IPSN 2008
Workshop on Signal and Information Processing
St. Louis, Missouri
http://ipsn.acm.org/2008/

Schedule: April 21 9:00AM-5:30PM

Session1: 9-11:00 AM, Chair: Moura

9:00 - 9:30AM: Statistical Inference and Interactive Statistical Mechanics, Mitter, MIT
9:30 -10:00AM: Location-free Distributed Coverage Verification in Sensor Networks, Jadbabaie, UPenn
10:00-10:30AM: Distributed Compressed Sensing, Baraniuk, Rice

10:30-11:00AM: Coffee Break

Session2: 11:00-1:00 PM, Chair: Shah

11:00- 11:30PM: Clock Synchronization in Wireless Networks, Freris and Kumar, UIUC
11:30- 12:00PM: Distributed LMS for Consensus-Based Adaptive Signal Processing, Giannakis, UMN
12:00-12:30PM: Distributed Processing in Sensor Networks under Imperfect Communication, Kar and Moura
12:30 - 1:00PM: Morning Group Discussion

1:00 - 2:00PM: Lunch Break

Session3: 2 - 3:30 PM, Chair: Jadbabaie

2:00-2:30PM: Abnormal Event Detection through Behavior Subtraction, Saligrama, BU
2:30-3:00PM: Decentralized Random-field Estimation for Sensor Networks Using Quantized Spatially Correlated Data and Fusion-center Feedback, Dogandzic, Iowa State
3:00-3:30PM: Linear Decentralized Estimation, Xiao, Cui, Luo (UMN) and Goldsmith (Stanford)

3:30 - 4:00PM: Coffee Break

Session4: 4:00-5:30 PM, Chair: Dogandzic

4:00 - 4:30PM: Some algorithms for sensor networks, Shah, MIT
4:30 - 5:00PM: The Marginal Utility of Cooperation in Sensor Networks, Pottie, UCLA
5:00 - 5:30PM: Afternoon Group Discusion

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Statistical Inference and Interactive Statistical Mechanics.

Sanjoy Mitter
Electrical Engineering and Computer Science
MIT, Cambridge MA

In this talk we discuss Bayesian Statistical Inference from the point of view of Interactive Statistical Mechanics and the theory of Gibbs Measures.

Location-free distributed coverage verification in sensor networks

Ali Jadbabaie
Department of Electrical and Systems Engineering
University of Pennsylvania, Philadelphia, PA

Joint work with Alireza Tahbaz-Salehi

In this talk, we present a series of distributed algorithms for coverage verification in sensor networks when no location information is available. We demonstrate how, in the absence of localization devices, simplicial complexes and tools from algebraic topology (specifically computational homology) can be used in providing valuable information on the properties of the sensor cover. We show how the sensor cover can be represented by a combinatorial object known as the Rips complex (a generalization of the proximity graph of sensors to higher order relations). By computing the homology of the Rips complex corresponding to the sensor network, we verify whether there are any holes in the coverage. We use the theory of higher order combinatorial Laplacian operators to compute generators of the homology classes of the Rips complex in a distributed fashion. Furthermore, we formulate the problem of localizing coverage holes as an optimization problem to compute the sparsest generator of the first homology classes of the Rips complex. We also show that one can detect redundancies in the sensor network by finding the sparsest generator of the second homology of the cover relative to its boundary. Finally, we demonstrate how subgradient methods can be used in solving these optimization problems in a distributed manner.

Distributed Compressive Sensing

Richard Baraniuk
Department of Electrical and Computer Engineering
Rice University, Houston, TX

Sensors systems are under increasing pressure to accommodate ever larger and higher-dimensional data sets; ever faster capture, sampling, and processing rates; ever lower power consumption; communication over ever more difficult channels; and radically new sensing modalities. The foundation of today's digital data acquisition systems is the Shannon/Nyquist sampling theorem, which asserts that to avoid losing information when digitizing a signal or image, one must sample at least two times faster than the signal's highest frequency, at the so-called Nyquist rate. Unfortunately, the physical limitations of current sensing systems combined with inherently high Nyquist rates impose a performance brick wall to a large class of important and emerging applications.

This talk will overview our recent work on compressive sensing, a new approach to data acquisition in which analog signals are digitized for processing not via uniform sampling but via measurements using more general, even random, test functions. In stark contrast with conventional wisdom, the new theory asserts that one can combine "low-rate sampling" with digital computational power for efficient and accurate signal acquisition. impressive sensing systems directly translate analog data into a compressed digital form; all we need to do is "decompress" the measured data through an optimization on a digital computer. The implications of compressive sensing are promising for many applications and enable the design of new kinds of analog-to-digital converters, cameras, and imaging systems. This talk will focus on applications in distributed sensing for sensor networks.

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Clock Synchronization in Wireless Networks

Nikolaos Freris and P. R. Kumar
Electrical and Computer Engineering, and Coordinated Science Lab
University of Illinois, Urbana IL

We present some feasibility and infeasibility results on the synchronization of clocks in wireless networks. In a network of n nodes, we show that the skews of all n nodes as well as the roundtrip delays of all links can be estimated correctly. Every node can also estimate the time at which a packet transmitted by it will be received by a neighboring node according to that node's clock. However the vector of (n-1) clock offsets, excluding the reference clock node, and the one-way link delays cannot be estimated. There are (n-1) degrees of freedom that cannot be determined, where each unknown is a nodal offset. By further taking causality into account, the region of uncertainty is reducible to a compact set that can be precisely characterized. If only receiver-receiver synchronization is allowed and no sender time-stamps are used, then the uncertainty corresponds to a (2n-1) dimensional subspace which cannot even be reduced by taking causality into account. The basic infeasibility of determining all parameters remains even if the delay of a link has the further structure of a transmitter specific sending delay, a receiver specific receiving delay, and a known propagation delay.

Distributed LMS for Consensus-Based Adaptive Signal Processing

Georgios B. Giannakis
Electrical and Computer Engineering
Univ. of Minnesota, Minneapolis MN

Adaptive estimation based on in-network processing of distributed observations is well-motivated for tracking (non-) stationary signals using ad hoc wireless sensor networks. To this end, a fully distributed least-mean square (D-LMS) algorithm is presented in this talk, offering simplicity and flexibility whilst solely requiring single-hop communications among neighboring sensors. The algorithm entails the minimization of a pertinent squared-error cost by resorting to: (i) the alternating-direction method of multipliers so as to gain the desired degree of parallelization and, (ii) a stochastic approximation iteration to cope with the time-varying statistics of the process under consideration. For a linear data model and under mild assumptions aligned with those considered in the centralized LMS, stability

of the novel D-LMS algorithm is shown to guarantee that local sensor estimation error norms remain within a finite interval most of the time. Interestingly, this so called weak stochastic stability result extends to the pragmatic setup where inter-sensor communications are corrupted by additive noise. In the absence of observation and communication noise, consensus is achieved almost surely as local estimates are shown exponentially convergent to the parameter of interest with probability one. Mean-square error performance of D-LMS is also assessed. Numerical simulations illustrate that D-LMS outperforms existing approaches, highlight its tracking capabilities and corroborating the stability and performance results.

Distributed Processing in Sensor Networks under Imperfect Communication

Soummya Kar and José M. F. Moura
Department of Electrical and Computer Engineering,
Carnegie Mellon University, Pittsburgh, PA

We present a unified treatment, in the framework of controlled Markov processes and stochastic approximation, to prove almost sure convergence of distributed processing algorithms in sensor networks with imperfect inter-sensor communication. For clarity, we focus on distributed average consensus under various simultaneous inter-sensor communication distortions, including quantized transmission, random link failures, and possibly non-Gaussian additive channel noise. We characterize explicitly the resulting mean-squared error between the desired average and the converged estimates. Finally, we demonstrate the generality of the approach by applying it to distributed detection and parameter estimation problems.

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Abnormal Event Detection Through Behavior Subtraction

Venkatesh Saligrama
Electrical Engineering, Boston University, Boston, MA

Network of video cameras, developed in the last decade or so, permit today pervasive, wide-area visual surveillance. Visible-light cameras provide excellent temporal and spatial resolution, long range, wide field-of-view and low latency. However, video data production rates is generally not scalable to network bandwidth. Many applications such as some key tasks of computer vision generally require high data rates. Consequently, limited network rate can fundamentally constrain performing these tasks in real-time. On the other hand for other monitoring tasks such as the detection of suspicious behavior (i.e. identification of individuals or objects whose behavior differs from behavior usually observed) it is conceivable, on account of the relative sparsity of abnormal phenomena, that these tasks require relatively low bandwidth. Nevertheless, video data by its nature produces a high degree of clutter and it is difficult to identify the truly relevant information from clutter particularly in urban environments. Many methods based on object path analysis have been developed to date (motion detection followed by tracking and inferencing) but they are sensitive to motion detection and tracking errors, computationally complex and difficult to fuse across different cameras. We propose a new surveillance method capable of abnormal behavior detection without explicit estimation of object paths. Our main insight is to exploit ergodic aspects of normal behavior and map it on to a very low-dimensional model. Correspondence between these low dimensional models can then established across different cameras by exploiting certain invariance features of motion attributes. Our method requires little processing power and memory, is robust to motion segmentation errors, and general enough to monitor humans, cars or any other moving objects in uncluttered as well as highly-cluttered scenes.

Joint work with P.M. Jodoin (Univ. of Sherbrooke) and J. Konrad (Boston University)

Decentralized Random-field Estimation for Sensor Networks Using Quantized Spatially Correlated Data and Fusion-center Feedback

Aleksandar Dogandzic
Electrical Engineering, Iowa State, Ames, IA
In large-scale wireless sensor networks, sensor-processor elements (nodes) are densely deployed to monitor the environment; consequently, their observations form a random field that is highly correlated in space. We consider a fusion sensor-network architecture where, due to the bandwidth and energy constraints, the nodes transmit quantized data to a fusion center. The fusion center provides feedback by broadcasting relevant information to the nodes. In addition to saving energy, this feedback ensures reliability and robustness to node and fusion-center failures. We propose a Bayesian framework for fusion-center feedback, quantization, and estimation of the random field and its parameters. We also discuss field prediction at arbitrary locations within the region of interest, derive a simple suboptimal approach for estimating the unknown parameters, and present numerical examples demonstrating the performance of the proposed methods.

Linear Decentralized Estimation

Jinjun Xiao, Shuguang Cui, Zhi-Quan Luo UMN, and Andrea Goldsmith, Stanford

We consider the distributed estimation of an unknown vector signal in a resource constrained sensor network with a fusion center. Due to power and bandwidth limitations, each sensor compresses its data in order to minimize the amount of information that needs to be communicated to the fusion center. In this context, we study the linear decentralized estimation of the source vector, where each sensor linearly encodes its observations and the fusion center also applies a linear mapping to estimate the unknown vector signal based on the received messages. Our results indicate that the multiple access channel (MAC) between sensors and the fusion center plays a key role in the complexity of designing the optimal estimation schemes. Specifically we show that when the MAC is orthogonal, the complexity of designing the optimal encoding encoding is NP-hard in general. But for the coherent MAC case, the resulting problem either has a closed-form solution or can be efficiently solved by semi-definite programming (SDP). We also derive the optimal bandwidth and power scheduling among sensors using the tools of convex optimization.

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Some algorithms for sensor networks

Devavrat Shah
Electrical Engineering and Computer Science, MIT, Cambridge MA

Sensor networks impose stringent constraints on algorithms operating within them due to limited resources and lack of permanent network infrastructure. This has necessitated researchers to re-think the algorithm design paradigm for such networks. In this talk, I will discuss algorithms design method especially suitable for sensor networks for three important sensor network problems: dissemination (with and without simple coding), linear estimation (averaging) and computing separable functions. We will discuss the performance of these algorithms in the presence of communication constraints.

The Marginal Utility of Cooperation in Sensor Networks

Gregory J. Pottie
Electrical Engineering Department, University of California, Los Angeles, CA

A common assumption in sensor networks research is that as nodes become less expensive, large numbers of very simple nodes will provide either (1) a lower cost means of performing tasks than a small number of big nodes or (2) capabilities beyond what a small network of big nodes could provide. At one extreme nodes can communicate only a single bit regarding a given event, and cooperate in large numbers to perform tasks. At the other extreme, nodes with 32 bit processors, WiFi communications, and sophisticated sensors are employed, with extensive on-board optimizations to reduce resource consumption. In this talk, we show how the utility obtained from node cooperation in localization quickly saturates for nodes that can exchange high quality data. The saturation in utility is the result of three effects: the decreasing marginal utility of additional nodes even when there is no propagation loss, the order statistics of propagation losses for nodes in the region of the phenomenon, and the confounding effects of multipath which require some diversity of receivers. One might thus be tempted to argue as follows: below a critical density, even cooperation among very large numbers of nodes may be insufficient to meet utility targets, while above that density the closest node (or at most a small group) will sufficient. Because of the sharpness of the transition region many heuristics will work in selecting the groups of nodes to cooperate in a given task, and that number of nodes will be small. Since the number is small, management of their cooperation is an easy task. The design of algorithms to manage the scaling of the cooperation to large numbers becomes irrelevant since the expected utility is low. In our talk we will outline in what respects the preceding argument leads the reader down the proverbial Garden path, and what research issues need to be addressed in fairly comparing the alternative sensor network paradigms.