Signal processing techniques for multi-antenna systems

Ongoing collaborations of CNIT-Politecnico di Milano

- **CWC - University of Oulu**: *Subspace tracking for soft-iterative channel estimation in turbo-equalization* (6-month exchange of 1 Master student)

- **Signal and Systems – Uppsala University**: *Geometrical approach for spatial multiplexing in MIMO-OFDM broadcast systems* (6-month exchange of 1 PhD student).

- **UPC and CTTC - Barcellona**: *Statistical approach for broadcast opportunistic beamforming systems*

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Subspace tracking for soft-iterative channel estimation in turbo-equalization

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T. Matsumoto (CWC-UoO)
**Block-based convolutionally coded transmission system**

- **Convolutional Encoder**
- **Framing**
- **Symbol Mapper**
- **Data**
- **Training (L blocks)**
- **Channel estimator**
- **SISO equalizer**
- **SISO decoder**
- **Channel estimator**
- **SISO equalizer**
- **SISO decoder**

- **Multipath channel model**

- **Space-Time channel matrix:**
  \[
  \mathbf{H}_i = \mathbf{A}_i \cdot (\mathbf{a}^{(R)}_d \otimes \mathbf{a}^{(R)}_d) \cdot \text{diag}\{\mathbf{\beta}_d\} \cdot \mathbf{O}_d^{1/2} \mathbf{G}^{(t)}_d^T \quad (N_rN_T \times W)
  \]

- **Antenna arrays gains**
- **Fading amplitudes**
- **Power profile**
- **Delay profile**

**CNIT-Polimi, Newcom Cluster 2 Meeting, Barcelona 3-4 Nov. 2005**
Subspace-based channel model

Different varying rates between angles/delays and amplitudes

\[ \hat{H}_f = A'(\alpha_{(R)}, \alpha_{(T)}) \cdot \text{diag}\{\beta_f\} \cdot \Omega^{1/2} \cdot G(t) (N_r N_f \times W) \]

Rearrangement of the parameters to separate slow/fast varying components:

\[ \hat{H}_f = U_S G U_T^T \]

Soft-in adaptive channel estimation based on the subspace model:

- Slow tracking of the channel subspace by subspace and rank tracking algorithms
- Use of soft-valued information data (available in turbo receivers) to refine the channel estimate

Adaptive Soft-in Channel Estimator/1

MSE comparison between soft-in channel estimation methods:
- Least squares (LS) burst by burst
- Adaptive subspace-based method by subspace and rank tracking
- Batch implementation of the subspace-based method by EVD

1) The MSE of the subspace tracking method is always lower than that of LS method and it is close to performance obtained by EVD
2) A transitory is required for rank adaptation when one path is disappearing/appearing, due to the forgetting factor

- SNR = 6 dB
- \( N_t W + 46 \) training symbols
- 10 frames with \( L=20 \) blocks
- \( N_d = 200 \) data symbols
- QPSK modulation
- Rayleigh fading channel (\( W=10 \))
1) The BER performance of the subspace-rank tracking method is always close to that of the EVD batch implementation.

2) The BER performance of the subspace-rank tracking method at 3rd iteration is close to that of the turbo equalizer with perfect channel knowledge.

3) When r=2, ISI effects due to multipath are effectively reduced by the soft-iterative processing already at 3rd iteration.

- SNR = 6 dB
- N_t - W - 1 = 46 training symbols
- 10 frames with L = 20 blocks
- N_d = 200 data symbols
- QPSK modulation
- Rayleigh fading channel (W = 10)

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**Geometrical approach for spatial multiplexing design in MIMO-OFDM broadcast systems**

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M. Sternard (Uppsala University)
**Spatial Multiplexing**

2 users with non-overlapping spatial beams

2 users with overlapping spatial beams

Users belonging to overlapping spatial beams should be spread over time and/or frequency

**Problem statement for broadcast/1**

Assumptions

- Limited angular spread $\Phi$ at the BS
- One main direction of departure (DOD)
- Flat fading over one time-frequency bin (MIMO OFDM system, $N$ frequency bins)
- Slow varying terminal positions
- Full CSI at the receiver, limited transmission rate for the feedback channel
- $N_t \geq 3$ transmit antennas

Target

- Spatial multiplex of $M$ independent streams for the downlink to $M$ users

$rank(H_i) \equiv 1$
**Problem statement for broadcast/2**

The $N_c$ signal received by the $k$-th user ($k = 1, \ldots, M$), on a single sub-carrier and within a single OFDM symbol:

$$y_k = P_k^{1/2} H_k w_k c_k + \sum_{m=1,m \neq k}^M P_m^{1/2} H_m w_m c_m + n_k$$

Steering vector

$$H_k = v_k \cdot b^H (f_k)$$

- Limited angular spread at the BS
- One main direction of departure (DOD) from BS to each users

$$[b(f)]_k = \frac{1}{\sqrt{N_r}} \exp \left( -j\frac{2\pi f}{\lambda} (m-1)\Delta \right)$$

$$f_k = \cos(\alpha_k)$$

Each users feeds back to the BS the estimated SINR and the spatial frequency $\hat{f}_k$ for each sub-carriers group

$$\hat{f}_k = \arg \min_f \left\| H_k - v_k \cdot b^H (f) \right\|^2 = \arg \max_f \left( b^H (f) H_k^H H_k b(f) \right)$$

Frequency estimate

**Scheduling and Precoder Design**

Among all possible user subsets $\mathcal{X} = \{k_1, \ldots, k_M\}$ with spatial frequencies $\{f_{k_1}, \ldots, f_{k_M}\}$ choosethe user subset $S = \{k_i, \ldots, k_{i_M}\}$ such that:

$$S = \arg \max_{S} (S)$$

s.t. $\gamma(S) = \max \gamma(S), \ L(S) > \beta$

$\gamma(S)$ is a throughput measure (function of feedback SINRs) over subset $S$. $L(S) = \min_{\hat{f}_k} |\hat{f}_k - \hat{f}_{k_M}|$

Comparison with a Switched Beams technique (GoB) and interference free case

- *Zero-Forcing precoder at the BS*
  
  $W = [w_{k_1}, \ldots, w_{k_M}] = B (B^H B)^{-1}$
  
  $B = [b(f_{k_1}), \ldots, b(f_{k_M})]$

- *MVDR beamforming at each receiver*
Statistical approach for broadcast opportunistic beamforming schemes*

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* Integration with Work Project E “Multiuser diversity and cross layer-design”

Ongoing activities

Opportunistic beamforming (OB)

- Enhancement of conventional opportunistic schemes by capitalizing on LT-CSI at the transmitter \( \mathbf{R}_i = \mathbb{E}[\mathbf{h}_i \mathbf{h}_i^H] \) \( \forall 1 \leq i \leq N \)
- Design of limited feedback schemes
- Asymptotic performance (for large number of users \( N \))
- Adaptive selection of the number of beams \( M \)
User clustering based on covariance feedback

Opportunistic schemes capitalizing on the spatial covariance

- Previous proposal: **eigenbeamforming (EB)** to each users in different time slots.
- Proposal: enhance the multiuser diversity by clustering users according to their spatial properties

Users $i$ and $j$ are said compatible if $\text{span}(R_i) = \text{span}(R_j)$

We propose the following metric to measure the compatibility of each couple $(i,j)$ of users

$$
\eta_{i,j} = \frac{\text{tr}(R_i R_j^H)}{\sqrt{\text{tr}(R_i^H R_i) \text{tr}(R_j^H R_j)}}
$$

Users Clustering

A tree-based approach groups the users in $G$ clusters $C_i$ containing compatible users, such as

$$
\eta_{i,j} = 1 \text{ if } i,j \in C_k
$$

Multiuser diversity strategy

Each cluster $C_i$ is served by a single beam $u_k$

The long term average scheduled SNR employing PF scheduling is

$$
\text{SSNR} = \frac{1}{N} \sum_{k=1}^{G} \sum_{i \in C_k} \frac{w_i^H R_i w_i}{\sigma_i^2}
$$

Optimum precoding is the eigenbeamforming to the cluster covariance

$$
w_k = \max \left\{ \text{eig} \left( \frac{R_i}{\sigma_i^2}, \ldots, \frac{R_{|C_k|}}{\sigma_{|C_k|}} \right) \right\}
$$

Advantages

- Throughput improvement
- Feedback reduction: only the users belonging to the cluster $k$-th are required to report the SNRs.

$$
G=1 \text{ (Single cluster)}
$$

Low cluster SNR, high diversity gain.

$$
G=N \text{ (Single user clusters)}
$$

High cluster SNR, low diversity gain

Adaptive selection of the number of clusters
**Numerical results**

Comparison between Cluster Eigenbeamforming (Clust-EB), Eigenbeamforming (EB) and OB:

![Graph showing sum-rate vs. antennas for different clusters and users]

- $N = 30$ users, ring scatter correlation model with angular spread $\phi_i = \phi = 0.1 \forall i$
- System SNR $\mu = 1 / \sigma_i \forall i \leq N$

Feedback saving due to users clustering, $N=10, 30, 50, 70$.

![Graph showing feedback saving]

**Multiplexing strategy**

The scheme has been enhanced to spatial multiplexing:

- Design $G$ clusters $C_i$ containing quasi-orthogonal users, such as $\eta_{i,j} = 0$ if $i,j \in C_i$
- In each time slot the BS transmits $K=|C_i|$, eigenbeamforming vectors corresponding to the users of cluster $C_i$
- Users scheduling performed by proportional fair algorithm

- Effective for $K>M$ as the clustering technique has enough degrees of freedom to select orthogonal users

![Graph showing sum-rate vs. SNR for different multiplexing schemes]

- $N=30$ users, $M=8$ antennas, ring scatter correlation model