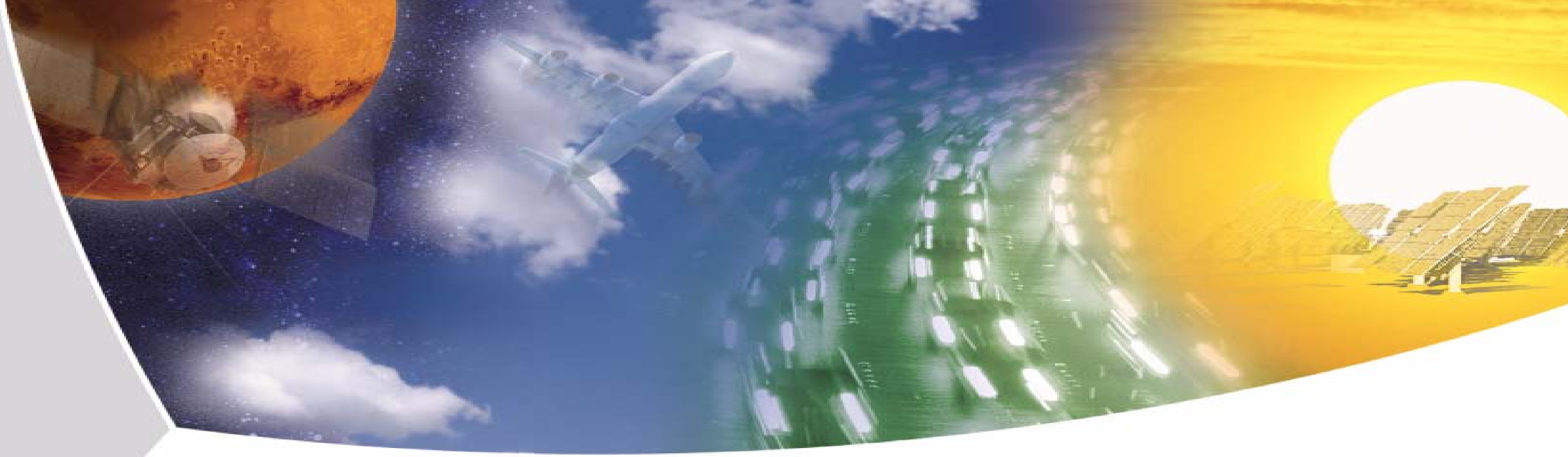


Iterative Channel Estimation for MIMO MC-CDMA

Stephan Sand, Ronald Raulefs, and Armin Dammann

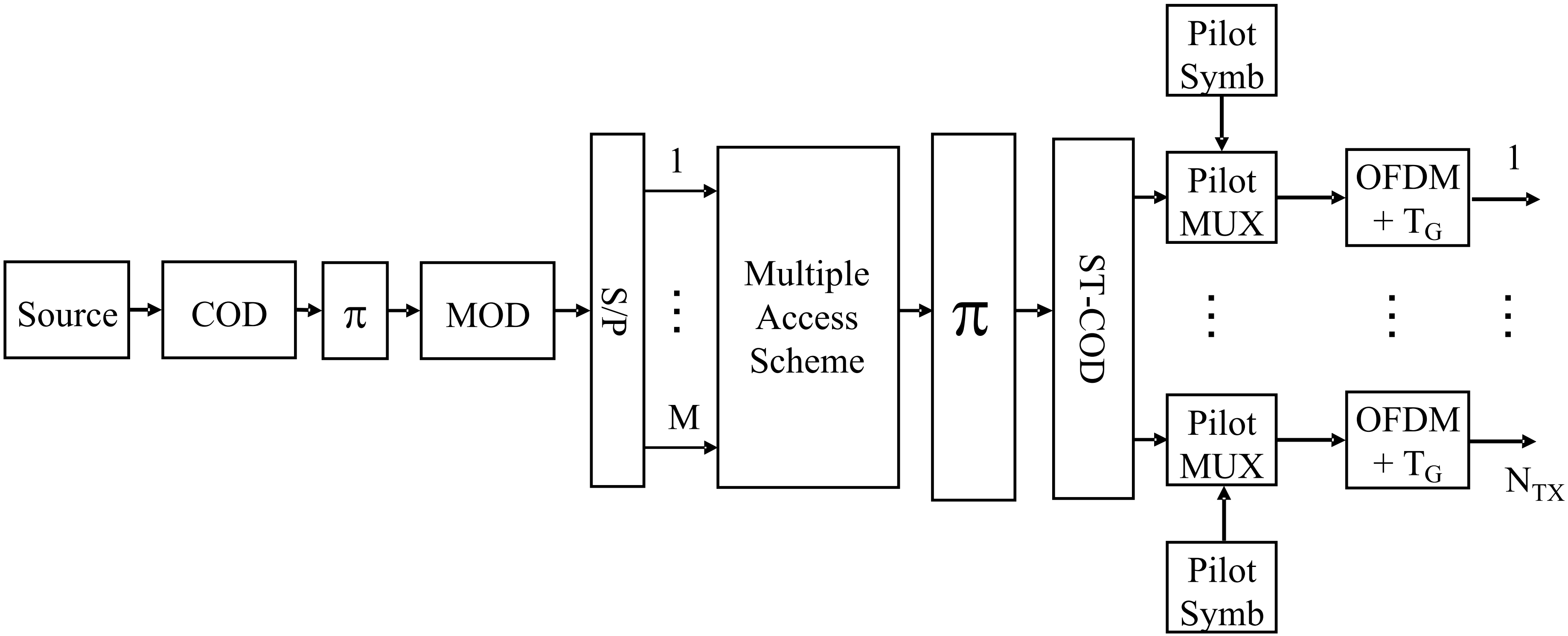
German Aerospace Center (DLR)

2^{nd} COST 289 Workshop, Antalya, Turkey, 6^{th} July

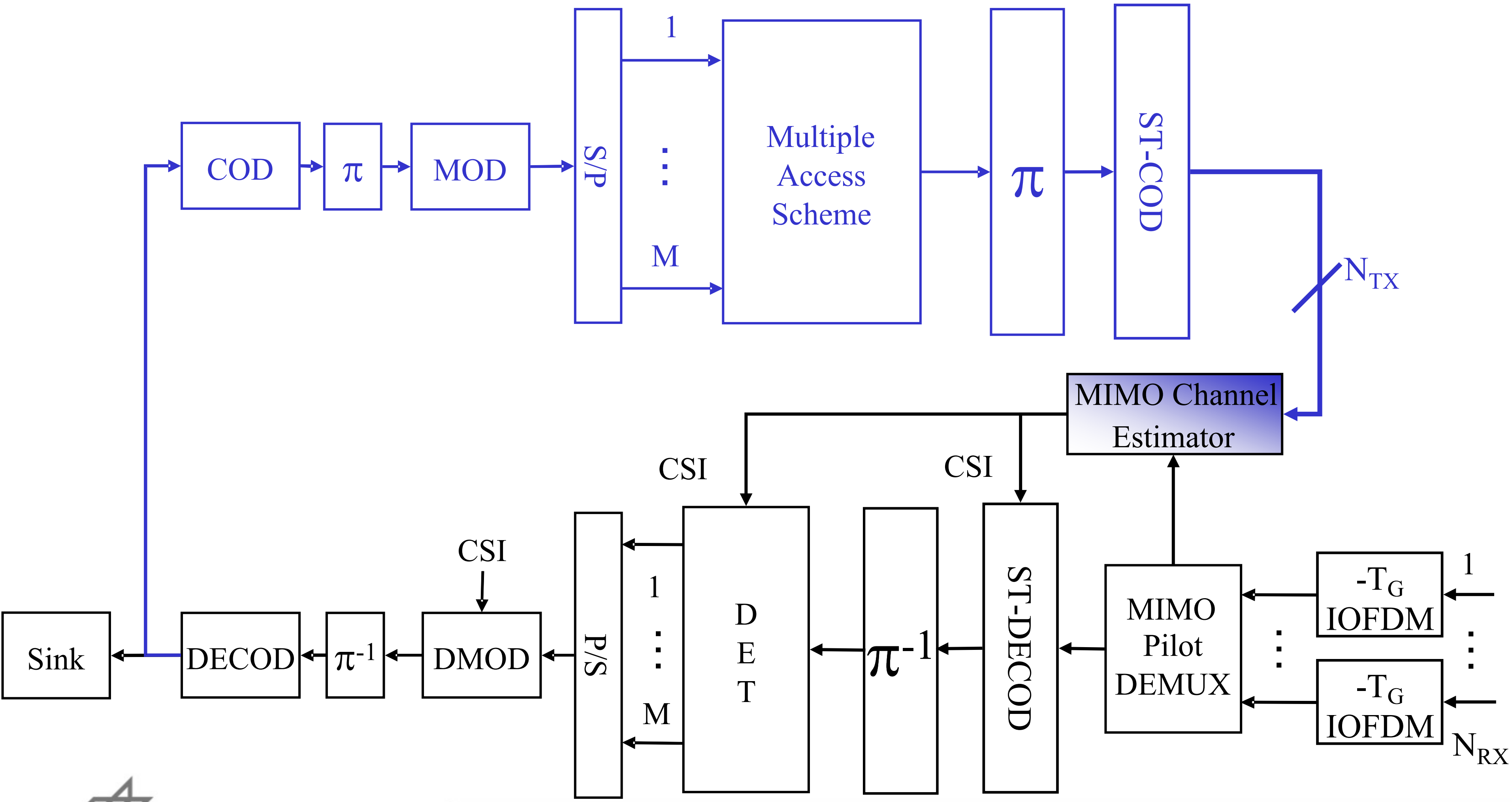
Outline

- System model
- Frame structure
- Pilot aided channel estimation (PACE)
- MC-CDMA and iterative channel estimation (ICE)
- Extension of ICE to MIMO
- Simulation results
- Conclusions & outlook

System Model: Downlink MC-CDMA Transmitter

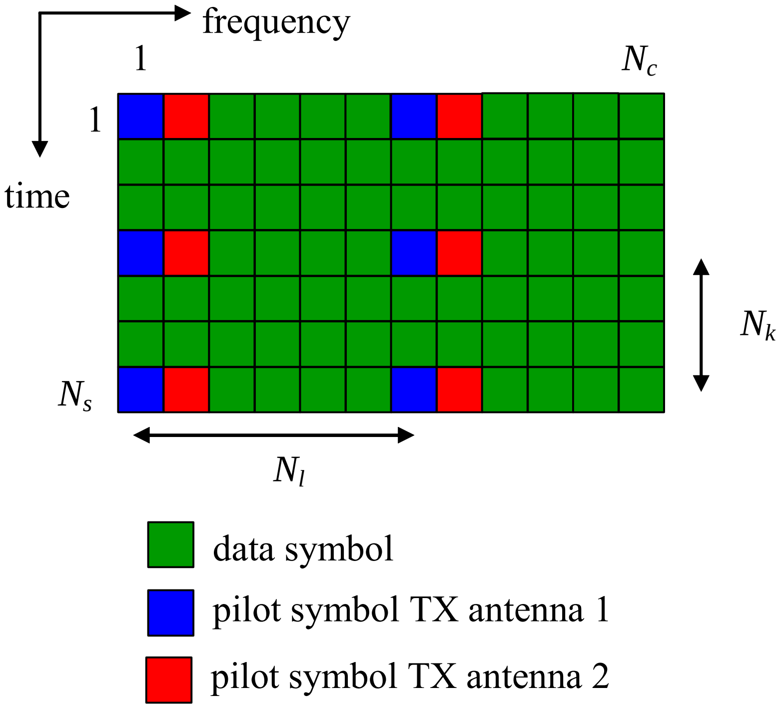


System Model: Receiver with Iterative Channel Estimation (ICE)



Frame Structure

- Burst transmission
- Rectangular grid
  - Pilot distance in frequency direction: N_l
  - Pilot distance between OFDM symbols: N_k
- 2 × oversampling channel transfer function



Pilot Aided Channel Estimation (PACE)

- PACE:
  - Pilot symbols yield initial estimates for the channel transfer function at pilot symbol positions, i.e., the least-squares (LS) estimate:

$$H_{n',l'} = \frac{R_{n',l'}}{S_{n',l'}} = H_{n',l'} + \frac{Z_{n',l'}}{S_{n',l'}}, \qquad \forall \{n',l'\} \in \mathcal{P},$$

where $\mathcal{P}$ denotes the set of pilot symbols.

  - Filtering pilot symbols yields final estimates for the complete channel transfer function:

$$\hat{H}_{n,l} = \sum_{\{n',l'\} \in \mathfrak{I}_{n,l}} \omega_{n',l',n,l} H_{n',l'}, \qquad \mathfrak{I}_{n,l} \in \mathcal{P}, \qquad n = 1, \quad , N_c , l = 1, \quad , N_s ,$$

where $\omega_{n',k',n,k}$ is the shift-variant 2-D impulse response of the filter. $\mathfrak{I}_{n,k}$ is the set of initial estimates that are actually used for filtering.

Pilot Aided Channel Estimation (PACE)

Filter design:

- knowledge of the Doppler and time delay power spectral densities (PSDs)

  ⇒ optimal 2D FIR Wiener filter

- separable Doppler and time delay PSDs

  ⇒ two cascaded 1-D FIR Wiener filters perform similar than 2D FIR Wiener filter

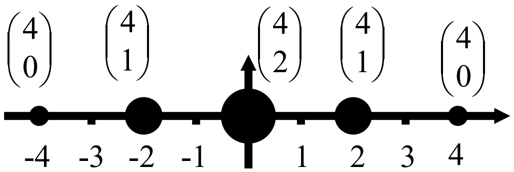
- in practice, Doppler and time delay PSDs are not perfectly known

  ⇒ robust design assuming rectangular Doppler and time delay PSDs

⇒ Set of filter coefficients can be pre-computed and stored in the receiver

MC-CDMA and Iterative Channel Estimation (ICE)

- MC-CDMA:
  - Walsh-Hadamard spreading code:
    zero-valued subcarriers can occur during transmission
  - Example : Walsh-Hadamard spreading code, L=4, BPSK modulation,
    possible transmission points for one subcarrier (constellation) after spreading:



    Zero-valued subcarriers occur with 37.5% probability

- How to use estimated data in the LS-Estimate if zero-valued subcarrier occurs?

$$H_{n',l'} = \frac{R_{n',l'}}{\hat{S}_{n',l'}}$$

MC-CDMA and Iterative Channel Estimation (ICE)

- Modified LS Method:

$$H_{n',l'}^{(i),m,p} = \begin{cases} \dfrac{R_{n',l'}^{m,p}}{S_{n',l'}^{m}} & \text{if pilot symbol } S_{n',l'}^{m} \\ \dfrac{R_{n',l'}^{(i),m,p}}{S_{n',l'}^{(i),m}} & \text{if estimated data symbol } \left|S_{n',l'}^{(i),m}\right| > \rho_{th} \\ 0 & \text{if estimated data symbol } \left|S_{n',l'}^{(i),m}\right| \leq \rho_{th} \end{cases}$$

  - If the reconstructed subcarrier is zero or below a certain threshold, set the LS channel estimates to zero
  - The filtered channel estimates are independent of subcarriers that would only cause noise enhancement and degrade the channel estimates.

Extension of ICE to MIMO

- Data symbols from different transmit antennas superimpose non-orthogonal:

$$R_{n,l}^{p} = \sum_{r=1}^{N_{TX}} H_{n,l}^{r,p} S_{n,l}^{r} + Z_{n,l}^{p}$$

- Interference reduced receive signal:

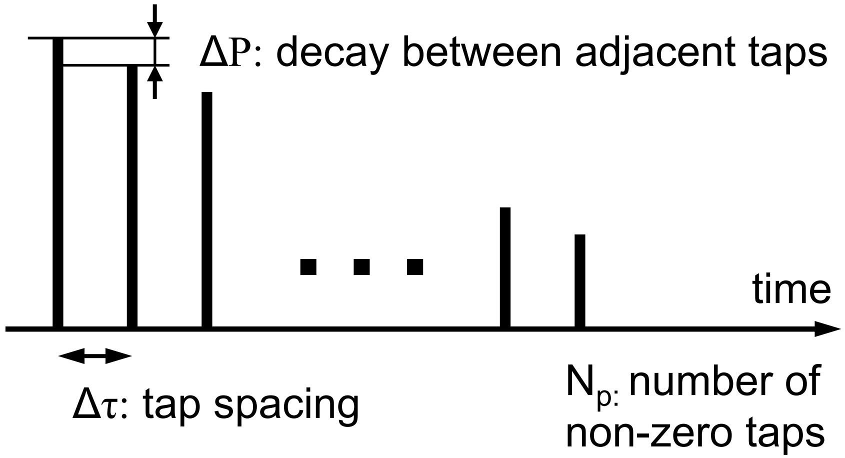
$$R_{n,l}^{(i),m,p} = R_{n,l}^{p} - \sum_{\substack{r=1 \\ r \neq m}}^{N_{TX}} \hat{H}_{n,l}^{(i-1),r,p} S_{n,l}^{(i),r}$$

Initially estimate the CSI between transmit antenna m and receive antenna p by first canceling the current estimates of the received signals from the other transmit antennas

Simulation Results: Scenario

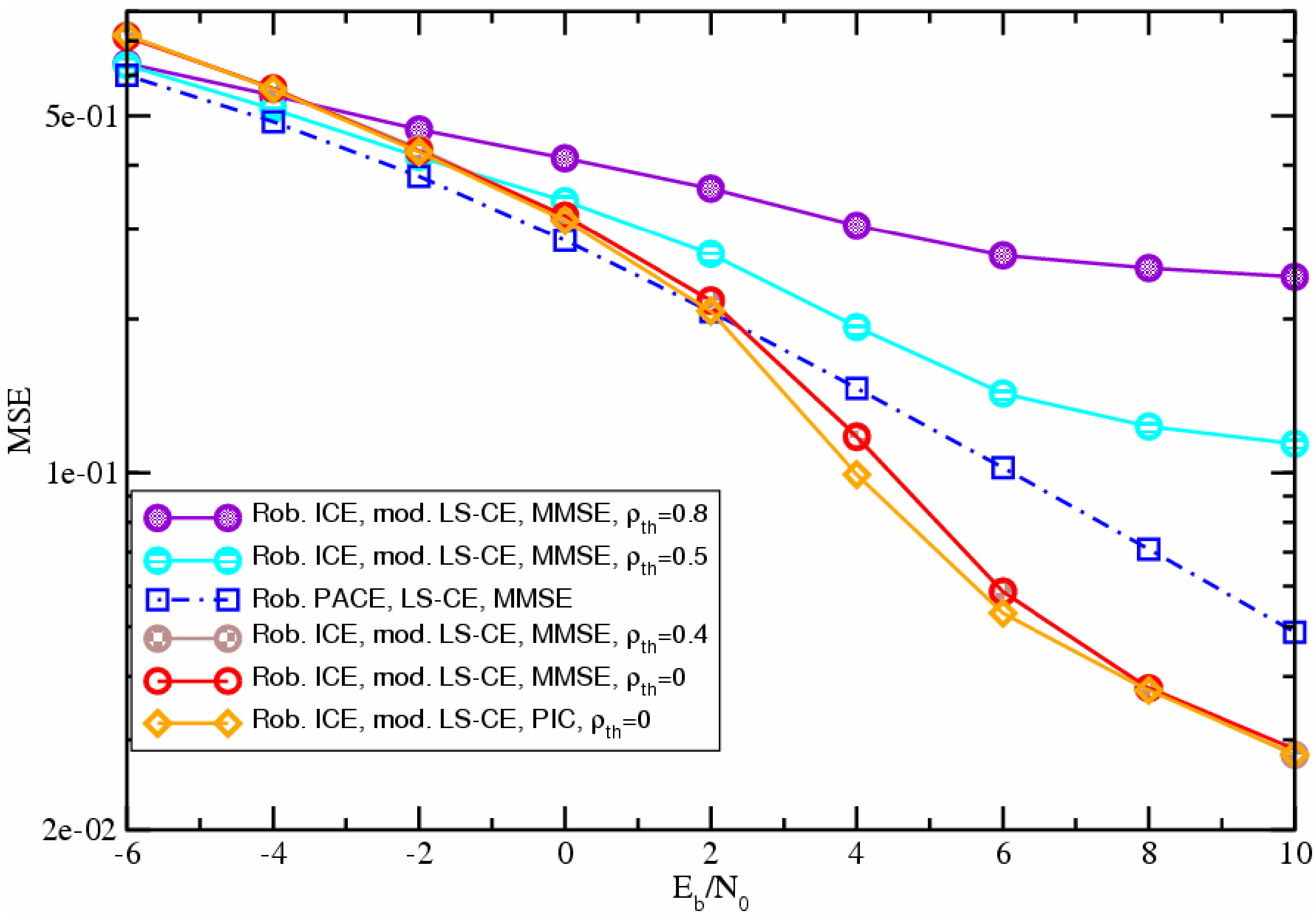
Bandwidth	101.5 MHz
Subcarriers	768
FFT length	1024
Sampling duration T_{spl}	7.4 ns
Guard interval T_{GI}	226 T_{spl}
Subcarrier spacing Δf	131.836 kHz
OFDM symbols / Frame	64
Modulation	4-QAM
Coding	Conv. code, R=1/2, (133,171)
Detection	MMSE, PIC
Pilot spacing frequency	3
Pilot spacing time	9
Max delay channel estimator	T_{GI} =226 T_{spl}
Max Doppler channel estimator	0.01 Δf

Channel model



$f_{D,max}$	$0.01\Delta f \approx 1500$ Hz
τ_{max}	176 T_{spl}
N_p	12
ΔP	1dB
$\Delta\tau$	16 T_{spl}

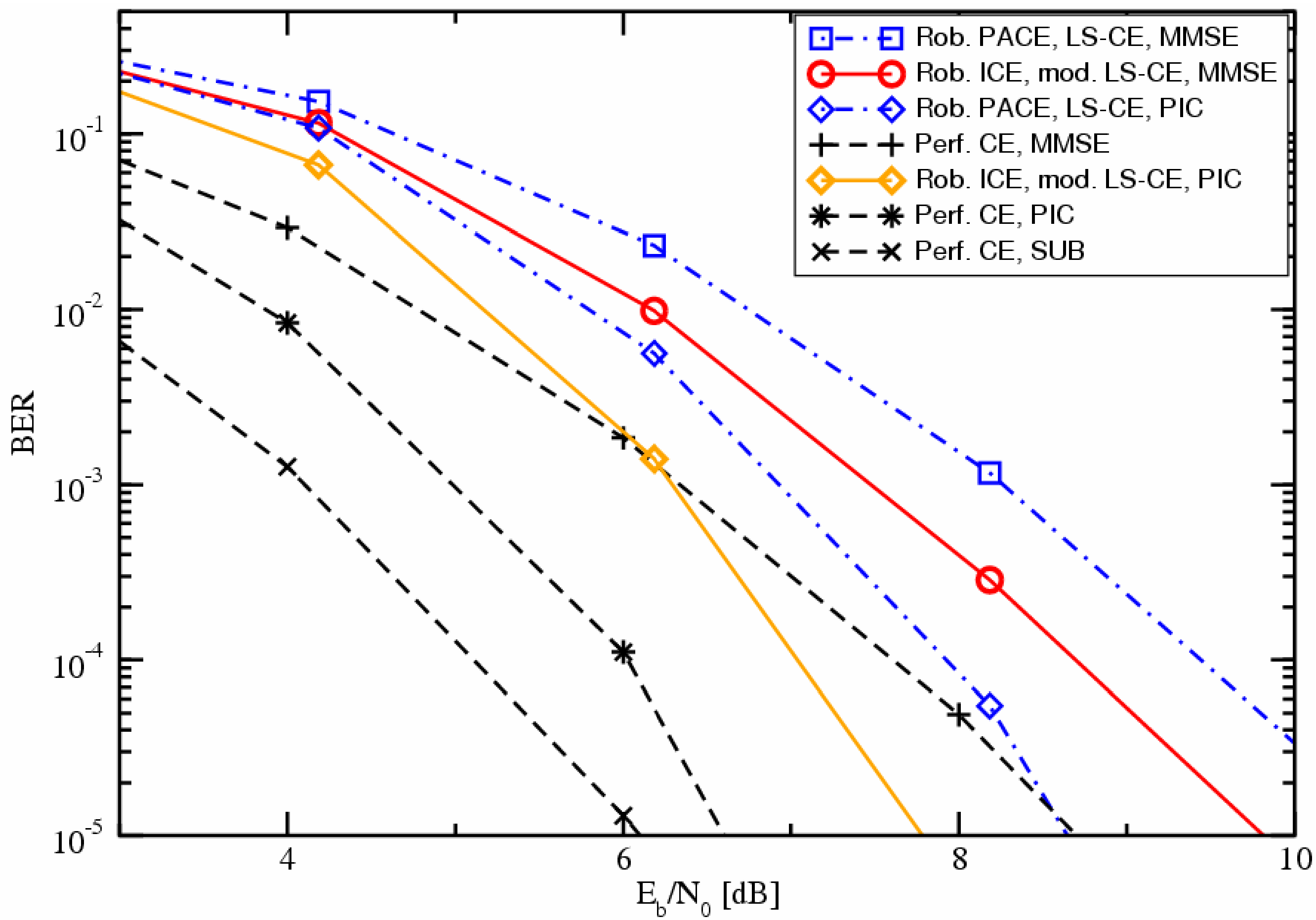
Simulation Results: f_D=1500Hz (300km/h @ 5GHz)



Default Values:

- **Spreading Length:** L=8
- **Users**: K=8
- **Rob. Wiener filter:** 15x4 filter coefficients both for PACE, ICE
- **ICE:** Probability of subcarrier ignored:
  ρth=0.8: 50%
  ρth=0.5: 30%
  ρth<0.5: 8%

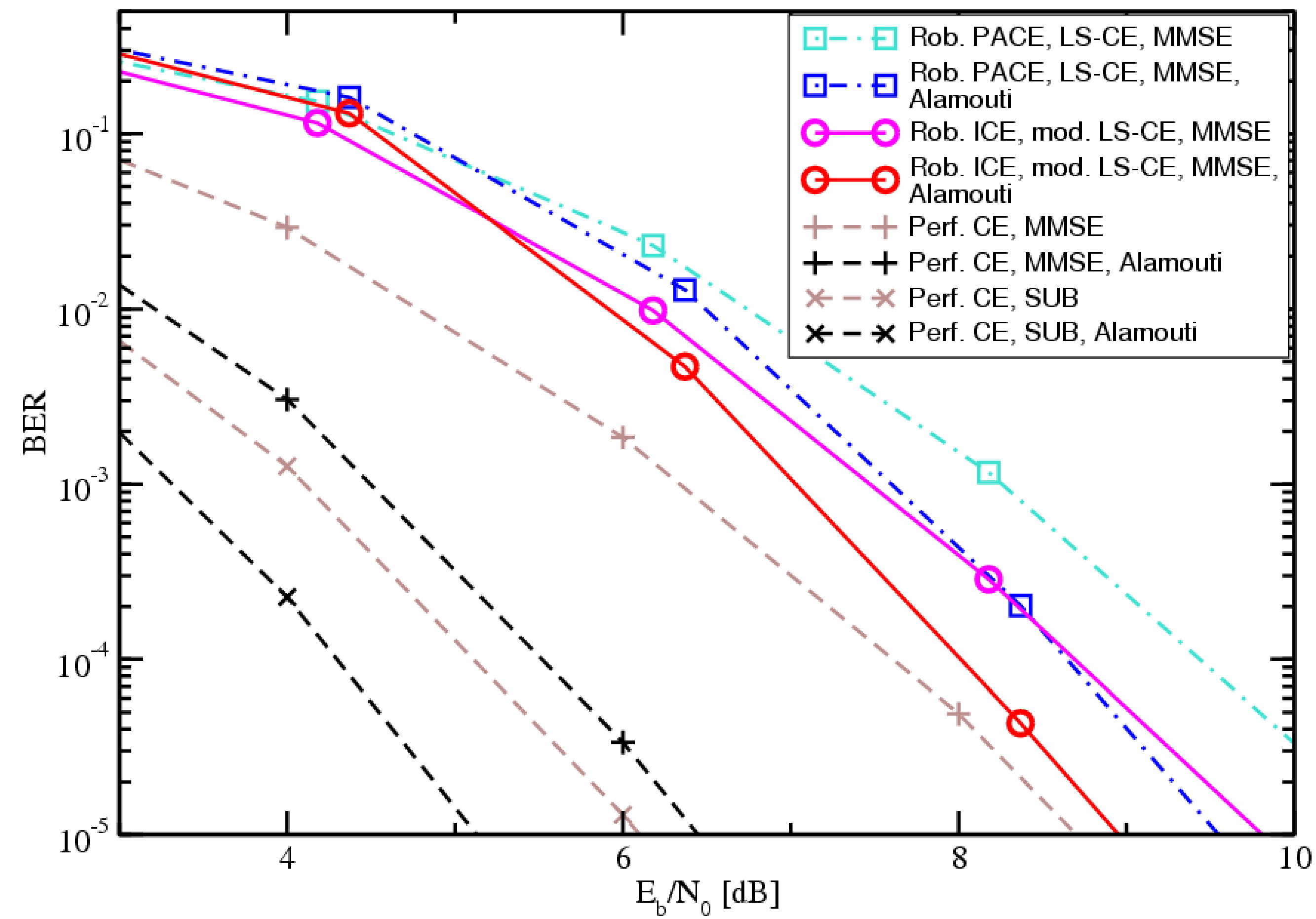
Simulation Results: f_D=1500Hz (300km/h @ 5GHz)



Default Values:

- **Spreading Length:** L=8
- **Users**: K=8
- **Rob. Wiener filter:** 15x4 filter coefficients both for PACE, ICE
- **ICE:** mod. LS-CE: ρ_{th}=0, hard feedback, 1 Iteration, all users detected
  PIC: soft feedback, 1 Iteration

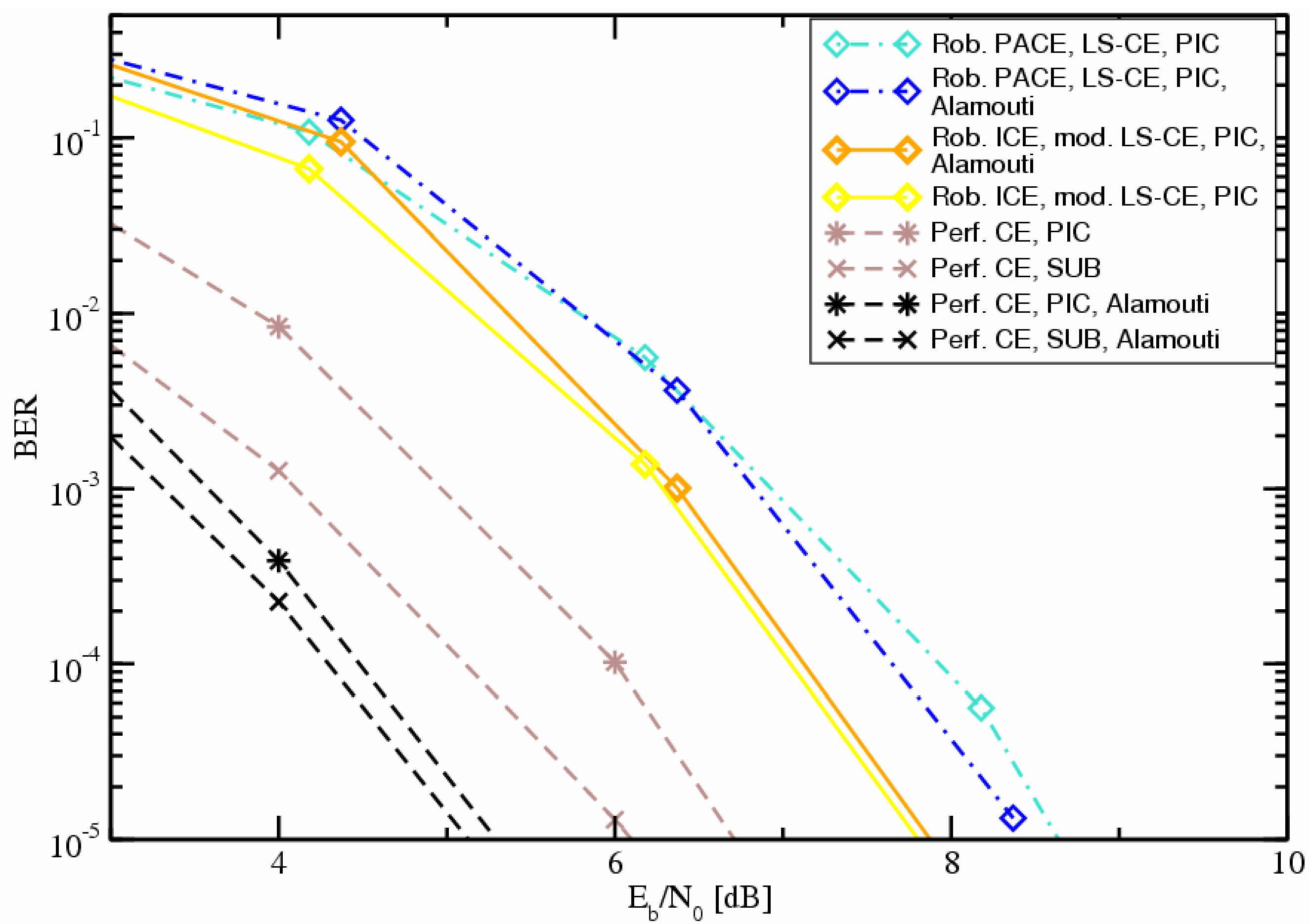
Simulation Results: f_D=1500Hz (300km/h @ 5GHz)



Default Values:

- **Spreading Length:** L=8
- **Users**: K=8
- **STBC:** Alamouti
- **Pilot symbol power:**
  SISO 1
  Alamouti 1/2
- **SNR loss (pilot overhead):**
  SISO 0.18 dB
  Alamouti 0.38 dB

Simulation Results: f_D=1500Hz (300km/h @ 5GHz)



Default Values:

- **Spreading Length:** L=8
- **Users**: K=8
- **STBC:** Alamouti
- **Pilot symbol power:**
  SISO 1
  Alamouti 1/2
- **SNR loss (pilot overhead):**
  SISO 0.18 dB
  Alamouti 0.38 dB

Conclusions & Outlook

- ICE for MIMO MC-CDMA with Walsh-Hadamard spreading: zero-valued subcarriers and non-orthogonal data symbols
- Modified LS channel estimation method and interference reduced received signal
- Simulation results indicate:
  - Small threshold for modified LS
  - Robust ICE improves robust PACE
  - Performance gains with robust ICE even for scenarios optimized for robust PACE
  - MIMO gain reduced by pilot overhead and energy constraint
- Outlook:
  - Soft feedback in ICE to improve convergence
  - Reduce pilot overhead for MIMO MC-CDMA

Thank you!