/MTS OCEANS Conf.*, 2009, pp. 1–6.
3) W. Li and J. C. Preisig, “Estimation of rapidly time-varying sparse channels,” *IEEE J. Ocean. Eng.*, vol. 32, no. 4, pp. 927–939, Oct. 2007.
4) J. W. Choi, T. J. Riedl, K. Kim, A. C. Singer, and J. C. Preisig, “Adaptive linear turbo equalization over doubly selective channels,” *IEEE J. Ocean. Eng.*, vol. 36, no. 4, pp. 473–489, Oct. 2011.
5) S. Roy, T. M. Duman, V. McDonald, and J. G. Proakis, “High rate communication for underwater acoustic channels using multiple transmitters and space-time coding: Receiver structures and experimental results,” *IEEE J. Ocean. Eng.*, vol. 32, no. 3, pp. 663–688, Jul. 2007.
6) K. Tu, D. Fertonani, T. M. Duman, M. Stojanovic, J. G. Proakis, and P. Hursky, “Mitigation of intercarrier interference for OFDM over time-varying underwater acoustic channels,” *IEEE J. Ocean. Eng.*, vol. 36, no. 2, pp. 156–171, Apr. 2011.

7) C. R. Berger, S. Zhou, J. C. Preisig, and P. Willett, "Sparse channel estimation for multicarrier underwater acoustic communication: From subspace methods to compressed sensing," *IEEE Trans. Signal Process.*, vol. 58, no. 3, pp. 1708–1721, Mar. 2010.
8) Y. M. Aval and M. Stojanovic, "Differentially coherent multichannel detection of acoustic OFDM signals," *IEEE J. Ocean. Eng.*, vol. 40, no. 2, pp. 251–268, Apr. 2015.
9) F. Campagnaro *et al.*, "The DESERT underwater framework v2: Improved capabilities and extension tools," in *Proc. Underwater Commun. Netw. Conf.*, Aug. 2016, pp. 1–5.
10) C. Petrioli, R. Petroccia, J. R. Potter, and D. Spaccini, "The SUNSET framework for simulation, emulation and at-sea testing of underwater wireless sensor networks," *Ad Hoc Netw.*, vol. 34, pp. 224–238, 2015.
11) M. Chitre, R. Bhatnagar, M. Ignatius, and S. Suman, "Baseband signal processing with UnetStack," in *Proc. Underwater Commun. Netw.*, Sestri Levante, Italy, Sep. 2014, doi: 10.1109/UComms.2014.7017156.
12) J. Alves, J. Potter, P. Guerrini, G. Zappa, and K. LePage, "The LOON in 2014: Test bed description," in *Proc. Underwater Commun. Netw.*, Sep. 2014, pp. 1–4.
13) H. S. Dol, P. Casari, T. van der Zwan, and R. Otnes, "Software-defined underwater acoustic modems: Historical review and the NILUS approach," *IEEE J. Ocean. Eng.*, vol. 42, no. 3, pp. 722–737, Jul. 2017.
14) L. Wan *et al.*, "Adaptive modulation and coding for underwater acoustic OFDM," *IEEE J. Ocean. Eng.*, vol. 40, no. 2, pp. 327–336, Apr. 2015.
15) P. Angangi and M. Chitre, "Data-driven learning algorithm for tuning an underwater acoustic link," in *Proc. Underwater Commun. Netw.*, Aug. 2018, pp. 1–4.
16) R. Ahmed and M. Stojanovic, "Joint power and rate control for packet coding over fading channels," *IEEE J. Ocean. Eng.*, vol. 42, no. 3, pp. 697–710, Jul. 2017.
17) A. Radosevic, R. Ahmed, T. M. Duman, J. G. Proakis, and M. Stojanovic, "Adaptive OFDM modulation for underwater acoustic communications: Design considerations and experimental results," *IEEE J. Ocean. Eng.*, vol. 39, no. 2, pp. 357–370, Apr. 2014.
18) A. Singer, M. Oelze, and A. Podkowa, "Mbps experimental acoustic through-tissue communications: MEAT-COMMS," in *Proc. IEEE Int. Workshop Signal Process. Adv. Wireless Commun.*, Jul. 2016, pp. 1–4.
19) G. T. Crossin *et al.*, "Acoustic telemetry and fisheries management," *Ecological Appl.*, vol. 27, no. 4, pp. 1031–1049, 2017.
20) H. Schmidt and T. Schneider, "Acoustic communication and navigation in the new Arctic— A model case for environmental adaptation," in *Proc. Underwater Commun. Netw. Conf.*, 2016, pp. 1–4.
21) P. Mikhalevsky *et al.*, "Multipurpose acoustic networks in the integrated Arctic Ocean observing system," *Arctic*, vol. 68, pp. 11–27, 2015.
22) M. B. Porter, *The Bellhop Manual and User's Guide*. [Online]. Available: http://oalib.hlsresearch.com/Rays/HLS-2010-1.pdf
23) M. Siderius and M. B. Porter, "Modeling broadband ocean acoustic transmissions with time-varying sea surfaces," *J. Acoust. Soc. Amer.*, vol. 124, no. 1, pp. 137–150, 2008.
24) P. Qarabaqi and M. Stojanovic, "Statistical characterization and computationally efficient modeling of a class of underwater acoustic communication channels," *IEEE J. Ocean. Eng.*, vol. 38, no. 4, pp. 701–717, Oct. 2013.
25) P. A. van Walree, F. X. Socheleau, R. Otnes, and T. Jenserud, "The Watermark benchmark for underwater acoustic modulation schemes," *IEEE J. Ocean. Eng.*, vol. 42, no. 4, pp. 1007–1018, Oct. 2017.
26) D. B. Kilfoyle, J. C. Preisig, and A. B. Baggeroer, "Spatial modulation experiments in the underwater acoustic channel," *IEEE J. Ocean. Eng.*, vol. 30, no. 2, pp. 406–415, Apr. 2005.
27) G. Edelmann, H.-C. Song, S. Kim, W. S. Hodgkiss, W. Kuperman, and T. Akal, "Underwater acoustic communications using time reversal," *IEEE J. Ocean. Eng.*, vol. 30, no. 4, pp. 852–864, Oct. 2005.
28) J. R. Buck, J. C. Preisig, M. Johnson, and J. Catipovic, "Single-mode excitation in the shallow-water acoustic channel using feedback control," *IEEE J. Ocean. Eng.*, vol. 22, no. 2, pp. 281–291, Apr. 1997.
29) E. Bjornson, M. Bengtsson, and B. Ottersten, "Optimal multiuser transmit beamforming: A difficult problem with a simple solution structure," *IEEE Signal Process. Mag.*, vol. 31, no. 4, pp. 142–148, Jul. 2014.
30) K. Kredo II, P. Djukic, and P. Mohapatra, "STUMP: Exploiting position diversity in the staggered TDMA underwater MAC protocol," in *Proc. IEEE INFOCOM*, Apr. 2009, pp. 2961–2965.
31) M. Chitre, M. Motani, and S. Shahabudeen, "Throughput of networks with large propagation delays," *IEEE J. Ocean. Eng.*, vol. 37, no. 4, pp. 645–658, Oct. 2012.
32) U. Mitra *et al.*, "Structured sparse methods for active ocean observation systems with communication constraints," *IEEE Commun. Mag.*, vol. 53, no. 11, pp. 88–96, Nov. 2015.
33) J. Potter, J. Alves, D. Green, G. Zappa, I. Nissen, and K. McCoy, "The JANUS underwater communications standard," in *Proc. Underwater Commun. Netw.*, Sep. 2014, pp. 1–4.



Aijun Song (M'05) received the Ph.D. degree in electrical engineering from the University of Delaware, Newark, DE, USA, in 2005.

He is currently an Assistant Professor at the Department of Electrical and Computer Engineering, University of Alabama, Tuscaloosa, AL, USA. From 2005 to 2008, he was a Postdoctoral Research Associate at the College of Earth, Ocean and Environment, University of Delaware, Newark, DE, USA. During this period, he was also an Office of Naval Research (ONR) Postdoctoral Fellow, supported by the special research award in the ONR Ocean Acoustics program. He was an Assistant Research Professor with the University of Delaware from 2008 to 2014 and an Associate Research Professor from 2014 to 2015. His current research interests include digital communications and signal processing techniques for radio frequency and underwater acoustic channels, ocean acoustics, sensor networks, and ocean monitoring and exploration.

Milica Stojanovic (SM'08–F'10) received the Dipl. Ing. degree in electrical engineering from the University of Belgrade, Belgrade, Serbia, in 1988, and the M.S. and Ph.D. degrees in electrical engineering from Northeastern University, Boston, MA, USA, in 1991 and 1993, respectively.

She was a Principal Scientist with the Massachusetts Institute of Technology, Cambridge, MA, USA and in 2008 joined Northeastern University, where she is currently a Professor of Electrical and Computer Engineering. She is also a Guest Investigator with the Woods Hole Oceanographic Institution, Woods Hole, MA, USA. Her research interests include digital communications theory, statistical signal processing and wireless networks, and their applications to underwater acoustic systems.

Dr. Stojanovic is an Associate Editor for the IEEE JOURNAL OF OCEANIC ENGINEERING and a past Associate Editor for the IEEE TRANSACTIONS ON SIGNAL PROCESSING and the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY. She Chairs the IEEE Ocean Engineering Society's Technical Committee for Underwater Communication, Navigation and Positioning, and also serves on the Advisory Board of the IEEE COMMUNICATION LETTERS and the Editorial Board of the IEEE SIGNAL PROCESSING MAGAZINE. She was the recipient of the 2015 IEEE/OES Distinguished Technical Achievement Award, and is the 2008 IEEE/OES Distinguished Lecturer.

Mandar Chitre (S'04–M'05–SM'11) received the B.Eng. and M.Eng. degrees in electrical engineering from the National University of Singapore (NUS), Singapore, in 1997 and 2000, respectively, the M.Sc. degree in bioinformatics from the Nanyang Technological University, Singapore, in 2004, and the Ph.D. degree in underwater communications from NUS, in 2006.

From 1997 to 1998, he was with the Acoustic Research Laboratory (ARL), NUS. From 1998 to 2002, he headed the technology division of a regional telecommunications solutions company. In 2003, he rejoined ARL, initially as the Deputy Head (Research) and is currently the Head of the laboratory. He also holds a joint appointment with the Department of Electrical and Computer Engineering, NUS, as an Associate Professor, and with the Marine and Offshore Programme Office of the Agency for Science, Technology and Research (A*STAR), Singapore, as an Associate Director (Marine Robotics). His current research interests include underwater communications, autonomous underwater vehicles, and acoustic signal processing.

Dr. Chitre has served on the technical program committees of the IEEE OCEANS, WUWNet, DTA, and OTC conferences and has served as a reviewer for numerous international journals. He serves as the Editor-in-Chief for the IEEE JOURNAL OF OCEANIC ENGINEERING, and has also severed on editorial boards for the IEEE COMMUNICATIONS MAGAZINE and the IEEE ICRA conference. He was the Chairman of the Student Poster Committee for IEEE OCEANS'06 in Singapore, and the Chairman for the IEEE Singapore AUV Challenge 2013. He is currently the IEEE Ocean Engineering Society Technology Committee Co-Chair of underwater communication, navigation, and positioning.