CQI-report optimization for multi-mode MIMO with unitary codebook based precoding

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Introduction

- In MIMO downlink transmission the base station selects the transmission mode (single user, multiuser) and the transmission parameters (rate, antennas weigths) based on feedback from the users.
- There is tradeoff between amount of feedback and performance of the downlink transmission.
- In this presentation, we consider channel quality indication (CQI) reporting problem in a MIMO downlink system with adaptive switching between single user and multiuser mode.
- CQI is a feedback report of n bits that indicates the transmission rate that can be supported by the user.
- The value of CQI is different for single user and multiuser transmission modes.
- To reduce the amount of feedback we consider differential CQI for the multiuser mode, where the offset levels are optimized.

CQI for multi-mode MIMO

- As the CQI report indicates the modulation and coding to be used by the base station it has to be relative to the SINR experienced by the UE.
- CQI taken to be a quantized value of the SINR after receiver processing.
- If the CQI is incorrect it results in suboptimum rate adaptation.
- Especially if the CQI is too optimistic, the selected transmission rate is too high which may result to 0 throughput for that transmission.
- SINR for the single user mode is higher than for the multiuser mode due to
  - power splitting between users
  - multiuser interference

System model

- We consider a single cell MIMO downlink system with N_u users , each having N_r receive antennas.

- The base station has N_t antennas and transmits simultaneously single stream $(N_\mathrm{s} = 1)$ to K users.

- The signal $\mathbf{y}_k$ received by the k:th user reads

$$\underset{N_\mathrm{r}\times 1}{\mathbf{y}_k} = \underset{N_\mathrm{r}\times N_\mathrm{t}}{\mathbf{H}_k} \underset{N_\mathrm{t}\times(N_\mathrm{s}\times K)}{\mathbf{W}} \underset{(N_\mathrm{s}\times K)\times 1}{\mathbf{s}} + \underset{N_\mathrm{r}\times 1}{\mathbf{n}_k}, \tag{1}$$

  where $\mathbf{H}_k$ is the MIMO channel between the base station and user k, $\mathbf{W}$ is the unitary precoding matrix, $\mathbf{s}$ contains the transmitted symbols and $\mathbf{n}_k$ is the noise vector.

Unitary multiuser precoding

- SVD of a general MIMO channel matrix $\mathbf{H}$ of size $M \times N$, $M \leq N$, results in $\mathbf{H} = \mathbf{U}\Sigma\mathbf{V}^{\mathrm{H}}$.

- Each user selects the precoding vector from a predefined codebook that best matches the channel i.e minimizing the chordal distance between $\mathbf{w}_{k,opt}$ and the first eigenvector in $\mathbf{V}_k$.

- The multiuser precoding is unitary when the selected precodnig vectors are orthogonal

$$\mathbf{W} = \left[\mathbf{w}_{1,opt}\ \mathbf{w}_{2,opt}\ \ldots\ \mathbf{w}_{K,opt}\right]. \quad (2)$$

- The amount of multiuser interference for user k depends on $\mathbf{W}$, thus on the selected pairs.

Differential CQI-reporting

- Generally, there are several options for the orthogonal pair depending on the choices in the precoding codebook.

- It follows that are at least two options for indicating the multiuser specific CQI.

- One options is that the UE feeds back a relative CQI per possible orthogonal pair.

- The other option is that the UE calculates an average SINR over all possible pairs and report a single relative CQI based on that.

Differential CQI-reporting

- The SU-CQI is reported as full CQI with 4 bits.
- The relative MU-CQI is reported with 0-2 bits.
- 0 bit MU-CQI report means that the base station substracts a known offset from the SU-CQI.
- For 1-2 bits, the offset levels are optimized by maximizing expected throughput.

CQI optimization I

- The offset optimization is done based on the SINR differences distribution between single user and multiuser SINRs.
- For 0 bit quantization the offset level is found by maximizing the throughput for the multiuser mode

$$\mathrm{E}_{-\infty}^{0}(s) = \int_{-\infty}^{0} d\delta \; \mathrm{p}(\delta) \; \mathrm{T}(b_s - s, \gamma_s + \delta) \tag{3}$$

  - δ is the SINR difference ranging from $-\infty$ to 0
  - γ_s is the single user CQI
  - b_s is the rate of the single user mode corresponding to the rate that maximizes the throughput
  - s is the offset level
  - $b_s - s$ is the multiuser transmssion rate in bits/s/Hz
- The offset level depends on the current value of γ_s

CQI optimization II

- For 1-bit quantization the integral is divided into two parts

$$\mathrm{E}_{-\infty}^{\delta_1}(s_1) + \mathrm{E}_{\delta_1}^{0}(s_2) \tag{4}$$

  - s_1 and s_2 are the relative offset levels corresponding to bit values 0 and 1.
  - δ_1 is a switching point between s_1 and s_2.

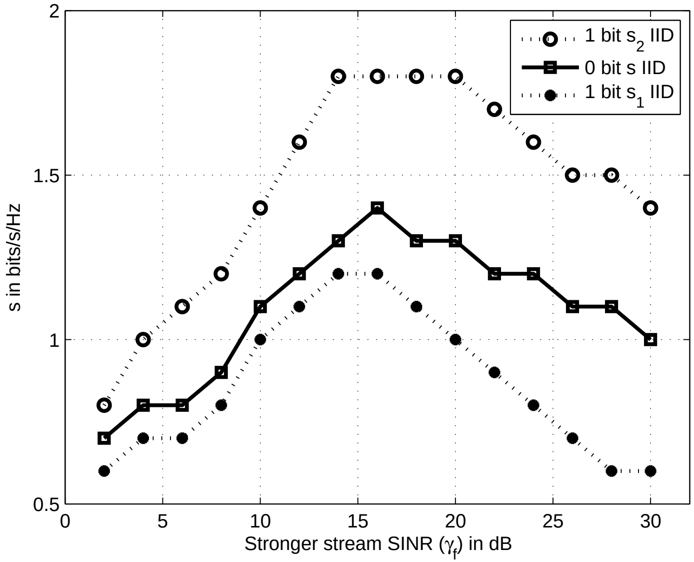
- The decision between the s_k is made based on whether the multiuser mode SINR value at UE is smaller or larger than δ_1.

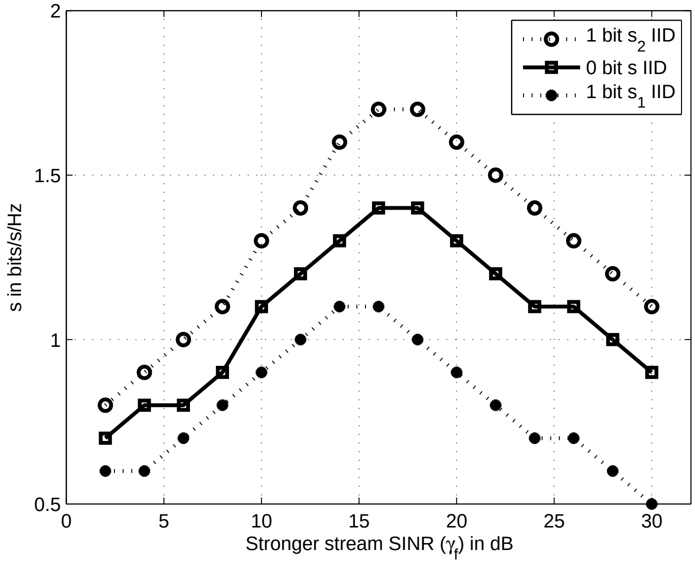
- The optimum rate differences and threshold are found by maximizing this sum.

- For simplicity we consider common switching points for all values of s_1 and s_2.

- For 2-bit quantization the integral is divided into four parts.

Optimization results

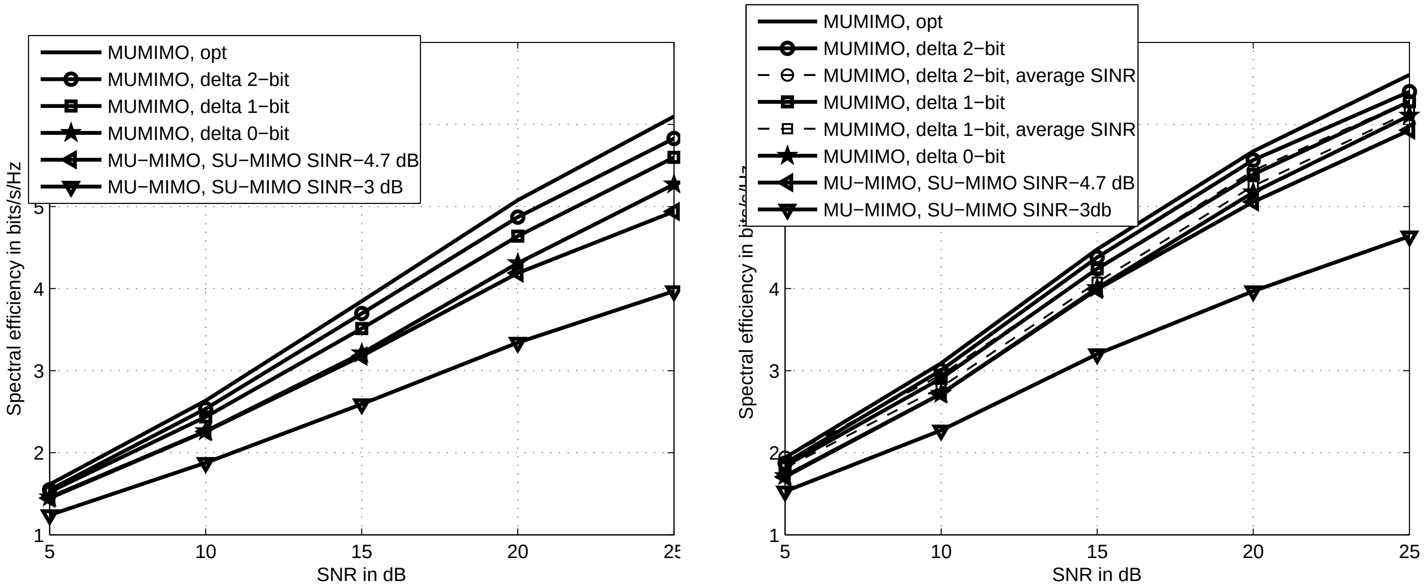




Simulation assumptions

- Simulations are done for 2×2 and 4×2 MIMO in i.i.d. flat Rayleigh fading channels.
- Precoding is unitary using single stream codebooks considered for LTE Rel. 8.
- For modulation and coding we consider adaptive M-QAM with punctured turbo coding of rate y.
- The base station selects one user randomly and then an orthogonal pair from a pool of 19 users so that the sum rate is maximized.
- The UE uses an MMSE receiver to cancel the interference from the paired user.
- All users are assumed to share the same average SNR.

Simulation results



Conclusions

- Even if the UEs perform spatial interference cancellation with an MMSE receiver the remaining interference needs to be taken into account in the multiuser transmission.
- Not accounting for the multiuser interference leads to clear performance degradation.
- Optimizing the zero-bit offset provides performance gain in medium to high SNR.
- The proposed 1-2 bit optimum quantization provides gain over zero-bit optimized offset that depends on the antenna configuration and the usage of these quantization levels.
- When transmit correlation is present, the ability of the unitary precoder to orthogonalize of the user's channel is more relevant.

Back up slide

- For modulation and coding we consider adaptive M-QAM with punctured turbo coding of rate y. The transmission bit rate is then $b = y * 2^M$, where M is the constellation size.

- The expected throughput for user k as a function of a post processing SINR γ_k reads

$$\mathrm{T}_k(\gamma_k, b_k) = b_k \left(1 - \mathrm{P_e}(\gamma_k, b_k)\right),$$

where b_k is the rate for user k and $\mathrm{P_e}$ is the block error probability.

- The performance is evaluated in an AWGN channel using the following continuous function

$$\mathrm{P_e}(\gamma, b) = 1 - \left[\frac{1}{1+\exp(-c_1\gamma + c_2 + c_3 b + c_4 b^2 + c_5 b^3)}\right]^{c_6 b}$$

where $c_j,\ j = 1, ..., 6$ are constants having values [5.34 -37.31 44.98 -7.25 0.64 9.72] for block size of 1024 symbols.

- The function covers 4-QAM, 16-QAM and 64-QAM.