An Adaptive Modulation Precoding Scheme for Mean BER Minimisation of ISI MIMO Channels

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Introduction

- With the increased demand for high-quality wireless communication services and the scarcity of available radio spectrum, MIMO technology is becoming indispensable and is therefore e.g. an integral part of the long term evolution (LTE) of 4G mobile communication systems
- These systems are characterised by broadband MIMO channels where both spatial and temporal interferences exist
- In order to achieve its anticipated multiplexing gain and provide high data rates, a sophisticated transceiver design is aimed to mitigate these MIMO interferences
- Broadband MIMO channels can be decoupled into a number of frequency selective (FS) SISO subchannels with ordered qualities using polynomial singular value decomposition (PSVD) [McWhirter2007], i.e., mitigating the spatial interference
- Temporal interference can then be mitigated using the well-known non-linear Tomlinson-Harashima Precoding (THP)
- An adaptive bit loading scheme is therefore proposed to minimise the mean BER while achieving a target data rate across the resultant SISO subchannels

PSVD Review

The ISI MIMO channel matrix $\mathbf{H}(z)$ can be decoupled into a number $N = \min(N_t, N_r)$ of FS SISO subchannels using the PSVD algorithm which leads to the decomposition

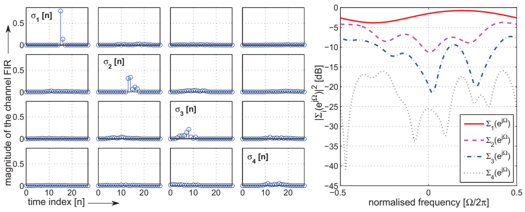
$$\mathbf{H}(z) = \mathbf{U}(z)\Sigma(z)\tilde{\mathbf{V}}(z), \quad (1)$$

where $\mathbf{U}(z) \in \mathbb{C}^{N_r \times N_r}(z)$ and $\mathbf{V}(z) \in \mathbb{C}^{N_t \times N_t}(z)$ are paraunitary matrices and $\Sigma(z) \in \mathbb{C}^{N_r \times N_t}(z)$ is a diagonalised and spectrally majorised matrix containing the FS SISO subchannels such as

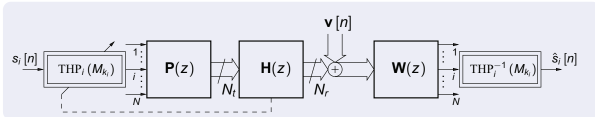
$$\Sigma(z) = \mathrm{diag}\{\Sigma_1(z), \Sigma_2(z), \cdots \Sigma_N(z)\} \quad (2)$$

The spectral majorisation property of the PSVD algorithm guarantees the SISO subchannels ordering such as

$$\Sigma_1(e^{j\Omega}) \geq \Sigma_2(e^{j\Omega}) \geq \cdots \geq \Sigma_N(e^{j\Omega}) \; \forall \Omega \quad (3)$$



System Model & Problem Formalisation



In this proposal, we are interested in achieving a target data rate R while minimising the mean BER $\overline{\mathcal{P}}_b$ of the overall broadband MIMO transmission. This problem can be formulated as:

$$\text{Minimise} \quad \overline{\mathcal{P}}_b = \frac{\sum_{i=1}^{N} b_i \mathcal{P}_{b,i}}{\sum_{i=1}^{N} b_i} \quad (4a)$$

$$\text{Subject to} \quad \begin{cases} \sum_{i=1}^{N} b_i = R, \\ 0 \leq b_i \leq b^{\max}, 1 \leq i \leq N, \end{cases} \quad (4b)$$

where b_i and $\mathcal{P}_{b,i}$ are, respectively, the number of bits and BER of the ith subchannel, while $b^{\max} = \log_2 M_K$ is the maximum permissible number of bits per subchannel. The theoretical BER $\mathcal{P}_{b,i}$ in (4a) of M-ary QAM modulation is given by [Goldsmith2005]

$$\mathcal{P}_{b,i} = \mathcal{F}(\gamma_i, M_{k_i}) = \frac{1-\left[1-2\left(1-\frac{1}{\sqrt{M_{k_i}}}\right)Q\left(\sqrt{\frac{3\gamma_i}{M_{k_i}-1}}\right)\right]^2}{\log_2 M_{k_i}} \quad (5)$$

Bit Loading Schemes

1. **Uniform Bit Loading (UBL)**
The easiest and most straightforward method is to uniformly distribute the total target bit rate R across all subchannels $i, 1 \leq i \leq N$, i.e., $b_i = R/N$
2. **Heuristic Bit Loading (HBL)**
This scheme, in general, considers the allocation of transmission symbols of the higher QAM orders to stronger subchannels while weak subchannels are loaded with lower QAM orders or even left inactive. HBL is assigned according to the Table below [Al-Hanafy2009]

data rate, R	8 bits	16 bits	24 bits
subchannel # 1	16-QAM	64-QAM	256-QAM
subchannel # 2	QPSK	64-QAM	256-QAM
subchannel # 3	QPSK	16-QAM	64-QAM
subchannel # 4	"off"	"off"	QPSK

3. **Adaptive Bit Loading (ABL)**
The ABL scheme adaptively allocates data bits according to the SISO subchannel SNRs γ_i, obviously, the strongest subchannel will demonstrate the best BER performance. The ABL algorithm is shown in the next Table

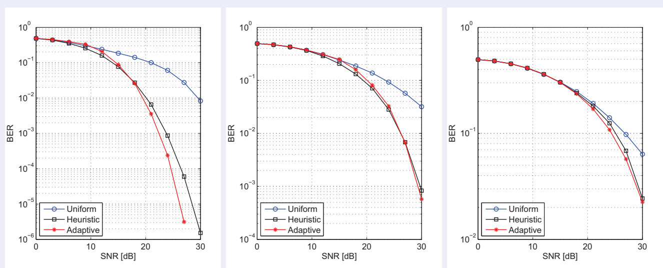
Adaptive Bit Loading (ABL) Algorithm

Input: $M_k, 0 \leq k \leq K$, $b^{\max}$, and $\gamma_i, 1 \leq i \leq N$ **Output:** b_i and $M_{k_i} = 2^{b_i}$

- Initiate all subchannels $i, 1 \leq i \leq N$ with $b_i = 0$, $k_i = 0$, and $\mathcal{P}_{b,i} = \mathcal{F}(\gamma_i, M_1)$ using (5)
- **while** $\sum_{i=1}^{N} b_i < R$
  - $j = \underset{1 \leq i \leq N}{\operatorname{argmin}} \left(\mathcal{P}_{b,i}\right)$
  - $k_j = k_j + 1$
  - **if** $k_j = 1$
    - $b_j = \log_2 M_1$, $\mathcal{P}_{b,j} = \mathcal{F}(\gamma_j, M_2)$
  - **elseif** $k_j < K$
    - $b_j = b_j + \log_2 \frac{M_{k_j}}{M_{k_j-1}}$, $\mathcal{P}_{b,j} = \mathcal{F}\left(\gamma_j, M_{k_j+1}\right)$
  - **else**
    - $b_j = b_j + \log_2 \frac{M_{k_j}}{M_{k_j-1}}$, $\mathcal{P}_{b,j} = +\infty$
  - **end**
- **end**

Performance Results

BER performance of different bit loading schemes



Performance results for a 4×4 PSVD-THP MIMO system for data throughputs of 8 bits (left), 16 bits (middle), and 24 bits (right) using square QAM modulation schemes of orders $M = 2^b, b \in \{2, 4, 6, 8\}$, where $b^{\max} = 8$ bits

Conclusions

Concluding Remarks

- A broadband MIMO precoding scheme with adaptive bit loading is proposed to minimise the mean BER performance under a target data rate and fixed QAM modulation schemes constraints
- The proposed scheme considers the polynomial singular value decomposition (PSVD) technique followed by a non-linear SISO-THP scheme to remove both CCI and ISI and obtain an equivalent SISO subchannels system
- Adaptive bit loading (ABL) is proposed based on these SISO subchannel SNRs and tries to allocate bits across subchannels to achieve the target data rate with a minimised mean BER
- Simulation results show that better mean BER performance of the ABL is achieved compared to other schemes of uniform and heuristic bit loading