MAXIMUM EXPECTED ACHIEVABLE RATE COMBINING FOR LIMITED FEEDBACK BLOCK-DIAGONALIZATION

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Contributions
- Downlink MU-MIMO transmission with limited feedback
- Receive antennas: antennas per user > streams per user
- Block-diagonalization precoding over channel subspaces

We propose:
- Novel "blind" channel subspace selection strategies
- Corresponding receive antenna combiners

We compare to existing schemes

Block-diagonalization precoding [1]
Transmit strategy: block-diagonalization precoding
\[ B_n = \text{null}(\bar{P}_n) = \left[ H_1, \ldots, H_{L-1}, H_{L+1}, \ldots, H_N \right] \]
\[ F_n = \sqrt{\frac{P}{L}} F_n \] \[ \bar{P}_n = \text{span}(B_n H_n) \] zero interference after RX antenna combining in case of perfect CSI at the TX
Achievable rate with imperfect CSI at the TX
Decompose the channel into \( u \)
\[ H_n = \left( \hat{H}_n H_n^H + (I - \hat{H}_n H_n^H) \right) \]
Interference is received over \( H_n^H \)
\[ R_u = \log_2 \left( 1 + \| H_n^H F_n H_n \| \right) \]

Interference aware MMSE reception [2]

MMSE receiver design criterion
\[ G_u = \arg \min_{G_u} \mathbb{E} \left( \| x_n - G_u y_n \|_2^2 \right) \]
\[ G_u = \left( \hat{H}_n H_n^H F_n H_n + \sum_{l \neq n} H_l H_l^H F_l H_l \right)^{-1} \]

Simulation setup
Channel model: spatially correlated Rayleigh fading
\[ H_n = H_n C_n^{1/2}, \quad \left[ H_n \right]_{i,j} = \mathcal{N}(0, 1) \]
Number of transmit antennas: \( N_t = 8 \)
Number of receive antennas: \( N_r = 4 \)
Number of streams per user: \( L = 2 \)
Number of users: \( U = 4 \)
Number of feedback bits: \( B \approx [7, 14] \) bit
Antenna correlation:
\[ C_r = \begin{bmatrix} 1 \alpha_r & \alpha_r & \alpha_r & \alpha_r \\ \alpha_r & 1 \alpha_r & \alpha_r & \alpha_r \\ \alpha_r & \alpha_r & 1 \alpha_r & \alpha_r \\ \alpha_r & \alpha_r & \alpha_r & 1 \end{bmatrix} \], \alpha_r = 0.9

System model
Input-output relationship
\[ r_n = G_n^H y_n \in \mathbb{C}^{L \times 1} \]
\[ y_n = H_n^H F_n x_n + H_n^H \sum_{j \neq n} F_j x_j + z_n \in \mathbb{C}^{L \times 1}, \quad \| z_n \|_2 = 1 \]

Channel, precoding matrices and additive noise
\[ H_n^H = H_n G_n \in \mathbb{C}^{N_t \times L}, \quad H_n \in \mathbb{C}^{N_t \times L} \]
\[ F_n \in \mathbb{C}^{N_t \times L}, \quad \text{tr} \left( F_n F_n^H \right) = P_L / U \]

Achievable sum rate [bit/s/Hz]
\[ \frac{1}{N_t} \sum_{n=1}^{N_t} \log_2 \left( 1 + \left( \begin{array}{c} \| H_n^H \| \end{array} \right)^2 \right) \]

Maximum eigenmode transmission [3]
Transmission over the \( L \) maximum eigenmodes
\[ H_n^M_{\text{MET}} = \sum_{l=1}^{L} \left( \mathcal{S}_n \right)_{r,l} \quad \mathcal{S}_n = \left( \begin{array}{c} \| H_n \| \end{array} \right)^2 \]

Required CSI feedback for BD over \( H_n \):
Grassmannian quantization is applicable
\[ H_n = \arg \min_{Q \in \mathcal{Q}_{n}} d^2(Q, U_n) \]
Minimum choral distance quantization [4]
\[ d^2(Q, U_n) = \| Q - U_n \|_F^2 - \text{tr} \left( Q^H U_n^H (U_n^H)^H Q \right) \]
\[ d^2(Q, U_n) = \| Q \|_F^2 - \text{tr} \left( Q^H U_n^H (U_n^H)^H Q \right) \]

Feedback bit-encoding with VQ [5]: \( L(N_t - L) \)

Performance with interference unaware antenna combining

Causal chain of events:
1. Each user blindly decides for an \( L \)-dimensional subspace for which precoding is performed \( H_n \in \mathbb{C}^{N_t \times L} \)
2. CSI feedback: quant. orthonormal basis \( H_n \) for span\( (H_n^H) \)
3. Precoder calculation for \( H_n \)
4. Detection at the users

Advantage: reduced feedback overhead and complexity
Disadvantage: suboptimal

Maximum expected achievable rate combining
Consider the achievable rate
\[ R_u = \log_2 \left( 1 + \| G_n^H H_n \| \right) \]
\[ S_u = \mathbb{E} \left( F_n x_n^2 \right) \]

\[ C_u = \sum_{l \neq n} \log_2 \left( 1 + \| C_r^H H_n \| \right) \]

Exploit excess antennas to reduce feedback overhead
\[ \left\{ H_n, G_n^{(\text{SQBC})} \right\} = \arg \max_{Q \in \mathcal{Q}_{n}} \text{d}^2(Q, U_n) \]

Independent channel subspace quantization
\[ H_n = \arg \min_{Q \in \mathcal{Q}_{n}} d^2(Q, U_n) \]

SQBC antenna combiner
\[ G_n^{(\text{SQBC})} = H_n^H H_n \]
\[ H_n^H = (H_n^H)^{-1} H_n^H \]
Reduced feedback bit-encoding [5]: \( L(N_t - L) \)

Performance with interference aware antenna combining

References

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