1st Annual Review of ARO MURI:
"Space-Time Processing for Enhanced Mobile Ad-Hoc Wireless Networking"
AGENDA WITH ABSTRACTS
Eucalyptus Point, UC San Diego

THURSDAY, JULY 28th, 2005	
7:30	Breakfast & Registration
8:00	Introduction » James Zeidler, UCSD

8:15 **"Understanding Channel Access Control in Ad Hoc Nets with MIMO Nodes"**
» JJ Garcia-Luna-Aceves, UCSC

This talk addresses the modeling of the impact of the physical layer in channel access protocols, and the capacity of ad hoc networks with MIMO nodes. In the first part of this talk I discuss extensions we have made recently of our analytical modeling of ad hoc networks [mobicom04], which consider fading and MIMO nodes. In the second part of this talk I address the benefits derived from using the proper multiple access schemes with MIMO nodes.

The capacity of wireless ad hoc network has received considerable attention recently since Gupta and Kumar showed that the per source-destination throughput and delay degrade as the number of nodes in the network increases. To attain better network utilization, we use a new scheme based on a collaboration-driven approach, called opportunistic cooperation [wcom1]}. In this new approach, multiple nodes simultaneously communicate with each other within a cell in the network. Sender-receiver nodes collaborate rather than compete with each other to access the channel. Each sender node either relays a message to all receiver nodes or to one of the receiver nodes as destination in a pre-defined cell. Within the context of a cell in the network, multiple sender nodes either relay or transmit data to a destination simultaneously. I report analytical results showing that the capacity of mobile ad hoc networks (MANETS) when all the nodes in the network are endowed with multiple antennas grows with increase in transmit power of the nodes in the network.

References:

R. Moraes, H. Sadjadpour, and J.J. Garcia-Luna-Aceves, "A New Communication Scheme for MANETs," Proc. IEEE WirelessCom 2005, Maui, Hawaii, June 13--16, 2005.

X. Yu, R. Moraes, H. Sadjadpour, and J.J. Garcia-Luna-Aceves, "Capacity of MIMO Mobile Wireless Ad hoc Networks," Proc. IEEE WirelessCom 2005, Maui, Hawaii, June 13--16, 2005.

M. Carvalho and J.J. Garcia-Luna-Aceves, "A Scalable Model for Channel Access Protocols in Multihop Ad Hoc Networks,"
Proc. ACM Mobicom 2004, Philadelphia, Pennsylvania, Sept. 26--Oct. 1, 2004.

M. Carvalho and J.J. Garcia-Luna-Aceves, "Modeling Wireless Ad Hoc Networks with Directional Antennas," submitted to the International Conference on NET Protocols (ICNP) 2005.

R. Moraes, H. Sadjadpour, and J.J. Garcia-Luna-Aceves, "Ergodic Capacity of MIMO MANETs," submitted to IEEE Infocom 2005

R. Moraes, H. Sadjadpour, and J.J. Garcia-Luna-Aceves, "Opportunistic Cooperation: A New Approach for Scalable Mobile Ad Hoc Net works," submitted to Infocom 2005.

8:45 "Adaptive MAC Protocols for Mobile Ad-Hoc Networks"
» Rene Cruz, UCSD

GSRs: Manish Amde, Yoav Nebat, Bongyong Song, Eric Wong

In this talk, I will describe a network-level architecture for mobile ad-hoc networks. Our long-term research plan is to flesh out various aspects of system optimization for this architecture, and to implement low cost prototype communications nodes that will self organize and adapt to the wireless environment to provide energy efficient information transport. Our architecture uses adaptive MAC protocols that combine code division multiple access with adaptive transmission policies based on carrier sense multiple access, and coarse grained channel estimation. The dimensions of adaptation that we will consider are link data rates, packet transmission rates, transmission power, antenna weights, network topology, and routing. I will describe several sub-projects that relate to system optimization, and discuss some preliminary results and experimental demonstrations.

The first subproject I will discuss relates to network topology design for CSMA-based networks with spatial re-use. We model an ad-hoc network as a random graph, and study the average throughput per unit area as a function of parameters of the CSMA protocol, including idle threshold, packet transmission rate, link transmission rate, transmission power, and transmission radius. This will give insight into the properties of “good” network topologies as a function of the physical environment and data transport requirements.

The second subproject I will discuss relates to the problem of incorporating channel state estimates into MAC and routing protocols. One preliminary result, reported in [1], suggests that the efficacy of using “cooperative transmission” is limited, when route diversity in a network context is taken into account.Prof. M. Zorzi and his students have reported initial results [2] relating to how the RTS/CTS mechanism in CSMA-protocols can be modified in networks that can support more than one concurrent transmission in a geographic area. The third subproject relates to timing and packet acquisition in low

SINR environments. We have developed an implementation technique that leverages the processing gain across a large number of bits in a packet transmission in order to detect packet transmissions reliably at SINR levels substantially below that possible with commonly deployed implementations. Initial experimental results are encouraging. We expect to apply this developed technology in our prototype communication nodes in the following contexts: channel estimation protocols, improved “carrier sense” mechanisms for CSMA, and adaptive hybrid CDMA/CSMA MAC protocols.

The fourth subproject relates to antenna weight optimization. Our past work in this area, reported in [2], has been focused on joint transmitter/receiver beam-forming in generic mesh-networks when accurate channel state information is available.

References:

Y. Nebat and R. L. Cruz, “Routing, Cooperative Transmission and the Relaying Bound: the Effect of Multi-User Diversity,” Proc. 2005 CISS.

B. Song, R. L. Cruz and B. D. Rao, "Network duality and its application to multi-user MIMO wireless networks with minimum SINR constraints," in Proc. IEEE ICC'05, Seoul, Korea, May 2005.

9:15 "Cross Layer Protocols for Use with Antenna Arrays"
» Srikanth Krisnamurthy, UCR

GSRs: Gentian Jakllari, Ece Gelal

Our objective is to build MAC/Routing protocols that incorporate antenna arrays and space-time codes to offer increased end-to-end performance in ad hoc networks. Since cross layer design is not still well understood, we have taken the following preliminary steps towards our final objective of designing an architecture for facilitating the integration of MIMO links.

(i) We first consider directional antennas and construct a polling based MAC protocol, called PMAC, to fully exploit the capabilities of such antennas. The protocol integrates a neighbor discovery and tracking mechanism along with the medium access control. The protocol design allows for modifications to facilitate its use when space-time codes or more sophisticated antenna arrays are used. These will be considered in future work. Our work has resulted in a publication in IEEE WoWMoM 2005.

(ii) We are working towards building a routing layer that is closely knit with PMAC. The major intricacy of the integration between the two layers is the topology control, i.e. deciding the number of neighbor and the transmit power levels to be used by each node in the network. We have designed centralized and distributed topology control algorithms that provide bounded node degree, while guaranteeing connectivity and

constant path stretch factor.
The work to date does not completely take into account MIMO characteristics and integration; this will be considered in the next several months.

(iii) We have considered the use of cooperative diversity and virtual MISO/MIMO in ad hoc networks.
The ability to use SISO transmissions in parallel (facilitates backward compatibility) has provided us with a better handle on using cooperative diversity.
Nodes jointly facilitate the use each other's singe antennas, to create a virtual antenna array. We have built centralized and distributed protocols for broadcasting that enable and exploit virtual antenna arrays. Our simulations show significant improvement to the end-to-end performance. A preliminary paper on the use of broadcasting with cooperative diversity will appear as an invited paper in WPMC 2005.

References:

Jakllari, G., Luo, W., and Krishnamurthy S.V., "An
Integrated Neighbor Discovery and MAC protocol for Ad hoc Networks using Directional Antennas", Proceedings of IEEE WoWMoM, Taormina, Italy.

Jakllari, G., Krishnamurthy S.V., Faloutsos M., and
Krishnamurthy, P. "Power Efficient Broadcasting with Cooperative Diveristy in Ad hoc Networks", Proceedings of Wireless Personal Multimedia Communications (Invited Paper), Aalborg, Denmark (to appear).

Jakllari G., Broustis I., Korakis, T., Krishnamurthy S.V. and Tassiulas, L., "Handling Asymmetry in Gain in Directional Antenna Equipped Ad hoc Networks", Proceedings of PIMRC 2005, Berlin.

9:45 "On the Implications of Layered Space--Time Multiuser Detection on the Design of MAC Protocols for Ad Hoc Networks"
» Michele Zorzi, UCSD

In this work, we wish to analyze the implications of using a recent layered space--time multiuser detection technique in MAC protocol design for ad hoc networks with multiple antennas. From this point of view, this work relates to both physical layer and network layer studies.

Typical access protocols for ad hoc networks are based on CSMA/CA technology, whose main representative is IEEE 802.11. In these protocols, one tries to avoid simultaneous transmissions in the same area, which cannot be sustained in a traditional narrowband system. Following a Request-to-send (RTS) packet, issued by the sender, the desired receiver responds with a Clear-to-send (CTS) packet, which grants the sender an opportunity to transmit the data packet. This mechanism, coupled with a physical carrier sensing mechanism, is meant to avoid that two packet transmissions overlap in the same network area, leading to a collision and the resulting loss of all

packets involved.

On the other hand, in the presence of interference-tolerant transmission technologies (including MUD, MIMO, and interference cancellation), this approach is too conservative and leads to poor throughput performance. In the presence of these capabilities, it is better to adopt a more aggressive approach where multiple transmission requests can be issued and served simultaneously, while relying on PHY processing to separate the signals. If this capability is to be exploited, one needs to design new MAC mechanisms which incorporate it in the access rules.

As a first step towards this concept, we evaluate the capture performance of a layered space-time MUD scheme, characterizing the number of RTS, CTS, and data packets that can be simultaneously received (correctly) as a function of the interference level and number of antennas. We find that several such packets can be in fact received, which makes it possible to provide for enhanced parallelism in the network (more requests can be granted) as well as a means to estimate network traffic (also for those RTS that are denied), which can also be used in making decisions at the networking level.

Following these preliminary results, we have developed and compared some policies for how a node which receives RTS packets is to decide whether or not to grant those requests (i.e., to issue a CTS), and if so how many and which ones. When detecting multiple RTSs a node becomes aware of data requests for itself as well as requests for some other nodes it can overhear, and this makes it possible to gain some knowledge on the expected interference level as well as the CSI of the interfering signals which may therefore be cancelled. According to the number of signals a node can hear and track, different schemes can be developed, in which we trade off complexity for interference cancellation capabilities. Our results show that making CTS issuance decisions while ignoring interfering traffic leads to very poor throughput performance (as expected), whereas a scheme where a node willingly decides to limit the number of CTSs in order to be able to receive some strong interferers and to cancel it results in a much better performance.

References:

This line of work has been pursued by two of my Italian students (Paolo Casari and Marco Levorato), and has resulted in the following paper:

Paolo Casari, Marco Levorato, Michele Zorzi, “On the Implications of Layered Space--Time Multiuser Detection on the Design of MAC Protocols for Ad Hoc Networks,” accepted for presentation at IEEE Personal, Indoor, and Mobile Radio Communications (PIMRC) conference, Sep. 2005.

A related paper on this topic will also appear in the Wireless Personal Multimedia Communications (WPMC) conference this September.

10:00 Break

10:30 **"A Formal Approach to Analysis and Design of Self-Configuring Wireless Ad-hoc Networks"**
» Tara Javidi, UCSD

The area of ad hoc networks has become increasingly important, as new applications emerge in areas from coordinate underwater robotics mission to space exploration. Typically in these networks , the use of centralized coordination is either cost prohibitive or simply not possible. In such networks, the ability of the group of nodes to self-configure into a feasible network architecture is critical. The goal is for these nodes to use locally available information to establish a communication structure that supports an overall network communication.

In order to achieve this goal, we propose using graph grammars as a tool for designing appropriate local rules, and as a method of analyzing the resulting global behavior and network properties. Recent work in self-assembly has shown how to develop graph grammar rules that produce specific stable components using at most ternary rules (rules that depend on the state of the node and two neighbors). This is promising for developing local rules for use in sensor networks. The challenge will be to translate the graph-grammar symbols into meaningful parameters based on the specific communication scheme used. In addition, we need to translate the desired network properties (which will be based on both the communication scheme used and the sensing/reporting goals of the network) into the desirable stable component (e.g. tree of degree n). We can, then, input the desirable stable component into algorithms synthesizing local rules to guarantee reachable of the outcome.

Initial results have been generated for a communication network that uses both time and code division multiplexing (TDMA and CDMA) in a broadcast network where nodes have a single antenna. The goal of this network is to maximize the amount of information transmitted from each node to its nearest neighbors. We have shown that the configuration problem consists of three basic components: neighbor discovery, time-slot assignment, and rate assignment. By decomposing the network configuration problem into separate logical components (neighbor discovery / time-slot assignment, and rate assignment), we are able to generate rules that generate stable, feasible network architectures in a finite amount of time. We also show the existence of practical signaling mechanisms that allow for a truly decentralized implementation of the synthesized graph-grammar rules.

References:

J. Price and T. Javidi. “Joint Scheduling and Rate Control for Self-Configuring Ad-Hoc CDMA Networks,” in Proceedings of the Allerton Conference on Communication, Control and Computing, 2004.

11:00 "Quantifying Performance Improvements Due to Spatial-Temporal Diversity in Mobile MIMO Spread-Spectrum Ad-Hoc Networks"
» James Zeidler, UCSD

GSRs: Haichang Sui, Adam Anderson, Jittra Jootar

The effect of the spatial diversity due to multiple antennas and the temporal diversity due to interleaving and coding are studied for mobile ad-hoc networks with spread-spectrum. The effects of Doppler spreading in a time-varying fading channel are analyzed for a DS-CDMA system. The tradeoffs in channel estimation accuracy that are realizable at low Doppler rates and the effects of increased time diversity at high Doppler rates are evaluated. The gains associated with the use of finite depth interleaved convolutional codes at high doppler rates are derived. For a DS-CDMA two-branch transmit diversity system, the performance of Alamouti's space-time code in time-varying channels with noisy channel estimates is derived. It is shown that the Alamouti space-time code with a maximum likelihood symbol detector and linear combining is outperformed by a system with no transmit diversity at high Doppler rates or low pilot SNR. Comparisons of analytical results with experimentally measured channel data from BYU are provided.

In order to obviate channel time variability without excessive pilot power, non-coherent codes, such as differential space-time codes (DSTC), are analyzed to provide robustness in mobile ad-hoc networks. A frequency-hopped CDMA (FH-CDMA)system is evaluated with DSTC and error-correction codes to provide improved performance in tactical multiuser ad-hoc networks. The use of erasure insertion in such a system is evaluated. The results show that substantial improvement in performance can be achieved over a system without erasure insertion, especially when the partial band interference in the system is significant. In addition, a DSTC that is effective with offset modulations is developed in order to provide improved spectral performance in the presence of amplifier nonlinearities. It is shown that while traditional DSTC operates at a reduced transmission rate relative to other STC, the combination of DSTC with offset modulation allows full rate transmission at the expense of greater detector complexity.

References:

J. Jootar, J. R. Zeidler, and J. G. Proakis, "Performance of Alamouti Space-Time Code in Time Varying Channels with Noisy Channel Estimates," in Proceedings of the IEEE WCNC (New Orleans), pp 498-503, Mar. 2005.

J. Jootar, J. R. Zeidler, and J. G. Proakis, "Performance of Finite-Depth Interleaved Convolutional Codes in a Rayleigh Fading Channel with Noisy Channel Estimates," in Proceedings of the IEEE 61st Vehicular Technology Conference (Stockholm), June 2005.

A. Anderson, J. R. Zeidler, and M. A. Jensen, "Differential Space-Time Coding with

Offset Quadrature Phase-Shift Keying", Proceedings of the IEEE Workshop on Signal Processing Advances in Wireless Communications (New York, N. Y.), June 2005

H. Sui and J.R. Zeidler, "Erasure Insertion for Coded MIMO Slow Frequency-Hopping Systems in the Presence of Partial Band Interference", submitted to IEEE Globecom, December 2005

H. Sui and J. R. Zeidler, "An explicit and Unified Error Probability Analysis of Two Detection Schemes for Differential Unitary Space-Time Modulation", submitted to the IEEE Asilomar Conference, November 2005

J. Jootar, J. R. Zeidler, and J. G. Proakis, "Performance of Convolutional Codes with Finite-Depth Interleaving and Noisy Channel Estimates," submitted to IEEE Transactions on Communications, April 2005.

11:30 "The Effect of Channel Estimation Errors on System Performance"
» Larry Milstein, UCSD

GSR: Andrew Ling

This talk will consider the effect of imperfect channel state information (CSI) on both waveform design and scheduling protocols. Regarding the former topic, a tradeoff between the use of multicarrier CDMA and direct sequence multicarrier CDMA will be presented. With respect to the latter topic, the influence of mobility on the accuracy of CSI will be illustrated by considering the performance of a multiuser diversity system.

Consider the tradeoff between multi-carrier direct-sequence CDMA (MC-DS-CDMA) and multi-carrier CDMA (MC-CDMA) [1]. To make a fair side-by-side comparison between the two schemes, both systems were set up to match each other as closely as possible, and it was assumed that they operated under equal bandwidth, information rate, and transmitted power constraints. Waveform shaping was used in both systems to bandlimit the signal at each sub-carrier, and the sub-carriers were spaced in such a way that adjacent sub-bands did not overlap. Frequency diversity was achieved by using repetition coding to send a bit over multiple sub-carriers, and maximal-ratio combining was used at the receiver to combine the energy from these different channels. Since direct-sequence spreading is performed at each sub-carrier in MC-DS-CDMA, resulting in wider sub-bands when compared with those of MC-CDMA (in MC-CDMA, the data at each sub-carrier is modulated by only a single chip in the spreading sequence, with different sub-carriers modulated by different chips), over a given bandwidth, the MC-CDMA system has a larger number of sub-carriers. And since the information rate is kept constant between the two systems, a bit is repeated across a larger number of sub-carriers in MC-CDMA than in MC-DS-CDMA, potentially giving MC-CDMA greater frequency diversity. On the other hand, the energy for a given bit is distributed across a larger number of sub-carriers in MC-CDMA than in MC-DS-CDMA, such that the energy-per-repetition in MC-CDMA is lower than in MC-DS-CDMA. As a result, MC-CDMA suffers from noisier channel estimation, because the signal-to-noise

ratio (SNR) upon which the channel estimates are made is lower in MC-CDMA than in MC-DS-CDMA. Therefore, a trade-off with regards to frequency diversity and channel estimation errors may exist between the two systems.
Regarding the effect of channel estimation errors on scheduling protocols, the key consideration there is the Doppler spread of the channel. In our work ([2]), we analyzed the performance of a multiuser diversity system taking into account the feedback errors due to channel variability. Based upon a block fading model, we derived an expression for throughput as a function of system parameters, such as packet length and data rate thresholds, and channel characteristics, such as Doppler spread. Our results indicate that there is a tradeoff between multiuser diversity and mobility, with higher mobility resulting in a decrease in average throughput.

References:

A. S. Ling and L. B. Milstein, "Comparison of Multi-Carrier Modulation Techniques". Submitted to 2005 IEEE Conference on Military Communications.

D. Piazza and L. B. Milstein, "Impact of Feedback Errors in Multiuser Diversity Systems". To appear in 2005 IEEE Conference on Vehicular Technology

12:00 Lunch

13:00 **"System Design Issues for Mobile Wireless Networks"**
» Lee Swindlehurst, BYU

GSRs: Christian Peel, Michael Larsen

Wireless networks composed of highly mobile nodes pose difficult problems for the system designer. The most critical of these involves the ability of users in the network to obtain and maintain accurate channel state information (CSI) for those they communicate with. In this presentation, we use both simulated and real wireless channel data to study the trade-offs associated with designing a system for mobile wireless communications. In particular, for systems that use standard training-based techniques for CSI estimation, we derive the optimal training interval, training length and power allocation that maximizes capacity for a given wireless link given a certain degree of mobility for that link. We also address the issue of when it is better to use non-coherent (e.g., differential) modulation versus coherent (e.g., training-based) modulation in highly time-varying scenarios. When the network nodes possess multiple antennas, another important factor to consider is whether or not spatial multiplexing (i.e., one node communicating with several others simultaneously) is practical. We will present experimental results that illustrate how close two users can be before their ability to be spatially multiplexed breaks down.

References:

Q. Spencer, J. Wallace, C. Peel, T. Svantesson, A. Swindlehurst, H. Lee, A. Gummalla, "Performance of Multi-User Spatial Multiplexing with Measured Channel Data,"

submitted to edited book to be published by CRC Press

C. Peel and A. Swindlehurst, "Optimal Trained Space-Time Modulation over a Rician Time-Varying Channel," submitted to IEEE Transactions on Wireless Communications.

T. Svantesson and A. Swindlehurst, "A Performance Bound for Prediction of MIMO Channels," submitted to IEEE Transactions on Signal Processing.

13:30 "Experimental Evaluation of MIMO Channels: Multi-User Characteristics and Temporal Variability"

» Michael A. Jensen, BYU

GSRs: Nicholas Bikhazi and Jon W. Wallace

The performance gains associated with using MIMO technology in multi-user networks is critically dependent on the characteristics of the available communication channels. For example, the ability of MIMO algorithms to increase link efficiency while suppressing interference to other users can be limited if the channels from a transmit node to different receiving nodes are similar. Furthermore, the temporal (or spatial) variability of these channels dictates how frequently channel state information must be acquired and, in some implementations, shared within the network. This talk will explore these issues based on findings from experimentally-acquired data from a wideband channel sounder as well as a MIMO real-time communication system. Specifically, we examine the properties of MIMO channels as a function of the physical proximity of multiple users, and illustrate the effect of channel similarity on the performance of multi-user MIMO algorithms. Similarly, we explore the temporal variability of the channel through the use of new metrics which quantify the degradation in performance resulting from outdated channel estimates. Antenna topologies suitable for dismounted troops and vehicles which provide reduced temporal channel variability will be demonstrated. Furthermore, the incorporation of this enhanced understanding about the multi-user MIMO channel into network simulation tools will be addressed.

References:

M. A. Jensen and J. W. Wallace, “MIMO Wireless Channel Modeling and Experimental Characterization,” chapter 1 in Space-Time Processing for MIMO Communications, A. B. Gershman and N. D. Sidiropoulos, Eds., John Wiley & Sons, Ltd.:UK, 2005.

M. A. Jensen, M. D. Rice, and A. L. Anderson, “Orthogonal coding for multi-antenna aeronautical telemetry transmission,” submitted to IEEE Trans. Wireless Communications, May. 2004.

M. L. Morris and M. A. Jensen, “Improved network analysis of coupled antenna diversity

performance," to appear in IEEE Trans. Wireless Communications.

M. L. Morris and M. A. Jensen, "Impact of receive amplifier signal coupling on MIMO system performance," to appear in IEEE Trans. Vehicular Technology, Sept. 2005.

M. L. Morris, M. A. Jensen, and J. W. Wallace, "Superdirectivity in MIMO systems," to appear in IEEE Trans. Antennas Propag., Sept. 2005.

B. T. Maharaj, J. W. Wallace, L. P. Linde, and M. A. Jensen, "Frequency scaling of spatial correlation from co-located 2.4 GHz and 5.2 GHz wideband indoor MIMO channel measurements," Electronics Lett., vol. 41, pp. 65-66, 17 March, 2005.

M. A. Jensen and M. L. Morris, "Efficient capacity-based antenna selection for MIMO systems," IEEE Trans. Vehicular Technology, vol. 54, pp. 110-116, Jan. 2005.

M. L. Morris and M. A. Jensen, "Network model for MIMO systems with coupled antennas and noisy amplifiers," IEEE Trans. Antennas Propag., vol. 53, pp. 545-552, Jan. 2005.

M. A. Jensen and J. W. Wallace, "A review of antennas and propagation for MIMO wireless communications," IEEE Trans. Antennas Propag., vol. 52, pp. 2810-2824, Nov. 2004. Invited Review Article

J. W. Wallace and M. A. Jensen, "Experimental evaluation of the MIMO wideband channel temporal variation," Proceedings of the 27th General Assembly of International Union of Radio Science, New Delhi, India, Oct. 23-29, 2005. Invited

M. A. Jensen and J. W. Wallace, "Recent advances in antennas and propagation for MIMO systems: multi-user networks and channel temporal variation," Proceedings of the 2005 International Conference on Electromagnetics in Advanced Applications, Torino, Italy, Sep. 12-16, 2005. Invited

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14:00 "The McMaster Contributions to the MURI Project"
» Simon Haykin, McMaster University

GSR/Post-Doc: Nelson Costa and Stephen Feng

In this talk, we will do two things:

1. Describe the 4-by-4 "Wideband Software-defined MIMO System" for channel modeling; this system is being built by Nelson Costa 2. Present highlights of a novel approach to the design of wireless communication systems; the present work has focused on SISO configurations; it will be extended to MIMO configurations as we progress forward with further developments of the approach. This research topic is

being studied by Stephen Feng.

The intention of item 1 is to develop collaboration with the research team at BYU. We look forward to the Review meeting to see how we can build collaborative links with other members of the MURI project on item 2.

14:30 "Channel Equalization for MIMO Systems"
» John Proakis, UCSD

GSR: Patrick Amihood

This presentation briefly reviews receiver-based channel equalization techniques for direct sequence spread spectrum MIMO systems. The equalization techniques include linear, chip-level equalizers (LE), decision-feedback equalizers(DFE), and a two-stage LE-DFE structure. Such equalizer structures are especially suitable for point-to-point MIMO transmission systems. Then, we focus on point-to-multipoint MIMO transmission systems in which the transmitter employs channel state information to perform joint spatial and temporal equalization by precoding the information symbols prior to transmission. Both linear and nonlinear transmitter processing techniques are described.

References:

F. Blackmon, E. Sozer, M. Stojanovic, J. G. Proakis, "Performance Comparison of RAKE and Hypothesis Feedback Direct Sequence Spread Spectrum Techniques for Underwater Communication Applications", Proc. OCEANS' 2002, Biloxi, MS, October 29-31, 2002.

P. Amihood, L. B. Milstein and J. G. Proakis, "Channel Equalization for High Data Rate MIMO Systems", Proc. MILCOM' 2003, Boston, MA, October 13-16, 2003.

L. Mailaender and J. G. Proakis, "Linear-Aided Decision-Feedback Equalization for the CDMA Downlink", Proc. 2003 Asilomar Conference, Pacific Grove, CA, November 9-12, 2003.

S. Roy, T. Duman, L. Ghazikhanian, V. McDonald, J. G. Proakis, J. Zeidler "Enhanced Underwater Acoustic Communication Performance Using Space-Time Coding and Processing", Proc. OCEANS' 2004 Conference, October 2004.

15:00 Break

15:30 "Quantization Algorithms and their Analysis in feedback MIMO systems"
» Bhaskar Rao, UCSD

GSRs: June Chul Roh, Chandra Murthy, Jun Zheng

The performance of Multiple Input Multiple Output (MIMO) systems with limited feedback is studied in this work. In particular, we examine the capacity loss resulting from the use of finite number of bits for quantizing the channel state information. For effective feedback, we consider vector quantization (VQ) based techniques. For multiple input single output (MISO) systems, we introduce a new design criterion and develop the corresponding iterative design algorithm for quantization of the beamforming vector. For complexity-limited systems, tree-structured VQ is also examined and compared with the full-search VQ method. The performance of systems with VQ-based quantized beamforming is analyzed for the independent Rayleigh fading case. This requires finding the density of the squared innerproduct between the optimum and the quantized beamforming vector, which is obtained by considering a simple approximation of the quantization cell. The approximate density function is used to lower bound the capacity loss due to quantization, the outage probability and the bit error probability.

The methodology is extended to deal with the problem of transmit beamforming in MIMO spatial multiplexing (SM) systems with a finite-rate feedback channel. Assuming a fixed number of spatial channels and equal power allocation, we extend the capacity loss based design criterion for designing the codebook of beamforming matrices. Using the criterion, we develop an iterative design algorithm that converges to an optimum codebook. Under the i.i.d. channel and high SNR assumption, the effect on channel capacity of the finite-bit representation of beamforming matrix is analyzed. Central to this analysis is the complex multivariate beta distribution and tractable approximations to the Voronoi regions associated with the code points. Furthermore, to compensate for the degradation due to the equal power allocation assumption, we propose a multimode SM transmission strategy wherein the number of data streams is determined based on the average SNR. This approach is shown to allow for effective utilization of the feedback bits. Based on the insights gained from the codebook design and analysis work, we are developing a general framework based on high resolution techniques from source coding to address dependence on number of bits, spatial correlation, mis-matched quantizers etc.

References:

J. C. Roh and Bhaskar D. Rao, “Performance Analysis of Multiple Antenna Systems with VQ-Based Feedback,” Thirty Eight Asilomar Conference on Signals, Systems and Computers, Pacific Grove, Nov. 2004.

J. C. Roh and B. D. Rao, "Vector Quantization Techniques for Multiple-Antenna Channel Information Feedback," International Conference on Signal Processing and

Communications (SPCOM), Bangalore, India. Dec. 2004.

J. C. Roh and B. D. Rao, “MIMO Spatial Multiplexing Systems with Limited Feedback,” IEEE International Conference on Communications. Seoul, Korea. May, 2005.

C. R. Murthy, J. Zheng and B. D. Rao, “Multiple Antenna Systems With Finite Rate Feedback,” Submitted to MILCOM 2005.

16:00 "Beamforming and Space-Time Coding for Ad-Hoc Networks"
» Hamid Jafakhani, UCI

GSRs: Li Liu, Javad Kazemitabar, Siavash Ekbatani

First, we consider the combination of space-time coding and beamforming.
We propose a new scheme based on super-orthogonal space-time trellis codes (SOSTTCs) for a close-loop transmission system, where quantized channel phase information is available at the transmitter. Then, we study the problem of connectivity in multiple-input multiple-output
(MIMO) fading ad-hoc networks. Based on a probabilistic analysis of achievable capacity on individual links of a random topology, we introduce a novel connectivity metric for wireless ad-hoc networks. Our metric is more sophisticated compared to previously proposed metrics of connectivity as it captures the effects of time-varying fading channel, power, and multiple antennas. Finally, we show that employing mobile nodes with multiple antennas enhances the connectivity of fading wireless ad-hoc networks.

References:

H. Yousefi'zadeh, L. Zheng, and H. Jafarkhani, "Rate Constrained Power Control in Space-Time Coded Fading Ad-Hoc Networks," IEEE Global Communications Conference (Globecom-04), Volume 5, pp. 2962 – 2966, Nov. 2004.

L. Liu and H. Jafarkhani, "Space-Time Trellis Coded Based on Channel Phase Feedback," IEEE International Conference on Communications (ICC-05), May 2005.

H. Jafarkhani, H. Yousefi'zadeh, and J. Kazemitabar, "Capacity-Based Connectivity of MIMO Fading Ad-Hoc Networks," submitted to Globecom 2005.

16:30 "A Route-Guided SIMO Data Forwarding Policy for Wireless Relays"
» Yingbo Hua, UCR

GSRs: Z. Ye and X. Tang

In mobile ad hoc networks where there is no access to backbone infrastructure of base stations, wireless relays are essential for communication between two remote sites. Wireless relays should be designed to reduce power consumption, transmission delay and packet loss rate. For many applications, a network should allow for transmission of

many packets through a pre-established route of relays. A policy for forwarding data over relays in a given route is as important as a protocol to discover the route. In this work, we consider a single-input and multiple-output (SIMO) data forwarding policy. The SIMO policy allows a transmitting node to address a packet to multiple receiving nodes in the route and then directs the highest-ranked receiving node with successful reception of the packet to become the next transmitting node. The SIMO policy takes the advantage of both a pre-established route and the small-scale random nature of link quality between any two nodes. We provide a detailed analysis to show that the SIMO policy can indeed be a better alternative to the conventional single-input and single-output (SISO) policy. The SIMO data link policy is applicable to networks of both single-antenna nodes and multiple-antenna nodes.

References:

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17:00	Conclusion » James Zeidler, UCSD
17:15	Government Caucus
17:45	Government Feedback to MURI Team
18:00	Reception