UEP MIMO-OFDM with Beamforming- Combining for Imperfect Channel Information

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Outline

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Realizing UEP

- **UEP**: invokes the need for non-uniform error protection.
- **OFDM**: suitable for adapting individual subcarriers using different data rates, code rates, and powers
- **MIMO**: has high multiplexing gain and allows for channel layering.
- **UEP MIMO-OFDM**: devotes an arbitrary number of bits to different classes, eigenbeams, and subcarriers

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Why UEP ?

Equal Error Probability

Unequal Error Probability

- Source encoders deliver data of different importance.
- Matching the channel variations to enhance performance & capacity.
- Different error sensitivities of different communication devices.

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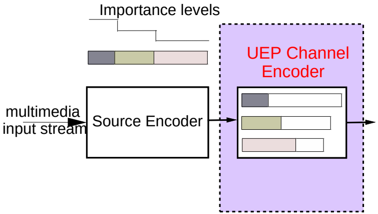
UEP Schemes in MCM

UEP coding layer

Adapt coding scheme/rate (i.e., use puncturing or pruning)

UEP physical layer

Adapt bit/power loading and physical transport, e.g.: MIMO channel



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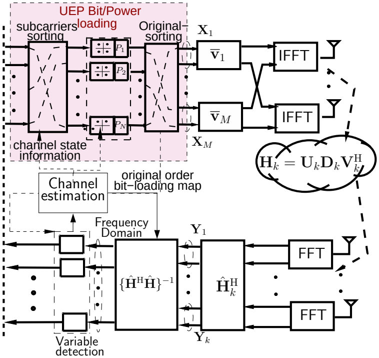

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Bit-Loading Algorithms

Bit-loading solutions:

- Optimum: add bits to the locations of minimum incremental power, e.g.: Hughes-Hartogs and Campello
- Sub-optimum: based on Shannon capacity (**Chow et al.**) or probability of error minimization (Fischer-Huber and Yu-Willson)

Bit-Loading by Chow (BRMP):

$$b_k = \log_2\left(1 + \frac{\text{SNR}_k}{\gamma}\right)$$

Quantization Error:

$$\begin{aligned} \hat{b}_k &= \lfloor b_k + 0.5 \rfloor_0^{b_{\max}} \\ \Delta b_k &= b_k - \hat{b}_k \end{aligned}$$

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MIMO UEP Bit-Loading (BRMP):

$$b_{k,l}^{(j)} = \log_2\left(1 + \frac{P_{k,l}^{(j)} \cdot \lambda_{k,l}^{(j)}}{\sigma^2 \cdot \gamma^{(j)}}\right)$$

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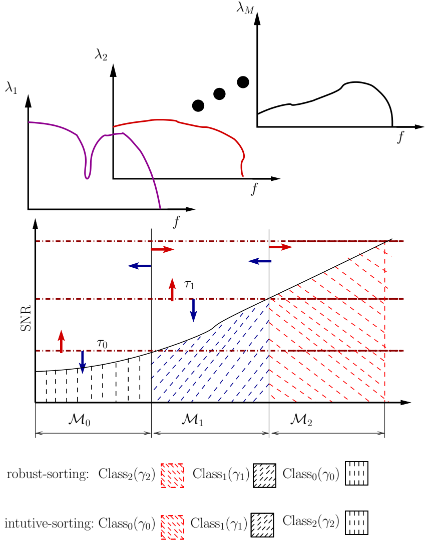
UEP Bit-Loading and SNR-Sorting Algorithms

- Compute $b_{k,l}^{(j)}$ using $\gamma^{(j)} = \gamma_0 - j \cdot \Delta\gamma$, then adjust $\mathscr{M}^{(j)}$ iteratively unit $\sum_{k,l} b_{k,l}^{(j)} = T^{(j)}$ or maximum iteration
- If B_T is not achieved, update γ_0 and recompute. If maximum iterations, add/subtract bits according to $\Delta b_k^{(j)}$
- The power is allocated according to SER. If the target SER is not fulfilled, reduce the total rate



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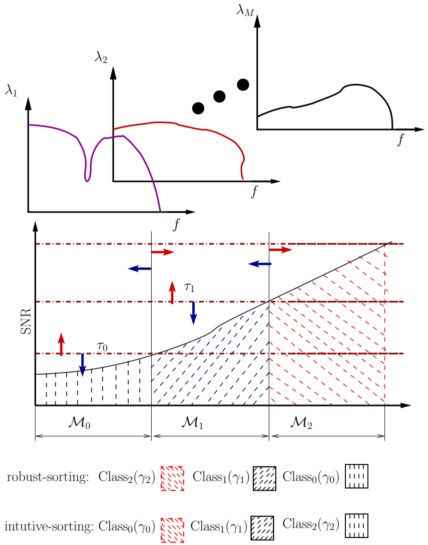

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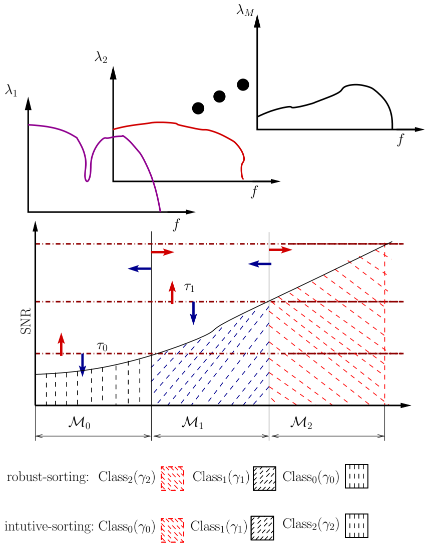
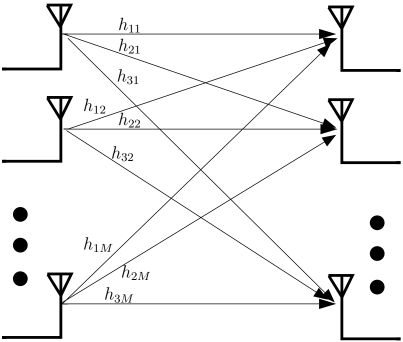


Outline

Potential of MIMO wireless links:

- Substantial improvement in throughput
- Effectively exploit multipath
- Scalability and adaptation



Main Problem!

CSI errors

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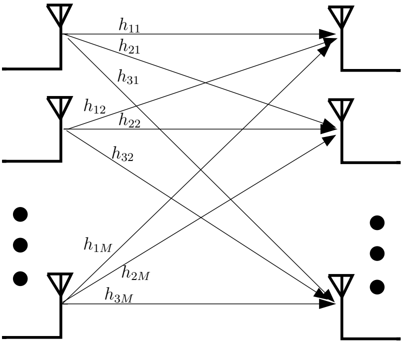

Main Problem!

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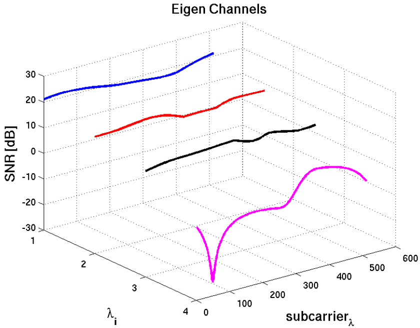
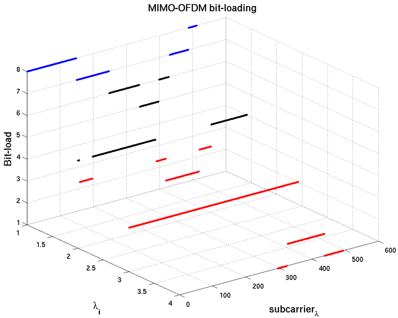
Eigen Channels Representation

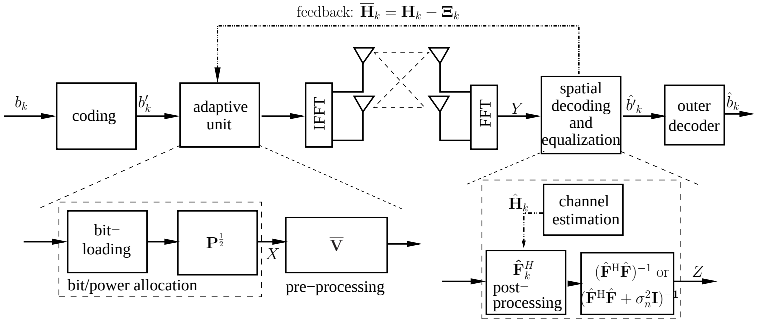
Eigen channels (modes)



Bit-loading for eigen channels



Channel side information feedback



CSI feedback schemes:

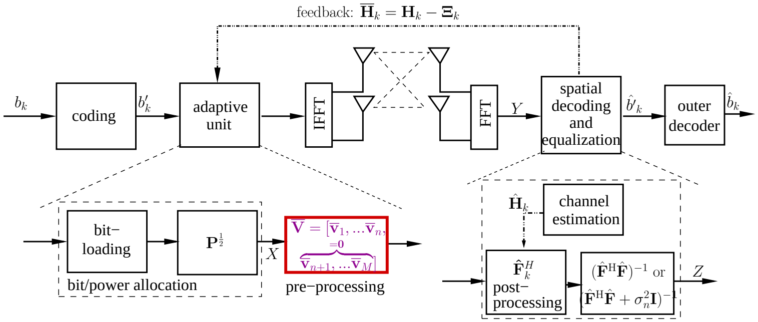
- Channel mean: $\overline{\mathbf{H}} = \mathbf{H} - \mathbf{\Xi}$,
- Channel corelation: $\mathbf{R}_{\hat{\mathbf{H}}^{\mathrm{H}}\hat{\mathbf{H}}} = E\{\mathbf{H}^{\mathrm{H}}\mathbf{H}\}$

CSI uncertainty:

- Channel estimation error
- Quantization error
- errors included by the feedback channel

Beamforming techniques:

Channel side information feedback



Beamforming techniques:

- I- **full-length beamforming (full-BF), when $n = M$**
- II- **shorter-length beamforming (n-D BF), due to antenna correlation or CSI errors**

System Analysis

CSI error: $\Xi_k = \mathbf{H}_k - \overline{\mathbf{H}}_k$
where $\Xi_k \sim \mathcal{CN}(0, \sigma_\Xi^2)$
the received vector:

$$\begin{aligned} \mathbf{Y}_k &= \mathbf{H}_k \overline{\mathbf{V}}_k \mathbf{P}^{1/2} \mathbf{X}_k + n_k \\ &= \overbrace{\mathbf{U}_k \mathbf{D}_k \mathbf{V}_k^* \overline{\mathbf{V}}_k \mathbf{P}^{1/2}}^{\mathbf{F}_k} \mathbf{X}_k + \eta_k \ , \end{aligned}$$

ZF detection:

$$\mathbf{W} = \{\mathbf{F}^*\mathbf{F}\}^{-1}\mathbf{F}^H$$

MMSE detection:

$$\mathbf{W} = \{\mathbf{F}^*\mathbf{F} + \sigma_N^2 \mathbf{I}\}^{-1}\mathbf{F}^H$$

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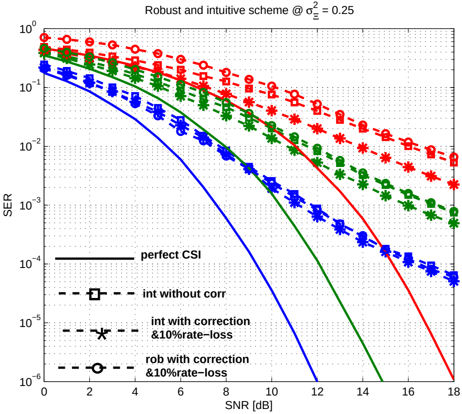
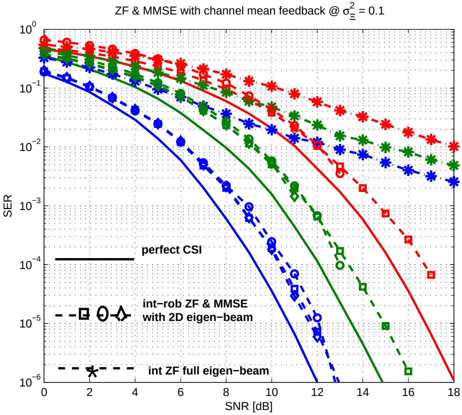
Roubst and intuitive loading using 4D-BF @σ_{Ξ}^2 =0.25)



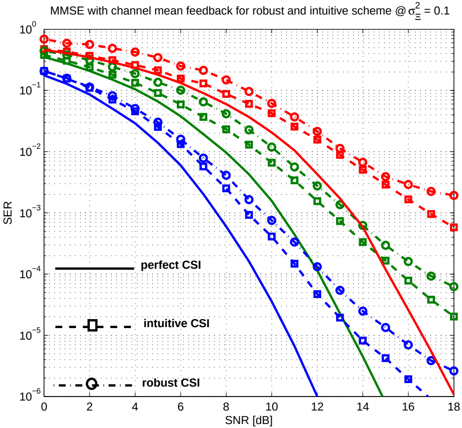
This simulation has been done using:

- 4×4 MIMO-OFDM equivelent to a 512 SISO subcarriers
- 3 classes, with $\Delta\gamma^{(j)} = 3$ dB, $T^{(j)} = 1024$ bits, and max 8 bits/subcarriers

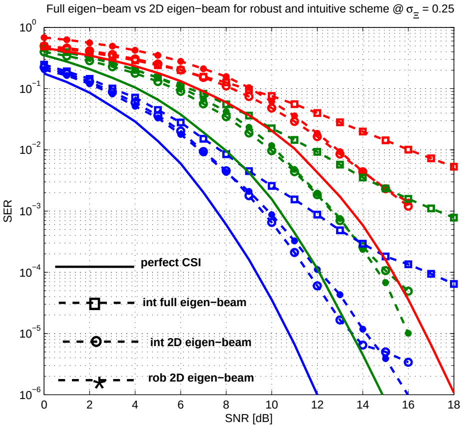
Different equalization using $\sigma_{\Xi}^2 = 0.1$):



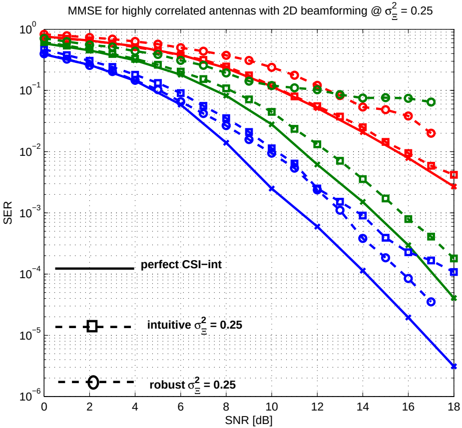
mean CSI using 4D-BF @σ^2_{Ξ} =0.1



Roubst and intuitive loading using different beamforming techniques @σ_{Ξ}^2 =0.25)



Highly correlated channels using 2D-BF @σ_{Ξ}^2 =0.25)



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Conclusions

- We described an UEP bit-allocation scheme for MIMO-OFDM
- Exploit channel layering using SVD, thereby realize UEP
- Allows for arbitrary margins, error probabilities, and bit-rates
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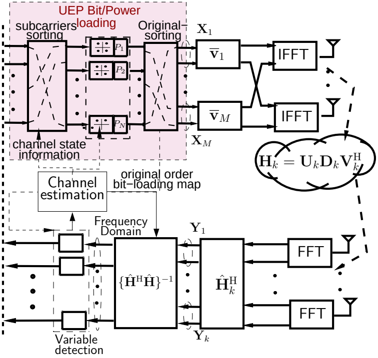

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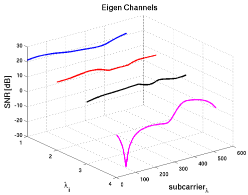

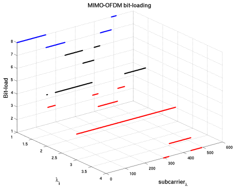

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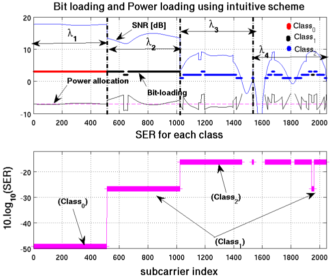

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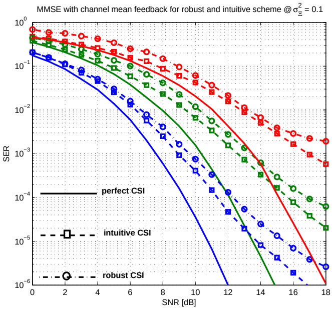

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