Signals, Information, and Algorithms

RLE Group
Signals, Information and Algorithms Laboratory

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Introduction

Our laboratory formulates, examines, and develops algorithmic solutions to a wide spectrum of problems of fundamental interest involving the manipulation of signals and information in diverse settings. Our work is strongly motivated by and connected with emerging applications and technologies.

In pursuing the design of efficient algorithm structures, the scope of research within the lab extends from the analysis of fundamental limits and development of architectural principles, through to implementation issues and experimental investigations. Of particular interest are the tradeoffs between performance, complexity, and robustness.

In our work, we draw on diverse mathematical tools—from the theory of information, computation, and complexity; statistical inference and learning, signal processing and systems; coding and communication; and networks and queuing—in addressing important new problems that frequently transcend traditional boundaries between disciplines.

We have many joint projects and collaborate closely with faculty, staff, and students in a variety of other labs on campus, including the Laboratory for Information and Decision Systems, the Microsystems Technologies Laboratories, and Computer Science and Artificial Intelligence Laboratory.

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Much of our activity over the last few years has centered around a variety of different types of problems arising naturally in the context of wireless, sensor, multimedia, and broadband networks.

Some topics of current interest include:

- cross-layer design techniques and architectural considerations for resource-efficient wireless networks
- coding for multiple-element antenna arrays in wireless networks, and interactions with other layers; advanced antenna designs
- new classes of source and channel codes, and decoding algorithms, particularly for new applications
- diversity techniques and interference suppression and management algorithms for wireless networks
- distributed algorithms and robust architectures for wireless networks, especially ad-hoc networks and sensor networks
- algorithms and fundamental limits for multimedia security problems, including digital watermarking, encryption, and authentication of multimedia content
- algorithms and architectures for multimedia and streaming media networks
- algorithmic and coding techniques for generating reliable advanced systems from aggressively scaled devices, circuits, and microsystems.
- information-theoretic and algorithmic aspects of learning, inference, and perception; universal algorithms
- information-theoretic and signal processing aspects of neuroscience, and computational and systems biology

1. Blind Calibration of ADC Non-linearities

Sponsors
National Defense Science and Engineering Graduate (NSDEG) Fellowship
MARCO/DARPA C2S2 under contract No. 2001-CT-888

Project Staff
Lane Brooks, Professor Harry Lee, and Professor Gregory Wornell

Digitally corrected analog circuit design is becoming increasingly more necessary as the speed, power, and area performance digital circuits advance faster than that of analog circuits. Furthermore, blind calibration and correction that can track environmental conditions without taking some or all of the system out of commission is desirous. We are studying the application of blind digital correction of nonlinearities of both pipelined and time-interleaved ADCs. These techniques seek to extract the information about the non-linearities of the ADC by analyzing the digital output stream in real time.

2. Estimation with Unknown Costs

Sponsors
National Defense Science and Engineering Graduate (NSDEG) Fellowship
Hewlett Packard under the HP/MIT Alliance

Project Staff
Vijay Divi and Professor Gregory W. Wornell

We explore the problem of filling in missing data in a non-classical manner. Similar to the problem of universal denoising where the source statistics are unknown, we examine cases where the heuristic for computing distortion is unknown. In particular, cases arise where it is optimal to randomly fill in missing data according to a prior distribution. This approach is useful in applications where it is unnatural to use a maximum-likelihood or minimum square error estimator, since the result of these estimators may be a set of data, which appears atypical.

3. Elements of an Efficient Wireless Gigabit LAN Architecture

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MIT Lincoln Laboratory

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Everest Huang, and Professor Gregory W. Wornell

In the context of a wireless gigabit LAN (the WiGLAN), we are exploring algorithmic and system architecture choices, which facilitate the efficient use of resources such as power, bandwidth, cost, etc. Although these optimizations can be made completely in the digital domain, taking into account the nonidealities and limitations of the analog circuitry leads to solutions with larger gains and are more advantageous from a total system standpoint.

Multiple antenna systems are capable of a greatly increased capacity over single antenna systems in a wireless fading environment, but the cost is additional hardware and complexity. By trading off some of this capacity, design constraints on the RF transceivers, such as the noise figure of the receiver circuitry, can be reduced. The relaxed noise figure requirement can lead to significant reductions in required chip area and power consumption. At the transmitter, large peak to average power ratio (PAPR) waveforms translate into high linearity and dynamic range requirements. Using iterative precoding techniques to trade off peak and average power, the PAPR of an encoded packet can be reduced without rate loss and transparently to the receiver. Alternately, nearly constant amplitude waveforms can be synthesized with a rate loss of one half, or constant amplitude amplifiers can also be used in tandem to emulate a single linear amplifier. This allows highly efficient nonlinear amplifiers to replace inefficient linear ones.

These systems also require parallel independent data paths to separately process the data to and from each antenna, with crosstalk potentially having adverse effects on the system noise performance. Since the magnitude of the crosstalk is essentially fixed for an individual chip, the circuit must be designed to accommodate a worst-case crosstalk degradation. However, by randomizing the crosstalk phase, each circuit can experience an averaged crosstalk performance, reducing the amount of signal margin that must be built into the system, and consequently reducing the need for isolation structures to be built.

4. Source Coding with Encoder-side Quality Side Information

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The rate-distortion bound characterizes the trade-off, in the lossy encoding of data, between bits spent for description and the amount of tolerated loss as measured by a distortion measure function. When side information affecting the distortion measure, such as quality, reliability, importance associated with the data, is available, the performance can be improved in the rate-distortion sense, even if the side information is available for encoding but unavailable for decoding. This project develops algorithms and architectures to exploit this information in a practical way. Potentially, this leads to more flexible designs for source coding applications.

5. Cooperative Diversity in Wireless Networks

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NSERC Fellowship

Project Staff
Ashish Khisti and Professor Gregory W. Wornell

The purpose of this research is to explore potential gains in performance through protocols that exploit cooperation among wireless nodes.
We study both the fundamental gains through user cooperation as well as practical schemes that approach these fundamental gains. We have observed a rather surprising result that user cooperation leads to a positive multicasting capacity in slow fading wireless networks, while this capacity is zero in conventional networks without cooperation. In another line of research, we have investigated possible interactions between network layer and physical layer protocols to simplify cooperative diversity. In particular we have investigated a novel relay selection algorithm at the network layer that can dramatically simplify cooperative diversity protocols at the physical layer without incurring any substantial loss in performance.

6. Low Complexity Rateless Codes for Parallel Gaussian Channels with Uncertain Quality

Sponsors
Hewlett Packard under the HP/MIT Alliance

Project Staff
Maryam Modir Shanechi and Professor Gregory W. Wornell

We try to develop low complexity rateless codes to achieve the capacity of parallel Gaussian channels with uncertain quality. In our problem, not only the overall quality of the two channels is uncertain, but also the relative quality of the two channels is unknown.

We first assume the overall channel has a certain achievable capacity and try to find low complexity codes that would approach this capacity no matter what the relative qualities of the two channels are. We then use the rateless property of the code to achieve capacity even when the overall channel quality is changing.

7. Throughput and Complexity Tradeoffs in the Multi-antenna Downlink

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Project Staff
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We consider the joint design of the multiplexing and scheduling of independent data streams for the Gaussian MIMO broadcast channel. It is well known that the use of multiple transmit antennas can greatly increase the capacity of the broadcast channel. However, the complexity of a capacity-achieving strategy is dominated by the underlying search for the best user subset to multiplex across the transmitter array, which can be prohibitively high if the number of users is much greater than the transmit dimension. To reduce this complexity, one can limit the search to a smaller set of users while ensuring that this restricted pool contains a set that is close to optimal with high probability. To this end, we define sets with guaranteed signal to interference ratio (SIR) and signal to noise ratio (SNR) values.

We provide good bounds on the probability that such a set exists. These bounds are derived through an interpretation of the multi-user multi-antenna channel as a random packing of the unit sphere. As such, we provide refined estimates on the content of spherical caps so that they can be applied as a model for interference. We then employ recent developments in the area of random geometric graph theory to characterize the probability of existence. We further show there is a phase transition phenomenon in channel geometry that can be used in the design of efficient algorithms for scheduling in the MIMO broadcast channel. Further, we use this transition to provide novel lower bounds for the expected rate of any multiplexer in a channel with choice.

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