Distributed MIMO

Patrick Maechler

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Outline

1. Motivation: Collaboration scheme achieving optimal capacity scaling
2. Distributed MIMO
3. Synchronization errors
4. Implementation
5. Conclusion/Outlook
Throughput Scaling

- **Scenario: Dense network**
  
  Fixed area with \( n \) randomly distributed nodes

  Each node communicates with random destination node

  at rate \( R(n) \). Total throughput \( T(n) = nR(n) \)

- **TDMA/FDMA/CDMA:** \( T(n) = O(1) \)

- **Multi-hop:** \( T(n) = O(\sqrt{n}) \)


- **Hierarchical Cooperation:** \( T(n) = O(n) \)

Cooperation Scheme

- All nodes are divided into clusters of equal size
- Phase 1: Information distribution
  
  Each node splits its bits among all nodes in its cluster
Cooperation Scheme

- Phase 2: Distributed MIMO transmissions

  All bits from source s to destination d are sent simultaneously by all nodes in the cluster of the source node s
Cooperation Scheme

- Phase 3: Cooperative decoding

  The received signal in all nodes of the destination cluster is quantized and transmitted to destination d.

  Node d performs MIMO decoding.
Hierarchical Cooperation

- The more hierarchical levels of this scheme are applied, the nearer one can get to a throughput linear in \( n \).
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Distributed MIMO

- Independent nodes collaborate to operate as distributed multiple-input multiple-output system

- Simple examples:
  
  Receive MRC (1xN_r): \[ \tilde{y} = \tilde{h}x + \tilde{n}, \quad \hat{x} = \frac{\tilde{h}^*}{\| \tilde{h} \|} \tilde{y} = \| \tilde{h} \| x + \tilde{w} \]
  
  Transmit MRC (N_t x 1, channel knowledge at transmitter)

  Alamouti (2xN_r): STBC over 2 timeslots

  \[ Y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} - \begin{bmatrix} s_2^* \\ s_1^* \end{bmatrix} + n \]

  \[ \hat{s}_1 = h_1^* y_1 + h_2 y_2^* \]
  \[ \hat{s}_2 = h_2^* y_1 - h_1 y_2^* \]

- Diversity gain but no multiplexing gain

MIMO Schemes

- Schemes providing multiplexing gain:
  
  **V-BLAST:** Independent stream over each antenna
  
  **D-BLAST:** Coding across antennas gives outage optimality (higher receiver complexity)

\[ \tilde{y} = H\tilde{x} + \tilde{n} \]


MIMO Decoders

- Maximum likelihood: \( \hat{x}_{ML} = \arg\min_{x \in \chi}(|y - Hx|) \)
- Zero Forcing / Decorrelator: \( \hat{x}_{ZF} = H^*y, \quad H^* = (H^*H)^{-1}H^* \)
- MMSE: \( \hat{x}_{MMSE} = \left( H^*H + \frac{1}{SNR} I \right)^{-1} H^*y \)

Balances noise and multi stream interference (MSI)

- Successive interference cancelation (SIC)
Error Rate Comparison

- MMSE-SIC is the best linear receiver
- ML receiver is optimal
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Synchronization

- Each transmit node has its own clock and a different propagation delay to destination
  
  No perfect synchronization possible.
  → Shifted peaks at receiver

What is the resulting error, if any?
Simulation results

- Flat fading channel assumed at receiver
- No large BER degradation for timing errors up to 20% of symbol duration (raised cosine with $\alpha=0.22$)
Frequency-selectivity

- Synchronization errors make flat channels appear as frequency-selective channels
- Receivers for freq.-sel. channels can perfectly compensate synchronization errors
- Implementation cost is much higher!
Promising results for SIC receiver that samples each stream at the optimal point

Compensation of synchronization errors possible for independent streams (V-BLAST)
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Implementation

- Goal: Show feasibility of distributed MIMO Systems using BEE2 boards
- Focus on synchronization algorithms at receiver
  - Timing synchronization
  - Frequency synchronization
  - Channel estimation
- Complex decoders required
  - All linear decoders need matrix inversion
Implementation

- BEE2 implementation of 2x1 Alamouti (MISO) scheme currently under development
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Conclusion/Outlook

- Standard flat-channel MIMO decoders useable for synchronization errors up to 20% of symbol duration
- More complex decoders can compensate different delays also for higher errors

Outlook:

- BEE2 implementation of MIMO receiver
- Frequency synchronization methods
- Measure achievable BER on real system for given synchronization accuracy at transmitters