

Editorial

Distributed Signal Processing Techniques for Wireless Sensor Networks

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Recent advances in micro electromechanical systems (MEMS) technology have enabled the design of low-power low-cost smart sensors equipped with multiple onboard functions such as sensing, computing and communications. Such intelligent devices networked through wireless links have been referred to as wireless sensor networks and recognized as one of the most important technologies for the 21st century. Wireless sensor networks hold the promise to revolutionize the sensing technology for a broad spectrum of applications, including infrastructure monitoring and surveillance, disaster management, monitoring the health status of humans, plants, animals and industrial machines, etc.

Wireless sensor networks can be viewed as a special case of wireless ad hoc networks, and assume a multi-hop communication framework with no centralized infrastructure and where the sensors cooperate spontaneously by forwarding each other's packets for delivery from a source to a destination node. The multi-hop nature of sensor networks is imposed by energy-consumption reasons because of the super-linear power loss of wireless transmissions with respect to the propagation distance.

In general, the design of wireless sensor networks is subjected to a number of challenges: low energy consumption which manifests in minimal energy expenditure in each sensor node and efficient usage of power-saving sleep/wake-up modes, scalability in the presence of a large number of sensors, possibility of frequent node failures and network topology changes, collaborative signal processing and data aggregation techniques to cope with the large number of sensors which might congest the network with information, and efficient communication protocols to deal with the special broadcast communication paradigm and the increased possibility of packet collisions and congestions for nodes operating in closely spaced transmission ranges.

The scope of this special issue was to present the state-of-the-art and emerging distributed signal processing techniques that deal with some of the above-mentioned design challenges. This special issue consists of seven papers that treat important signal processing aspects such as compression, quantization, estimation, detection, synchronization and localization in wireless sensor networks. A short description of the contributions brought by these papers is next presented.

In the paper "Energy-Constrained Optimal Quantization for Wireless Sensor Networks", X. Luo and G. B. Giannakis deal with the important problem of designing efficient quantizers that ensure optimal reconstruction at the fusion center of the measurements yielded by a sensor as well as the estimation of a deterministic parameter by exploiting the measurements collected by a set of sensors. The design is carried out under power constraints and information such as channel propagation effects, modulation, and energy consumed by transceiver circuitry is considered into the analysis. The effect of channel coding on the reconstruction performance is also studied, and the optimum number of quantization bits and energy levels are derived.

The problem of designing an optimal-level distributed transform for wavelet based spatio-temporal data compression in wireless sensor networks is addressed by S. Zhou et al. in the paper "Ring Based Optimal-Level Distributed Wavelet Transform With Arbitrary Filter Length For Wireless Sensor Networks." This paper proposes a distributed optimal-level spatio-temporal compression algorithm based on the ring model for general wavelets with arbitrary supports. The proposed compression algorithm accommodates a broad range of wavelet functions, effectively exploits the temporal and spatial correlation of data measurements, and achieves significant reduction in energy consumption and delay for data gathering in sensor clusters.

In the paper "Distortion-Rate Bounds for Distributed Estimation using Wireless Sensor Networks," D. Schizas et al. address the problem of centralized and distributed rate-constrained estimation of random signal vectors by exploiting a network of wireless sensors (encoders) that communicate with a fusion center (decoder). Within the proposed framework, the authors of this paper determine lower and upper bounds on the corresponding distortion-rate (D-R) function using both centralized as well as distributed estimation techniques.

The paper "Distributed Event Region Detection in Wireless Sensor Networks," co-authored by J. Fang and H. Li, proposes a graph-based method for distributed event-region detection in wireless sensor networks. The proposed detection scheme exploits a graphical model to take into account the fact that events occurring in geographically neighboring sensors present a statistical dependency. The proposed detection scheme admits also energy and bandwidth efficient distributed implementations.

Q. Chaudhari and E. Serpedin, in the paper "Clock Estimation for Long-Term Synchronization in Wireless Sensor Networks with Exponential Delays," deal with the maximum likelihood estimation of the clock parameters (phase, skew, and drift) in two-way timing exchange mechanisms and in networks with exponentially distributed delays.

The paper entitled "Extension of Pairwise Broadcast Clock Synchronization for Multi-Cluster Sensor Networks," co-authored by K. L. Noh et al., proposes a novel clock synchronization protocol to minimize the overall energy consumption in wireless sensor networks that assume general multi-cluster topologies. The proposed synchronization approach relies on a receiver-only synchronization approach and it can be viewed as a generalization of the Pairwise Broadcast Synchronization (PBS) protocol. Like PBS, the proposed synchronization approach exhibits the distinct advantage that the number of sensor nodes can be synchronized by only over-hearing time message exchanges between pairs of nodes, and therefore it reduces significantly the overall network-wide energy consumption by decreasing the number of required timing messages for synchronization.

Finally, in the paper "Optimization of sensor locations and sensitivity analysis for engine health monitoring using minimum interference algorithms," P. Cotae et al. address the problem of optimal placement of sensors in the presence of additive white Gaussian noise (AWGN) by considering the sensors as systems that present full communications capabilities and by minimizing the RF-interference induced by the wireless communication channels among the sensor nodes. Numerical simulations and a sensitivity analysis study are presented to illustrate the robustness of the proposed algorithm.

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Erchin Serpedin received (with highest distinction) the Diploma of Electrical Engineering from the Polytechnic Institute of Bucharest, Bucharest, Romania, in 1991. He received the specialization degree in signal processing and transmission of information from Ecole Supérieure D'Electricite, Paris, France, in 1992, the M.Sc. degree from Georgia Institute of Technology, Atlanta, GA, in 1992, and the Ph.D. degree in Electrical Engineering from the University of Virginia, Charlottesville, VA, in January 1999. In July 1999, he joined Texas A&M University in College Station, as an assistant professor, and where currently holds the position of associate professor. His research interests lie in the areas of signal processing, bioinformatics and telecommunications. He received the NSF Career Award in 2001, the CCCT 2004 Best Conference Award, the Outstanding Faculty Award in 2004, NRC Fellow Award in 2005, and TEES Award in 2005. He is currently serving as an associate editor for the IEEE Communications Letters, IEEE Transactions on Signal Processing, IEEE Transactions on Communications, IEEE Transactions on Wireless Communications, EURASIP Journal on Advances in Signal Processing and EURASIP Journal on Bioinformatics and Systems Biology. Dr. Serpedin served also as a technical co-chair of the Communications Theory Symposium at Globecom 2006 Conference, and VTC Fall 2006: Wireless Access Track.

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Paul Cotae was born in Falticeni, Romania, on June 21, 1955. He received the Dipl.Ing. and M.S. degrees in communication and electronic engineering from the Technical University of Iassy, Iasi, Romania, in 1980 and the Ph.D. degree in telecommunications from Politehnica University of Bucharest, Bucharest, Romania, in 1992. Since 1984, he has been with the Department of Electrical Engineering, Technical University of Iassy, where he conducted research and teaching in the area of digital communications as a Full Professor. From 1994 to 1998, he spent four years in the USA at the University of Colorado at Colorado Springs and Boulder as a Fulbright Scholar and Visiting Associate Professor, where he did research and teaching with the Electrical and Computer Engineering Department and Applied Mathematics Department, respectively. He also served as a Consultant to Navsys Corporation, Colorado Springs, in 1997. Currently, he is with the University of Texas, San Antonio. His current research interests include multiple access, modulation and coding, mobile communications, and digital communication systems. He has authored or coauthored more than 90 papers in these areas and four books. Dr. Cotae serves as an Associate Editor for IEEE COMMUNICATIONS LETTERS, and he has been on the Technical Program Committee and Session Chair of IEEE Conferences such as GLOBECOM (2003–2006), VTC Spring 2005, and ICC 2005 and 2006. He is a member of HKN (Eta Kappa Nu), the American Society for Engineering Education, and the Society for Industrial and Applied Mathematics.