On the Adaptivity in Down- and Uplink MC-CDMA Systems

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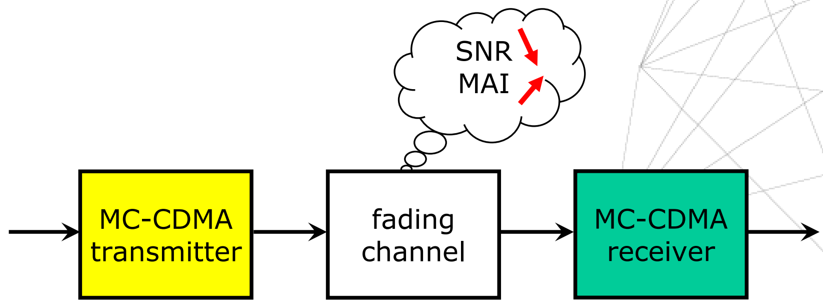
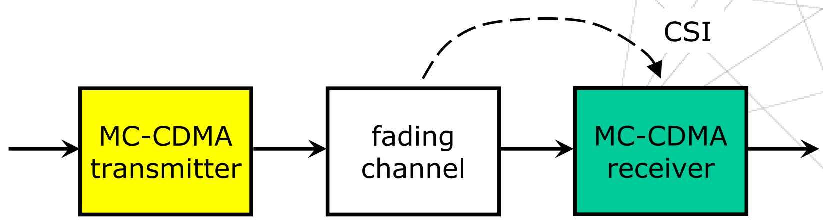
Introduction

- Adaptivity in MC-CDMA
- Concept of Adaptivity in Uplink MC-CDMA
- Concept of Adaptivity in Downlink MC-CDMA
- Conclusions

Adaptivity in MC-CDMA



Adaptivity in MC-CDMA



Post-Equalization at Rx

DLR

Adaptivity in MC-CDMA

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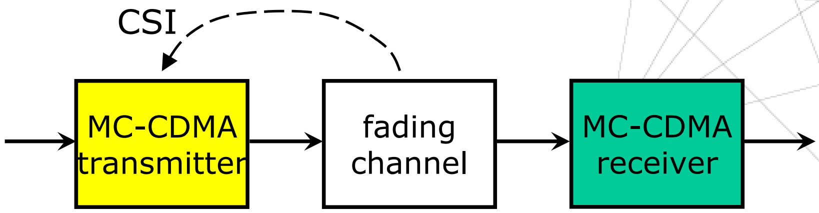

Pre-Equalization at Tx

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Adaptivity in MC-CDMA

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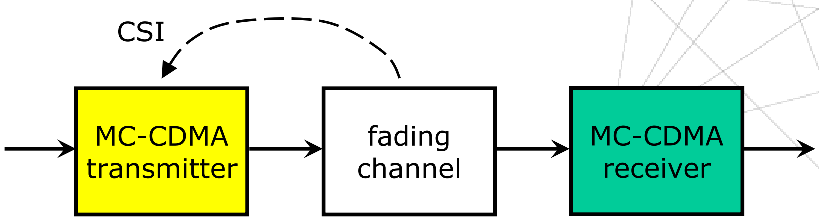
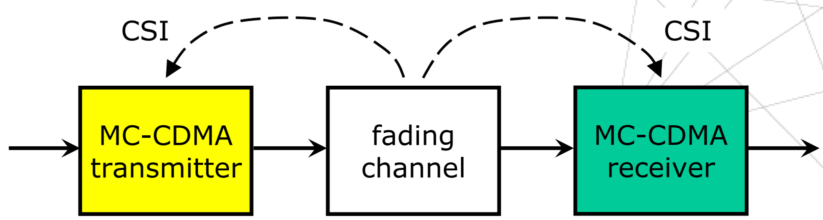


Pre-Equalization at Tx

Adapt transmission signal to CSI:

1) Eliminate MAI → Zero-forcing (ZF)
2) Maximize SNR → Maximum ratio transmission (MRT)
3) Trade-off between ZF and MRT → MMSE

Adaptivity in MC-CDMA



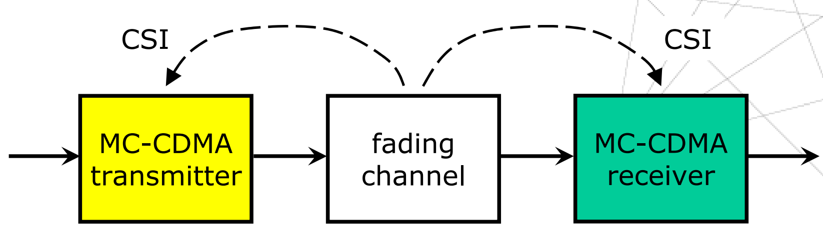
Pre-Equalization at Tx

+

Post-Equalization at Rx

Combined-Equalization

Adaptivity in MC-CDMA



Combined-Equalization

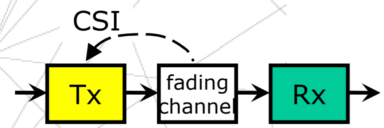
CSI at Tx and Rx – more degrees of freedom

Mobile station - low complexity
Base station - higher complexity

Adaptivity in Uplink MC-CDMA

CSI Available Only at Tx

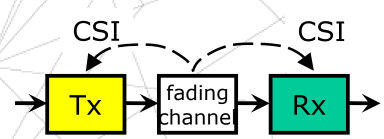
Input/output relation: $\mathbf{r} = \sum_{k=1}^{K} \mathbf{H}^{(k)} \mathbf{G}_{\text{pre}}^{(k)} \mathbf{c}^{(k)} d^{(k)} + w^{(\ell)}$



Pre-equalization Technique	Coefficients
ZF (eliminates MAI)	$G_{\text{pre},l}^{(k)} = \frac{H_l^{(k)*}}{\left\| H_l^{(k)} \right\|^2} W$
MRT (maximizes SNR)	$G_{\text{pre},l}^{(k)} = H_l^{(k)*} W$
MMSE (trade-off between ZF and MRT)	$G_{\text{pre},l}^{(k)} = \frac{H_l^{(k)*}}{\frac{K-1}{L}\left\| H_l^{(k)} \right\|^2 + \sigma_n^2} W$

Adaptivity in Uplink MC-CDMA

CSI Available at Tx and Rx



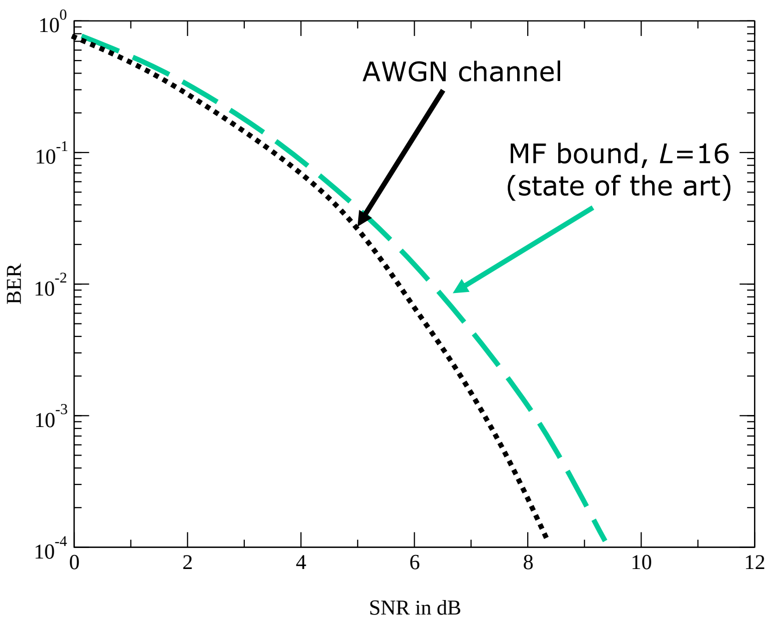
- Concept of combined-equalization
- Aim at maximizing SNR at Tx and suppressing MAI at Rx
  - New improved MC-CDMA single-user bounds
  - Closely approached even in a fully-loaded system
- Complexity
  - Low complexity at Tx – one-tap pre-equalization
  - Higher complexity at Rx – non-linear parallel interference cancellation (PIC)
- Optimization algorithm
  - Closed form solution not available in a multi-user case
  - A simple and effective approach; A single optimization parameter - parameter '*p*' of the generalized pre-equalization used to trade SNR and MAI

Controls power distribution over subcarriers

$$G_{\text{pre},l}^{(k)} = \left| H_l^{(k)} \right|^{p} H_l^{(k)*} W$$

Adaptivity in Uplink MC-CDMA

CSI Available at Tx and Rx



- Uncoded system
- QPSK
- Uncorrelated Rayleigh fading
- Spreading length $L=16$
- Single-user
- Ideal CSI

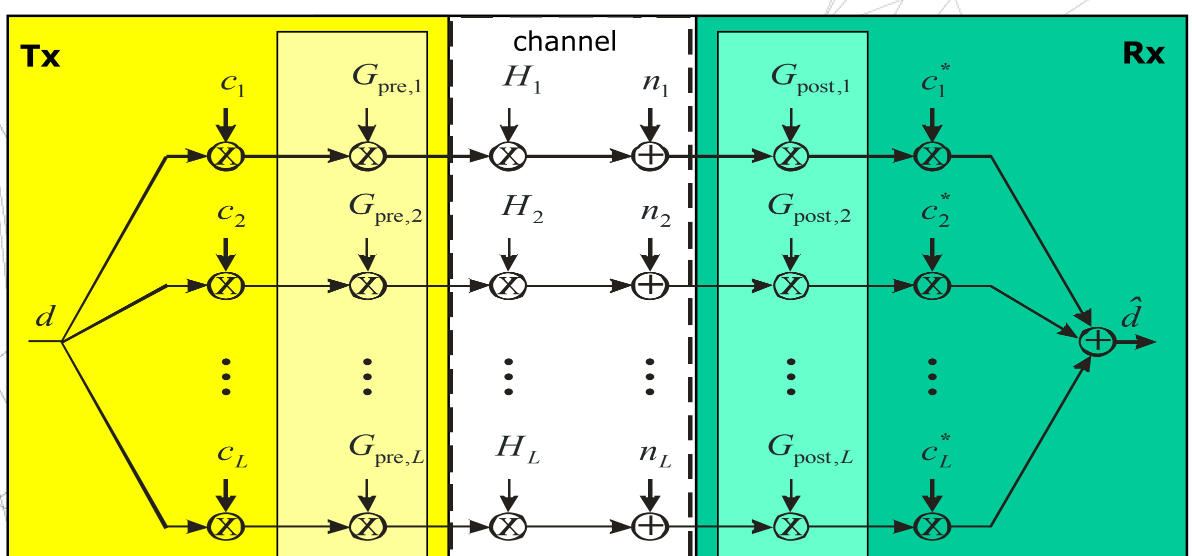
$$P_{\mathrm{MF}} = \left(\frac{1-\gamma}{2}\right)^{L} \sum_{\ell=0}^{L-1} \binom{L-1+\ell}{\ell} \left(\frac{1+\gamma}{2}\right)^{\ell}$$

$$\gamma = \sqrt{\frac{E_t/N_0}{L+E_t/N_0}}$$

MF – matched filter

Combined-Equalization

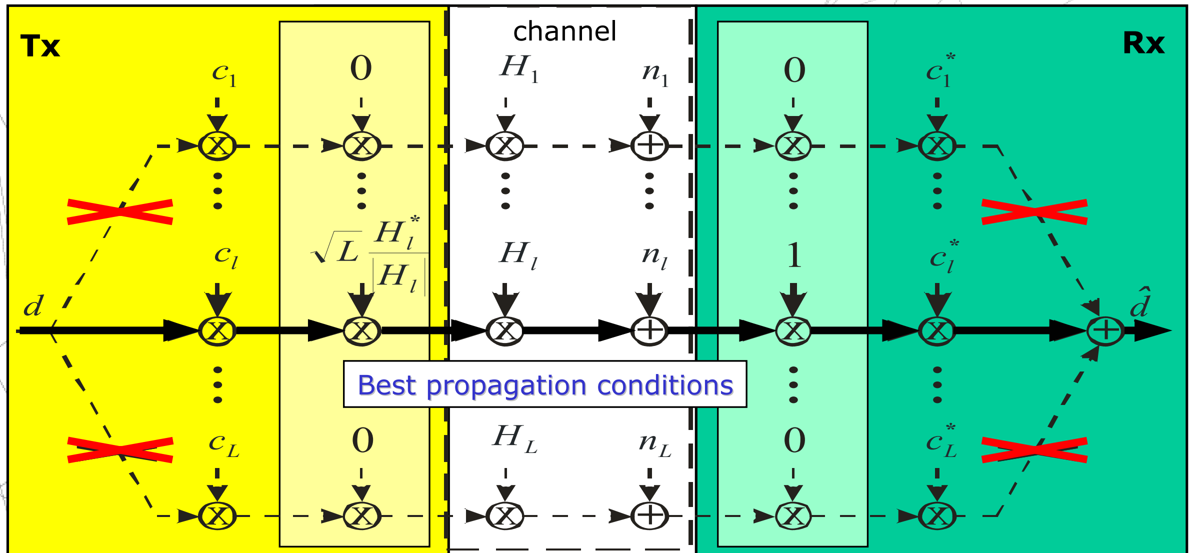
Frequency Domain Single-User Transmission System



$$G_{\mathrm{post},l} = f(G_{\mathrm{pre},l} \cdot H_l)$$

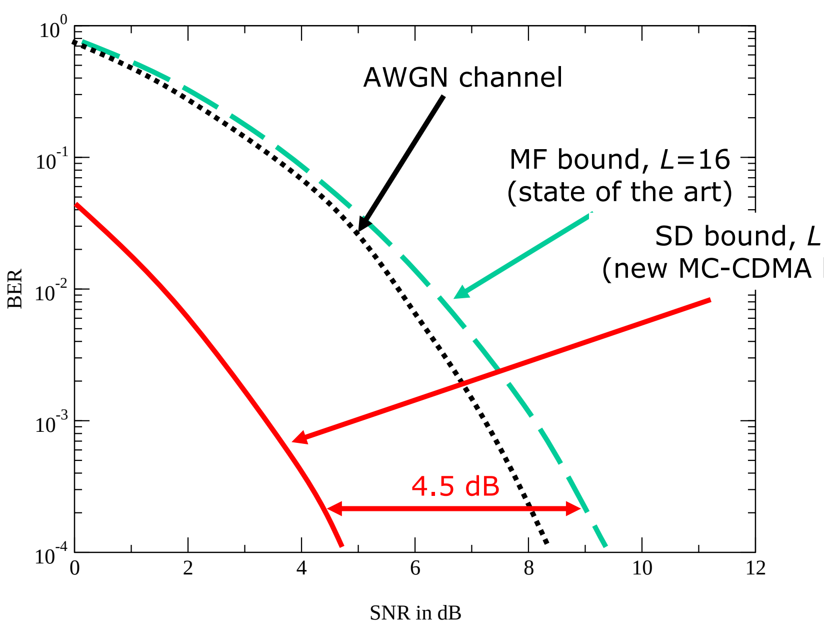
Combined-Equalization

Selection Diversity (SD) Combined-Equalization



Adaptivity in Uplink MC-CDMA

CSI Available at Tx and Rx



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$$\gamma = \sqrt{\frac{E_t/N_0}{L+E_t/N_0}}$$

$$P_{\mathrm{SD}} = \frac{L}{2} \sum_{\ell=0}^{L-1} \binom{L-1}{\ell} \frac{(-1)^{\ell}}{\ell+1} \left(1-\sqrt{\frac{E_t/N_0}{\ell+1+E_t/N_0}}\right)$$

SD – selection diversity

MF – matched filter

Combined-Equalization

Drawback of selection diversity: Not suitable for the multi-user case

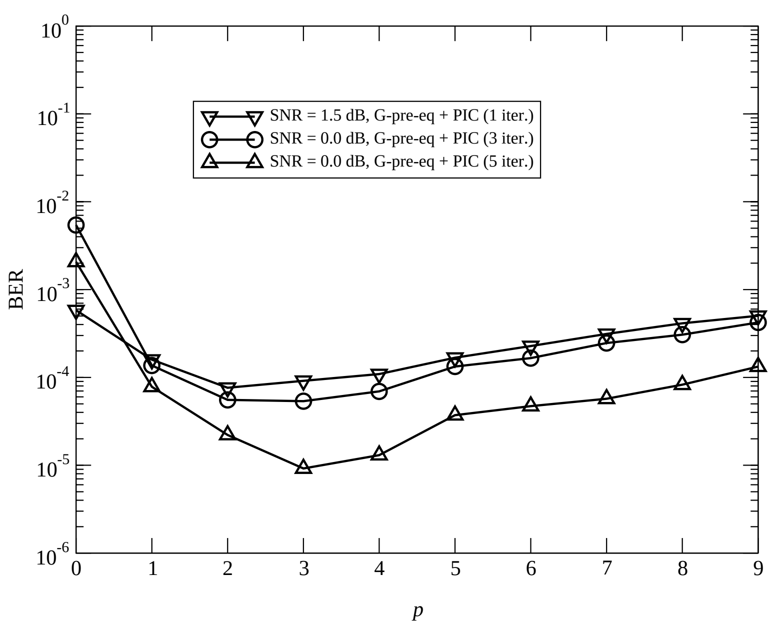
Requirements:

- Appropriate for application in multi-user uplink MC-CDMA
- Capable to closely approach selection diversity bound
- Preferably flexible

Solution: Generalized pre-equalization (G-pre-eq)

Combined-Equalization in Multi-User MC-CDMA

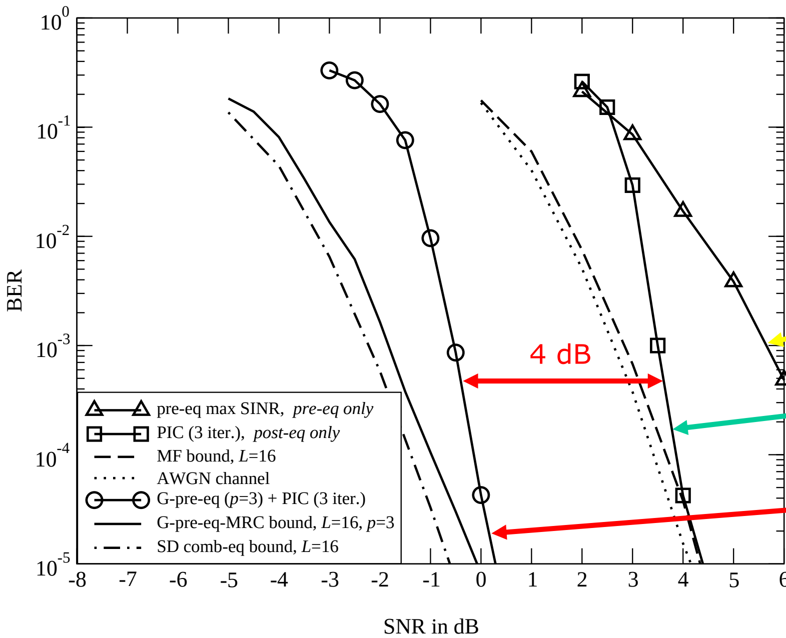
- As p grows single-user bounds are better, but more MAI is induced
- Optimization problem reduced to determination of parameter p



- Convol. coded system (R=1/2)
- QPSK
- Uncorrelated Rayleigh fading
- Spreading length L=16
- Number of active users K=16
- Ideal CSI

Concept of Adaptivity in Uplink MC-CDMA

Numerical Results



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- Number of active users $K=16$
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Concept of Adaptivity in Downlink MC-CDMA

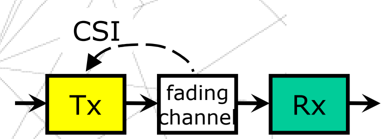
CSI Available Only at Tx

Input/output relation: $\mathbf{z} = \mathbf{F}^{\mathrm{H}}\mathbf{U}\mathbf{d} + \mathbf{w}$

Fading & despreading

$$\mathbf{F} = \left(\left(\mathbf{H}^{(1)}\right)^{\mathrm{H}} \mathbf{c}^{(1)} \quad \ldots \quad \left(\mathbf{H}^{(K)}\right)^{\mathrm{H}} \mathbf{c}^{(K)} \right)$$

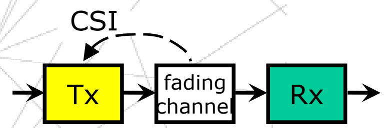
Pre-equalization
(& spreading)



Pre-equalization Technique	Pre-equalization matrix
ZF (eliminates MAI)	$\mathbf{U} = \mathbf{F}\left(\mathbf{F}^{\mathrm{H}}\mathbf{F}\right)^{-1} W$
MRT (maximizes SNR)	$\mathbf{U} = \mathbf{F} W$
MMSE (trade-off between ZF and MRT)	$\mathbf{U} = \mathbf{F}\left(\mathbf{F}^{\mathrm{H}}\mathbf{F} + \sigma_n^2 \mathbf{I}\right)^{-1} W$

Adaptivity in Downlink MC-CDMA

CSI Available Only at Tx



Non-linear interference pre-cancellation:

$$\mathbf{z} = \mathbf{F}^{\mathrm{H}}\mathbf{U}\mathbf{b} + \mathbf{w}$$

$\mathbf{F}^{\mathrm{H}} = \mathbf{R}\mathbf{Q}$ QR-decomposition; $\mathbf{R}$ lower triangular; $\mathbf{Q}$ unitary matrix $\left(\mathbf{Q}\mathbf{Q}^{\mathrm{H}} = \mathbf{I}\right)$

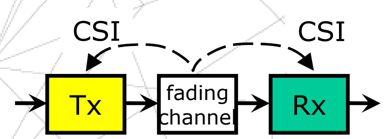
$$\mathbf{U} = \mathbf{Q}^{\mathrm{H}}$$

$\mathbf{b} = \mathbf{d} - \overline{\mathbf{R}}^{-1}(\mathbf{R} - \overline{\mathbf{R}})\mathbf{b}$ $\overline{\mathbf{R}}$ diagonal matrix - contains diagonal elements of $\mathbf{R}$

$\mathbf{z} = \mathbf{R}\mathbf{Q}\mathbf{Q}^{\mathrm{H}}\mathbf{R}^{-1}\overline{\mathbf{R}}\mathbf{d} + \mathbf{w} = \overline{\mathbf{R}}\mathbf{d} + \mathbf{w}$ MAI is completely eliminated

Adaptivity in Downlink MC-CDMA

CSI Available at Tx and Rx



- Complexity
  - Higher complexity at Tx – non-linear interference pre-cancellation
  - Low complexity at Rx – one-tap post-equalization, i.e., single-user detection (SUD)
- Optimization algorithm
  - Closed form solution is given by a complicated iterative procedure
  - Simple and effective approach
  - Pre-equalization is performed assuming that a certain SUD is employed at the receiver

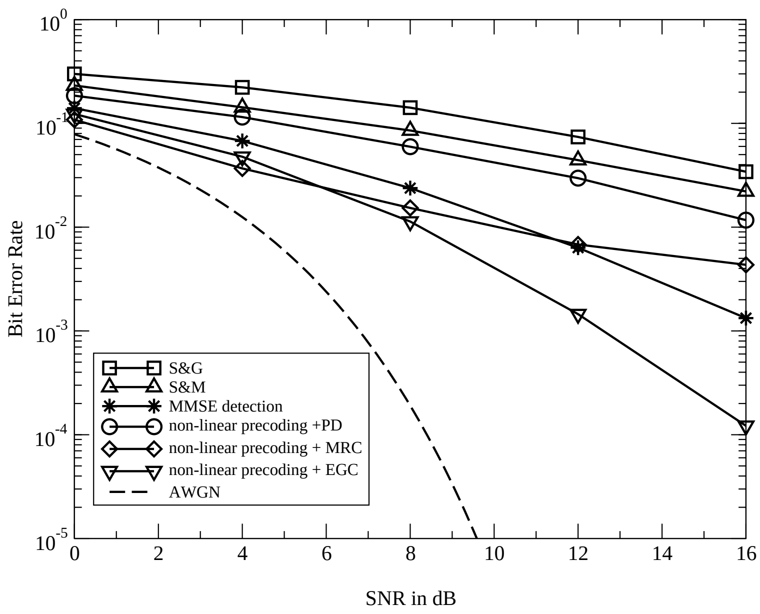
pre-equalization $\mathbf{U} = f'(\mathbf{F})$

fading, SUD & despreading $\mathbf{F} = \left(\left(\mathbf{H}^{(1)}\right)^{\mathrm{H}}\mathbf{g}^{(1)} \quad \ldots \quad \left(\mathbf{H}^{(K)}\right)^{\mathrm{H}}\mathbf{g}^{(K)}\right)$

SUD $\mathbf{g}^{(k)} = f''(\mathbf{H}^{(k)})$

Adaptivity in Downlink MC-CDMA

Numerical Results



- Uncoded system
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- Number of active users K=16
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Conclusions

- Combined equalization can properly be designed for uplink and downlink, allowing low complexity terminal stations and higher complexity base stations.
- Optimization based on generalized pre-equalization.
- Simulation results show that in multi-user scenarios combined equalization significantly outperforms systems with only pre- or post-equalization.
- Prerequisite is to have channel knowledge available at the transmitter and the receiver.

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