Physical Communication 5 (2012) 61–63

Contents lists available at SciVerse ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Guest editorial

Special issue on compressive sensing in communications

Compressive sensing, also known as compressive sampling, has made a tremendous impact on signal processing and statistical learning, and has facilitated numerous applications in areas ranging from medical imaging and computational biology to astronomy. Recently, there has been a growing interest in applying the principles of compressive sensing to an even wider range of topics, including those in communications and networking.

The basic thesis of compressive sensing – and its powerful appeal for many applications – is that under certain conditions it suffices to collect only a small number of signal observations (e.g., pixels of an image) and still be able to reconstruct the signal in its entirety when the signal admits a sparse representation in a basis or a frame. This statement has a profound impact on the way in which a communication system can be designed. From data compression in band-limited systems to estimation of communication channels that are naturally sparse; from active or passive delay, angle, and Doppler estimation of specific targets to distributed sensing of sparse fields, the principles of compressive sensing can be applied to provide system designs that are more efficient than the traditional ones.

This special issue is devoted to those areas of communication system and network design where compressive sensing brings new insights and tools to yield effective solutions for the problems of interest. The issue contains eleven high-quality papers whose topics range from signal detection and channel estimation to radio spectrum sensing and information gathering in energy-constrained sensor networks, offering innovative methodologies, algorithms, and theoretical results by using the existing results of compressive sensing or by extending them.

The first paper in this issue, "Measurement Design for Detecting Sparse Signals" [1], addresses the problem of binary hypothesis testing when it is known that the observed signal is sparse in some domain. The question of measurement matrix design is posed, with the goal of maximizing the signal-to-noise ratio at the input to the detector. Two optimization frameworks are considered—maximization of the worst case and of the average minimum signal-to-noise ratio, yielding respective performance bounds. The customized, deterministic measurement matrices are found to outperform random matrices typically used for sparse signal recovery.

The second paper, "Structured Sublinear Compressive Sensing via Dense Belief Propagation" [2], provides new insights in the design of compressive sensing schemes, by using ideas rooted in error correction coding theory. One scheme is based on codes of graphs, and is used in combination with the Orthogonal Matching Pursuit (OMP) for the reconstruction. To attain increased sensitivity for very sparse signals, the authors also propose a new dense list decoding belief propagation scheme with improved reconstruction performance.

The next three papers address estimation of and communication over sparse channels. The paper entitled "Belief-Propagation-Based Joint Channel Estimation and Decoding for Spectrally Efficient Communication Over Unknown Sparse Channels" [3] revisits the problem of spectrally efficient communication over a block-fading Rayleigh channel that has a sparse discrete-time impulse response. In contrast to the conventional approach of pilot-aided sparse channel estimation that decouples channel estimation from decoding, the focus of this paper is on joint sparse channel estimation and data decoding. This is accomplished through the use of a novel relaxed belief-propagation-based reception scheme in conjunction with a standard bit-interleaved coded orthogonal frequency division multiplexing (OFDM) transmitter. It is found through numerical simulations that the proposed receiver achieves the ergodic capacity scaling of noncoherent sparse channels and performs near-optimally at both low and high signal-to-noise ratios.

In the paper "An Integrated Sparsity and Model-Based Probabilistic Framework for Estimating the Spatial Variations of Communication Channels" [4], the spatial variations of a wireless channel are estimated based on a limited number of measurements. Two approaches have been considered: a sparsity-based approach exploiting the channel sparsity in the frequency domain, and a probabilistic model-based approach relying on multi-scale probabilistic models of the channel spatial variations. The underlying trade-offs between the two methods motivate a combined channel estimation approach that keeps the strengths of

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doi:10.1016/j.phycom.2011.11.003

both approaches and is shown to have superior performance when applied to outdoor as well as indoor channel measurements.

The last paper that focuses on channel estimation, "A Geometric Mixed Norm Approach to Shallow Water Acoustic Channel Estimation and Tracking" [5], includes important guidelines for applying compressed channel sensing to estimate shallow water acoustic channel responses. The sparse channel estimation algorithm is adaptive and is resilient to numerical ill-conditioning that is inevitable when considering shallow waters channel responses.

Application of compressive sensing theory to the problems in networking is addressed in the next two papers. In paper [6], entitled "Asynchronous Code-Division Random Access Using Convex Optimization", the authors propose a multi-user detection technique that capitalizes on the fact that at any time, only a random set of users are active in a given cell. A mixed-norm optimization technique is applied to find this set, and the corresponding signals are detected. The result is a multiple access scheme whose capacity significantly exceeds that of a traditional one. Specifically, the number of users supported by this technique is shown to grow polynomially with the signal space dimension (bandwidth) when specially designed algebraic codes are used.

In paper [7], "Compressed Sensing in Random Access Networks With Applications to Underwater Monitoring", random access and compressive sensing are integrated to arrive at an energy-efficient scheme for data gathering in a large sensor network where the sensing field is sparse. The key notion is that packet collisions, although inevitable, do not alter the random nature of sampling as seen by the fusion center. This fact is used to model the arrival process of useful packets and to determine the minimum per-node sensing rate that guarantees field recovery with a pre-specified probability. Results are discussed in light of underwater acoustic networks, showing significant savings in power and bandwidth as compared to conventional systems based on time-division multiple access.

The final four papers discuss specific applications, and benefits that result from inclusion of compressive sensing techniques into the underlying communication functions. In "Group Sparse Lasso for Cognitive Network Sensing Robust to Model Uncertainties and Outliers" [8], the authors address spectrum sensing for cognitive radio applications. Given a number of primary spectrum users, the problem is that of determining their locations as well as the frequency bands that they occupy. Sparsity is present both in the spatial domain, where primary users sparsely populate a dense grid, as well as in the frequency domain, where in each narrow sub-band a primary user may or may not transmit. The sparse spectrum map changes with time, and has to be estimated in the presence of channel uncertainty, i.e. using signal measurements that are subject to fading. To improve upon the existing solutions, the authors consider cognitive radios capable of cooperation, and propose a new type of algorithm based on alternating direction method of multipliers.

In the paper "GPS Signal Acquisition via Compressive Multichannel Sampling" [9], an efficient acquisition scheme for GPS receivers is proposed. Based on the recently proposed analog compressed sensing framework, the GPS signals can be effectively sampled and detected with many fewer (yet randomized) correlators than those used in existing GPS receivers, thereby leading to significant cost savings. The outputs of this compressive bank of randomized correlators allow one to identify the strongest satellite signals in the field of view and pinpoint the correct code-phase and Doppler shifts for finer resolution during tracking.

The paper [10], "Compressive Sampling based Differential Detection for UWB Signals", investigates the design of ultra-wideband (UWB) impulse radio receivers, for which compressive sampling is particularly motivated to circumvent costly Nyquist-rate sampling in the over-GHz regime. Noncoherent energy detectors are considered in this paper in combination with differential detection (DD), since they bypass channel estimation and provide highly efficient reception capabilities. Bringing the benefits of compressive sampling to noncoherent detection, this paper formulates an optimization problem to jointly recover the sparse received UWB signals as well as the differentially encoded data symbols. This joint approach to compressive-sampling-based DD meets the stringent performance-complexity requirements of UWB impulse radios in terms of affordable sampling and reconstruction costs, as well as comparable performance to a compressed maximum a posteriori (MAP) differential detector that is also derived in this paper.

The last paper in this special issue, entitled "The Impact of ADC Nonlinearity in a Mixed-Signal Compressive Sensing System for Frequency-Domain Sparse Signals" [11], numerically studies the impact of analog-to-digital converter (ADC) nonlinearities in a compressive sensing receiver for frequency-domain sparse signals. It is shown through numerical simulations that compressive sensing receivers have the ability to improve the Spurious-Free Dynamic Range (SFDR) of ADCs in the case of highly-sparse signals. Various factors that affect this SFDR improvement, including the signal sparsity and signal-to-noise ratio, are also numerically investigated.

We hope that the readers will enjoy this special issue that highlights the use of compressive sensing in communications. We would like to thank the Editor in Chief, Prof. Ian Akyildiz, for having us on board the Physical Communication Journal, and for providing an archival quality venue for the papers that we selected. The high-quality technical content, of course, owes to the authors. Our gratitude goes to them, and to the reviewers who provided constructive criticism that helped to bring out the best in these papers.

References

[1] R. Zahedi, A. Pezeshki, E.K.P. Chong, Measurement design for detecting sparse signals, Physical Communication 5 (2) (2012) 64–75.

[2] W. Dai, O. Milenkovic, H.V. Pham, Structured sublinear compressive sensing via belief propagation, Physical Communication 5 (2) (2012) 76–90.
[3] P. Schniter, Belief-propagation-based joint channel estimation and decoding for spectrally efficient communication over unknown sparse channels, Physical Communication 5 (2) (2012) 91–101.
[4] M. Malmirchegini, Y. Mostofi, An integrated sparsity and model-based probabilistic framework for estimating the spatial variations of communication channels, Physical Communication 5 (2) (2012) 102–118.
[5] A.S. Gupta, J. Preisig, A geometric mixed norm approach to shallow water acoustic channel estimation and tracking, Physical Communication 5 (2) (2012) 119–128.
[6] L. Applebaum, W.U. Bajwa, M.F. Duarte, R. Calderbank, Asynchronous code-division random access using convex optimization, Physical Communication 5 (2) (2012) 129–147.
[7] F. Fazel, M. Fazel, M. Stojanovic, Compressed sensing in random access networks with applications to underwater monitoring, Physical Communication 5 (2) (2012) 148–160.
[8] E. Dall'Anese, J.A. Bazerque, G.B. Giannakis, Group sparse lasso for cognitive network sensing robust to model uncertainties and outliers, Physical Communication 5 (2) (2012) 161–172.
[9] X. Li, A. Rueetschi, Y.C. Eldar, A. Scaglione, GPS signal acquisition via compressive multichannel sampling, Physical Communication 5 (2) (2012) 173–184.
[10] S. Gishkori, G. Leus, V. Lottici, Compressive sampling based differential detection for UWB impulse radio signals, Physical Communication 5 (2) (2012) 185–195.
[11] Z. Yu, J. Zhou, M. Ramirez, S. Hoyos, B.M. Sadler, The impact of ADC nonlinearity in a mixed-signal compressive sensing system for frequency-domain sparse signals, Physical Communication 5 (2) (2012) 196–207.

Waheed U. Bajwa received the BE (with Honors) degree in Electrical Engineering from the National University of Sciences and Technology, Pakistan in 2001, and MS and Ph.D. degrees in Electrical Engineering from the University of Wisconsin-Madison in 2005 and 2009, respectively. He was a Postdoctoral Research Associate in the Program in Applied and Computational Mathematics at Princeton University from 2009 to 2010, and a Research Scientist in the Department of Electrical and Computer Engineering at Duke University from 2010 to 2011. He is currently an Assistant Professor in the Department of Electrical and Computer Engineering at Rutgers University. His research interests include high-dimensional inference and inverse problems, compressed sensing, statistical signal processing, wireless communications, and applications in biological sciences, complex networked systems, and radar & image processing.

Geert Leus was born in Leuven, Belgium, in 1973. He received the Electrical Engineering degree and the Ph.D. degree in Applied Sciences from the Katholieke Universiteit Leuven, Belgium, in June 1996 and May 2000, respectively. He has been a Research Assistant and a Postdoctoral Fellow of the Fund for Scientific Research - Flanders, Belgium, from October 1996 till September 2003. During that period, Geert Leus was affiliated with the Electrical Engineering Department of the Katholieke Universiteit Leuven, Belgium. Currently, Geert Leus is an Associate Professor at the Faculty of Electrical Engineering, Mathematics and Computer Science of the Delft University of Technology, The Netherlands. During the summer of 1998, he visited Stanford University, and from March 2001 till May 2002 he was a Visiting Researcher and Lecturer at the University of Minnesota. His research interests are in the area of signal processing for communications. Geert Leus received a 2002 IEEE Signal Processing Society Young Author Best Paper Award and a 2005 IEEE Signal Processing Society Best Paper Award. He was the Chair of the IEEE Signal Processing for Communications and Networking Technical Committee, and an Associate Editor for the IEEE Transactions on Signal Processing, the IEEE Transactions on Wireless Communications, and the IEEE Signal Processing Letters. Currently, he serves on the Editorial Board of the EURASIP Journal on Applied Signal Processing.

Anna Scaglione received the M.S. and Ph.D. degrees in Electrical Engineering from the University of Rome La Sapienza, Italy, in 1995 and 1999, respectively. She is currently Professor in Electrical Engineering at the University of California at Davis, CA. Prior to this, she was a Postdoctoral Researcher at the University of Minnesota in 1999–2000, Assistant Professor at the University of New Mexico in 2000–2001, Assistant and Associate Professor at Cornell University in 2001–2006 and 2006–2008, respectively. Her research is in the broad area of signal processing for communication systems. Her current research focuses on cooperative communication systems and decentralized processing for sensor networks. Dr. Scaglione received the 2000 IEEE Signal Processing Transactions Best Paper Award, the NSF Career Award in 2002, the Fred Ellersick Award for the best unclassified paper in MILCOM 2005, and the 2005 Best paper for Young Authors of the Taiwan IEEE Comsoc/Information Theory section.

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. She was a Principal Scientist at the Massachusetts Institute of Technology until 2008, when she joined Northeastern University where she is currently a Professor of Electrical and Computer Engineering. She is also a Guest Investigator at the Woods Hole Oceanographic Institution, and a Visiting Scientist at MIT. Her research interests include digital communications theory, statistical signal processing and wireless networks, and their applications to underwater acoustic systems. Milica is an Associate Editor for the IEEE Journal of Oceanic Engineering, IEEE Transactions on Signal Processing, and the Elsevier Physical Communication Journal.

Zhi Tian received the B.E. degree in Electrical Engineering from the University of Science and Technology of China in 1994, and the M.S. and Ph.D. degrees from George Mason University, Virginia, in 1998 and 2000 respectively. Since August 2000, she has been on the faculty of the Michigan Technological University, where she is currently a Professor. Her general interests are in the areas of signal processing, wireless communications, and estimation and detection theory. Current research focuses on spectrum sensing for cognitive radio networks and distributed information processing in wireless sensor networks. She served as an Associate Editor for IEEE Transactions on Wireless Communications and IEEE Transactions on Signal Processing. She received a CAREER award from the US National Science Foundation in 2003.

Waheed U. Bajwa
Geert Leus
Anna Scaglione
Milica Stojanovic*
Zhi Tian
409 DA Northeastern University,
Department of Electrical and Computer Engineering,
Boston, MA 02115,
United States
E-mail address: millitsa@ece.neu.edu (M. Stojanovic).

Available online 20 November 2011

* Tel.: +1 617 373 5112; fax: +1 617 258 5730.