Scheduling and Pre-Conditioning in Multi-User MIMO TDD Systems

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Outline

- Introduction
- Prior Work
- System Model
- Pre-Conditioning Method
- Scheduling Strategy
- Numerical Results
- Conclusion
Introduction

- Multiple antennas provide throughput improvement
- Multi-user setting
  - Studied as Gaussian MIMO broadcast channel
  - Sum capacity achieved by Dirty Paper Coding
    [Caire-Shamai 2003, Viswanath-Tse 2003, Vishwanath-Jindal-Goldsmith 2003]
  - DPC characterizes capacity region
    [Weingarten-Steinberg-Shamai 2006]
- Possible issues: CSI assumption, complexity
- Are there more practical methods with no channel assumptions?
Prior Work

- Reduced complexity
  - Precoding techniques [Hochwald et al. 2005, Airy et al. 2006]
  - Opportunistic scheduling schemes [Jagannathan et al. 2006, Shen et al. 2006]
- Limited feedback from users [Yoo et al. 2007, Huang et al. 2007]
- Less training overhead if channel is slowly varying
- Estimation error is not significant if SINRs are high
Training in Multi-User MIMO

- Interested regime
  - Low SINRs – interference from neighboring cells
  - High mobility – aim of future wireless
- It is beneficial to increase the number of antennas at base station [Marzetta 2006]
- Key idea: Time Division Duplex (TDD)
  - Training on reverse link
  - Linear pseudo-inverse based pre-conditioning
- Assumption: Statistically identical users
Main Contributions

- Consider general setting
  - Heterogeneous users
  - Arbitrary weights assigned to users
- Account for training overhead and estimation error in net throughput given by
  \[ \frac{T - \tau - 1}{T} \sum_{i=1}^{K} w_i R_i \]
- Modified pre-conditioning technique
- Computationally efficient scheduling strategy
- Obtain lower bound on weighted-sum capacity using proposed schemes
Average power constraints at base station and users
- Channel entries are i.i.d. CN(0,1)
- Block fading over T symbols
- Reciprocal channel
- Frequency selectivity incorporated by OFDM
- Noise and interference are assumed to be Gaussian
Training and Channel Estimation

- Orthogonal training sequences
- Number of users $K$ must be less than $\tau$
- Base station obtains LMMSE estimate of channel
- Estimate is independent of the error
Scheduling and Pre-Conditioning

- Base station selects subset $S$ with $N$ users based on channel estimate
- Pre-condition the signals for these users
- Users do not have channel estimate
- How to design scheduler and precoder?
Modified Pre-Conditioning

- Assign positive values $p_1, p_2, \ldots, p_K$ to the users
- Pre-conditioning matrix is

$$A = \frac{\hat{H}_D^* \left( \hat{H}_D \hat{H}_D^* \right)^{\dagger}}{\sqrt{Tr \left[ \left( \hat{H}_D \hat{H}_D^* \right)^{\dagger} \right]}}$$

$$\hat{H}_D = diag[p_{S(1)}^{-0.5} \ldots p_{S(N)}^{-0.5}] \hat{H}_S$$
Lower Bound on Weighted-Sum Capacity

- Scheduling strategy: Any strategy which selects subset $S$ consisting of $N$ (fixed) users
- Theorem: A lower bound on downlink weighted-sum capacity is

$$C_{net} = \max_{\tau,N} \frac{T - \tau - 1}{T} \sum_{k=1}^{K} w_k \gamma_k (N, \tau) \log_2 \left( 1 + \frac{\rho_j^k p_k E^2[\chi]}{1 + \rho_j^k \left( \frac{1}{1 + \rho_j^k \tau} + p_k \text{var}[\chi] \right)} \right)$$

- Proof Idea
  - Convert to additive noise channel where the noise is uncorrelated with the signal
  - Lower bound by worst-case Gaussian noise
Optimization of Pre-Conditioning Matrix

- Assumptions: No scheduling, M large
- If $Z$ is $K \times M$ matrix with i.i.d. $\text{CN}(0,1)$ entries, then
  \[
  \lim_{M/K \rightarrow \infty} ZZ^* = MI_k
  \]
- Objective function
  \[
  J(p) = \sum_{i=1}^{K} w_i \log \left( 1 + \frac{b_i p_i}{\sum_{j=1}^{K} a_j p_j} \right)
  \]
- Theorem: A solution that maximize $J(p)$ is
  \[
  p_i^* = \left( \frac{w_i}{v^* a_i} - \frac{1}{b_i} \right)^+, \quad \sum_{i=1}^{K} a_i p_i^* = 1
  \]
Scheduling Strategy

- Variance of channel estimate depends on reverse SINR seen by that user and training length
- Normalize the rows of the channel estimate to obtain $Z$ with i.i.d entries
- Select $N$ users with largest $p_i^* |z_i|^2$
- Special Case: Homogeneous users with unit weights
  - Select $N$ users with largest estimated channel gains
Numerical Results: Homogeneous Users

- Forward SINR = 0dB
- Reverse SINR = -10dB
- Optimal training length
- Optimal number of users
Numerical Results:
Heterogeneous Users

- 8 users with forward SINRs of -4, -3, …, 3 dB
- Reverse SINR = Forward SINR - 10 dB
- T = 20 symbols
- Weight = 2 for first 4 users
- Unit weight for remaining 4 users
Conclusion

• Even with high interference and high mobility, effective utilization of multiple antennas can improve net throughput
• Importance of time division duplex
• Need to consider coherence interval while designing wireless systems
• Low complexity scheduling and precoding based schemes can give significant throughput gains