Proposed Projects

1 Universal Codes

Multiple transmit and receive antennas have the potential of increasing reliability of communication as well as permitting communication at higher rates. These aspects are quantified by the diversity and spatial multiplexing gains, respectively. Zheng and Tse showed that there is a fundamental tradeoff explained below, between diversity and multiplexing gain, referred to as the diversity-multiplexing gain tradeoff.

The main scope of this project to study explicit constructions of diversity-multiplexing gain optimal space-time codes, *i.e.,* codes that achieve the tradeoff for any number of receive antennas.

[1]. P. Elia, K. R. Kumar, S. A. Pawar, P. Vijay Kumar, and H. Lu, "Explicit, Minimum-Delay Space-Time Codes Achieving the Diversity Multiplexing Gain Tradeoff", IEEE Trans. Inform. Theory, vol. 52, no. 9, pp. 3869–3884, Sep. 2006.

[2]. H. Yao and G. W. Wornell, "Achieving the full MIMO diversity-multiplexing frontier with rotation based space-time codes," in Proc. Allerton Conf. Communication, Control and Computing, Monticello, IL, Oct. 2003.

[3]. H. Yao, "Efficient signal, code, and receiver designs for MIMO communication systems," Ph.D. dissertation, MIT, Cambridge, 2003.

[4]. J.C. Belfiore, G. Rekaya, and E. Viterbo, "The Golden code: A 2×2 full-rate space-time code with nonvanishing determinants," IEEE Trans. Inform. Theory, vol. 51, no. 4, pp. 1432–1436, Apr. 2005.

2 Diversity Embedded Codes

The use of multiple transmit and receive antennas to deliver higher data rate at higher reliability, while transmitting over wireless channels, has been an extremely active research area over the past decade. The codes designed for such systems are referred to as space time codes. Diversity order, which captures reliability in terms of error performance, and rate impose a fundamental trade-off in space-time coding. High-rate space-time codes come at a cost of lower diversity order, and high reliability (diversity order) results in a lower rate. Over the past few years, this trade-off has been quite well understood for flat fading channels while far less attention has been given to Inter Symbol Interference (ISI) or broadband channels.

Given the tradeoff between rate and reliability, if the overall system is designed for a fixed rate-diversity operating point it might be over-provisioning a resource which could be flexibly allocated to different applications. A new paradigm for the design of wireless links makes it possible to design a high rate code with an embedded high reliability code. This allows a form of communication where the high-rate code opportunistically takes advantage of good channel realizations whereas the embedded high-diversity code ensures that at least part of the information is received reliably.

[1]. S. Diggavi, A. Calderbank, S. Dusad, and N. Al-Dhahir, "Diversity embedded space time codes," IEEE Trans. Inform. Theory, vol. 54, no. 1, pp. 33–50, Jan. 2008.

[2]. S. Dusad, S. N. Diggavi, N. Al-Dhahir and A. R. Calderbank, "Diversity Embedded Codes: Theory and Practice," IEEE Journal on Selected Topics in Signal Processing, Special Issue on MIMO-Optimized Transmission Systems for Delivering Data and Rich Content, April 2008.

[3]. S. Dusad, "Diversity Embedding for Broadband Communication," Ph.D. dissertation, EPFL, 2008.

3 Cooperative Diresity

In wireless networks, signal fading arising from multipath propagation is a particularly severe channel impairment that can be mitigated through the use of diversity. Space, or multi-antenna, diversity techniques are particularly attractive as they can be readily combined with other forms of diversity, e.g., time and frequency diversity, and still offer dramatic performance gains when other forms of diversity are unavailable. In contrast to the more conventional forms of space diversity with physical arrays, this work builds upon the classical relay channel model and examines the problem of creating and exploiting space diversity using a collection of distributed antennas belonging to multiple terminals, each with its own information to transmit. This form of space diversity is called cooperative diversity because the terminals share their antennas and other resources to create a virtual array through distributed transmission and signal processing.

[1]. A. Sendonaris, E. Erkip and B. Aazhang, "User cooperation diversity-Part I: System descriptionm" IEEE Trans. Comm., vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[2]. A. Sendonaris, E. Erkip and B. Aazhang, "User cooperation diversity-Part II: Implementation aspects and performance analysis," IEEE Trans. Comm., vol. 51, no. 11, pp. 1939–1948, Nov. 2003.

[3]. N. Laneman, D. Tse and G. Wornell, "Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior," IEEE Trans. Inform. Theory, vol. 50, no. 11, Nov. 2004.

4 Network Error Correction Codes

Random network coding is a powerful tool for disseminating information in networks, yet it is susceptible to packet transmission errors caused by noise or intentional jamming. Indeed, in the most naive implementations, a single error in one received packet would typically render the entire transmission useless when the erroneous packet is combined with other received packets to deduce the transmitted message. It might also happen that insufficiently many packets from one generation reach the intended receivers, so that the problem of deducing the information cannot be completed.

The main goal in this project is to study the coding schemes can be used over a network in order to deal with such erroneous packets.

[1]. R. Koetter and F. R. Kschischang, "Coding for Errors and Erasures in Random Network Coding," to appear in IEEE Trans. Inform. Theory, available on `www.arxiv.org`.

[2]. R. W. Yeung and N. Cai, "Network error correction, Part I: Basic concepts and upper bounds," Communications in Information and Systems, vol. 6, no. 1, pp. 19–36, 2006.

[3]. N. Cai and R. W. Yeung, "Network error correction, Part II: Lower bounds," Communications in Information and Systems, vol. 6, no. 1, pp. 37–54, 2006.

5 Basic Secrecy and Wire-tap Channel

The wire-tap channel is introduced by Wyner. It is a form of degraded broadcast channel, with the novel difference that one information rate is to be maximized and the other minimized. The object is to maximize the rate of reliable communication from the source to the legitimate receiver, subject to the constraint that the wire-tapper learns as little as possible about the source output.

[1]. A. D. Wyner, "The wire-tap channel," Bell Cyst. Tech. J., vol. 54, pp. 1355–1387, Oct. 1975.

[2]. R. Ahlswede and I. Csiszar, "Common randomness in information theory and cryptography I: Secret sharing," IEEE Transactions on Information Theory, vol. 39, no. 4, pp. 1121–1132, July 1993.

[3]. U. Maurer, " Secret Key Agreement by Public Discussion Based on Common Information,", IEEE Transactions on Information Theory, vol. 39, no. 3, pp 733–742, May 1993.

6 Network Coding from an Algorithmic Point of View

The famous max-flow min-cut theorem states that a source node can send information through a network to a sink node at a rate determined by the min-cut separating the source and destination. It has been also shown that this rate can also be achieved for multicasting to several sinks provided that the intermediate nodes are allowed to re-encode the information they receive.

However, finding efficient algorithm to perform such encoding and decoding, is a very important issue, which will be studied in this project.

[1]. R. Koetter, M. Medard, "An Algebraic Approach to Network Coding," IEEE/ACM Transactions on Networking, vol. 11, no. 5, pp 782–795, Oct 2003.

[2]. S. Jaggi, P. Sanders, P. A. Chou, M. Effros, S. Egner, K. Jain, L. Tolhuizen, "Polynomial Time Algorithms for Multicast Network Code Construction," IEEE Transactions on Information Theory, 2005.

7 Scaling Laws for Wireless Networks

Consider networks consist of a group of nodes which communicate with each other over a wireless channel without any centralized control. Nodes may cooperate in routing each others' data packets. Lack of any centralized control and possible node mobility give rise to many issues at the network, medium access, and physical layers, which have no counterparts in the wired networks like Internet, or in cellular networks.

Studying the capacity scaling of such networks is the main scope of this project.

[1]. P. Gupta and P. R. Kumar, "The capacity of wireless networks," IEEE Trans. Inform. Theory, vol. 42, no. 2, pp. 388–404, Mar. 2000.

[2]. O. Leveque and I. E. Telatar, "Information-theoretic upper bounds on the capacity of large, extended ad hoc wireless networks," IEEE Trans. Inf. Theory, vol. 51, no. 3, pp. 858–865, Mar. 2005.

8 Hierarchical Cooperation for Wireless Networks

The capacity region of a wireless network with n nodes is the set of all simultaneously achievable rates between all possible n^2 node pairs. In this project, the main question is determining the scaling of the capacity region with respect to the number of nodes n, when the nodes are placed uniformly at random in a square region of area n and they communicate over Gaussian fading channels.

[1]. A. Ozgur, O. Leveque and D. Tse, "Hierarchical Cooperation Achieves Optimal Capacity Scaling in Ad Hoc Networks," IEEE Transactions on Information Theory, vol 53, no. 10, pp. 3549–3572, Oct 2007.

[2]. U. Niesen, P. Gupta, and D. Shah, "The Capacity Region of Large Wireless Networks," available on `www.arxiv.org`.

9 Interference Alignment

Over the past few decades several techniques have been devised for transmission on the interference channels; among them, superposition of information, power allocation, interference suppression (partly common information), and interference alignment are the most well-known ones.

Interference alignment refers to the simple idea that signal vectors can be aligned in such a manner that they cast overlapping shadows at the receivers where they constitute interference while they continue to be distinct at the receivers where they are desired.

[1]. V. R. Cadambe, S. A. Jafar, "Interference Alignment and the Degrees of Freedom for the K User Interference Channel," IEEE Transactions on Information Theory, Aug 2008, Vol. 54, Issue 8, pp. 3425–3441.

[2]. M. A. Maddah-Ali, A. S. Motahari, A. K. Khandani, "Communication Over MIMO X Channels: Interference Alignment, Decomposition, and Performance Analysis," IEEE Transactions on Information Theory, vol. 54, no. 8, pp. 3457–3470, Aug. 2008.

[3]. G. Bresler, A. Parekh, and D. Tse, "The approximate capacity of the many-to-one and one-to-many Gaussian interference channels", Allerton 2007.

10 Coding for Function Computation

Consider a communication scenario, wherein the receiver only wishes to reliably evaluate a function of the data available at the transmitter. The main question here is to find the minimum number of bits needed to be transmitted in order to such evaluation can be done with vanishing error probability.

[1]. J. Korner and K. Marton, "How to encode the modulo-two sum of binary sources, " IEEE Transactions on Information Theory, vol. 25, no. 2, pp. 219–221, March 1979.

[2]. A. Orlitsky and J. R. Roche, "Coding for computing," IEEE Transactions on Information Theory, vol. 47, no. 3, pp. 903–917, March 2001.

[3]. B. Nazer and M. Gastpar, "Computation over Multiple-Access Channels," IEEE Transactions on Information Theory, Special Issue on Models, Theory, and Codes for Relaying and Cooperation in Communication Networks, vol.53, no.10, pp.3498–3516, October 2007.

11 Interference Channel

The capacity of the two-user Gaussian interference channel has been open for thirty years. The understanding on this problem has been limited. The best known achievable region is due to Han-Kobayashi but its characterization is very complicated. It is also not known how tight the existing outer bounds are.

Etkin *et al.* have shown that a simplified Han-Kobayashi type scheme can achieve to within a single bit the capacity, by deriving new outer bounds, which leads to an approximation rate characterization for this problem. Also a deterministic version of the problem is studied by Bresler *et al.*, where the results are extended to a constant bit gap characterization for the Gaussian version of the problem.

[1]. T. S. Han and K. Kobayashi, "A new achievable rate region for the interference channel," IEEE Trans. Info. Theory, vol. 27, no. 1, pp. 49–60, Jan. 1981.

[2]. R. Etkin, D. Tse and H. Wang, "Gaussian Interference Channel Capacity to Within One Bit,“ IEEE Trans. Inform. Theory, Dec. 2008..

[3]. G. Bresler and D. Tse, "The two-user Gaussian interference channel: a deterministic view," European Transactions on Telecommunications. Vol 19, Issue 4. pp. 333-354. June, 2008.