Real-time Multi-user MIMO Channel Sounding and Capacity Evaluations

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Multi-user MIMO (MU-MIMO) in a nutshell:

- Multiple antennas at base station
  + Channel state information at transmitter
  ↓
  Increased downlink capacity
$y_k = H_k x + n_k, \quad k = 0, \ldots, K - 1$

$H_k = H_{m,q,k}$ is the $M \times N$ MIMO channel matrix of user $k$ at time $m$ and frequency $q$
Introduction

- Theory tells us that [Gesbert 2007, Jindal 2005]
  - MU-MIMO performs \( \max(\min(N/M, K), 1) \) better than
  - is immune to propagation limitations plaguing
  - SU-MIMO

- But is that really so?
- In this contribution: Performance comparison using real channel measurements
The maximum sum rate in a MU-MIMO downlink (broadcast) channel is achieved by dirty paper coding (DPC) [Weingarten 2006]

The sum-rates of the MU-MIMO downlink and uplink (multiple access) channels are equivalent [Vishwanath 2003]

It can be computed by solving the convex optimization [Jindal 2005]

\[
C_{\text{DPC}} = \max_{Q_k \succeq 0, \sum_k \text{tr}(Q_k) \leq P} \log_2 \left| I + \sum_{k=1}^{K} H_k Q_k H_k^H \right|, \quad (1)
\]

where \(Q_i\) are positive semidefinite covariance matrices.
Multi-user Linear Precoding

- Linear precoding ($M = 1$): $x = \sum_{k=1}^{K} w_k s_k \Rightarrow$

$$y_k = h_k w_k s_k + \sum_{j \neq k} h_k w_j s_j + n_k$$

- The sum rate under linear precoding is

$$\mathcal{R}_{\text{linear}} = \sum_{k=1}^{K} \log_2 (1 + \text{SINR}_k)$$

$$\text{SINR}_k = \frac{|h_k w_k|^2}{\sum_{j \neq k} |h_k w_j|^2 + K \sigma^2 / P}$$
Multi-user Linear Precoding

- Regularized channel inversion (MMSE precoder)
  \[ W = H^H (HH^H + \beta I)^{-1}, \]
  where \( H = [h_1^T \ldots h_K^T]^T \)
- When \( \beta = 0 \) ⇒ Zero forcing (ZF) precoding
- MMSE allows a certain amount of multi-user interference
- MMSE better then ZF at low SNR, but asymptotically equivalent
EMOS Center Frequency: 1917.6 MHz
EMOS Bandwidth: 4.8 MHz
Number of Antennas at BS: $N = 4$ (2 cross polarized)
Eurecom MIMO Openair Sounder: Rx

Number of Users: $K = 4$
Number of Antennas at UE: $M = 2$
- OFDM sounding sequence with $Q = 160$ subcarriers
- Frame length = 2.667 ms
- BCH contains frame number for frame synchronization
- Pilot symbols derotated and averaged before channel estimation
  - Minimizes phase-shift noise
  - Increases SNR
Users were only allowed on routes with RSSI $> -90$ dBm
Normalization

- One measurement contains 18,700 frames (50 sec)
- The measured MIMO channel of each user $k$ is normalized such that

$$E\{\|H_k\|_F^2\} = MN,$$

where the expectation is taken over frames and subcarriers

$$\Rightarrow$$ constant mean SNR=10 dB at receivers
Capacity with one antenna/user

- Performance slightly worse in real channels (due to correlation)
Antenna selection can be used to increase performance
Same asymptotic behavior for synthetic and measured channels
Conclusions

- Performance of MU-MIMO worse in measured channels (due to correlation)

- Measurements confirm theory, e.g., for $M = 1$ at high SNR
  - MU-MIMO MMSE 2.7 times better than SU-MIMO TDMA
  - MU-MIMO DPC 3.2 times better than SU-MIMO TDMA

- MU-MIMO MMSE with $M = 1$ better than SU-MIMO TDMA with $M = 2 \Rightarrow$ simplified receiver design

- CSIT can be achieved by feedback or reciprocity
Thank you for your attention!


