Iterative Channel Estimation for Broadband High Mobility MC-CDMA System

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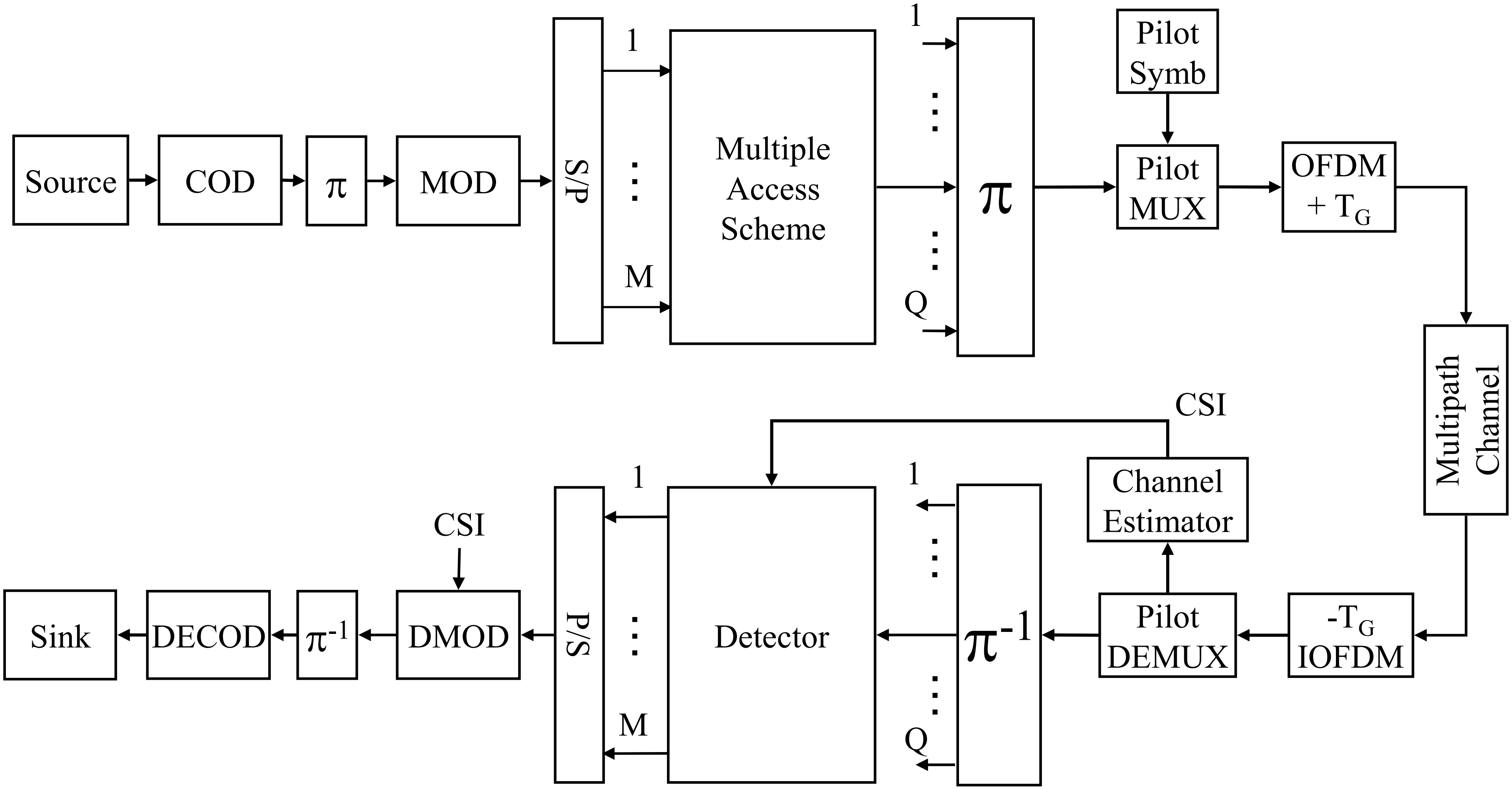
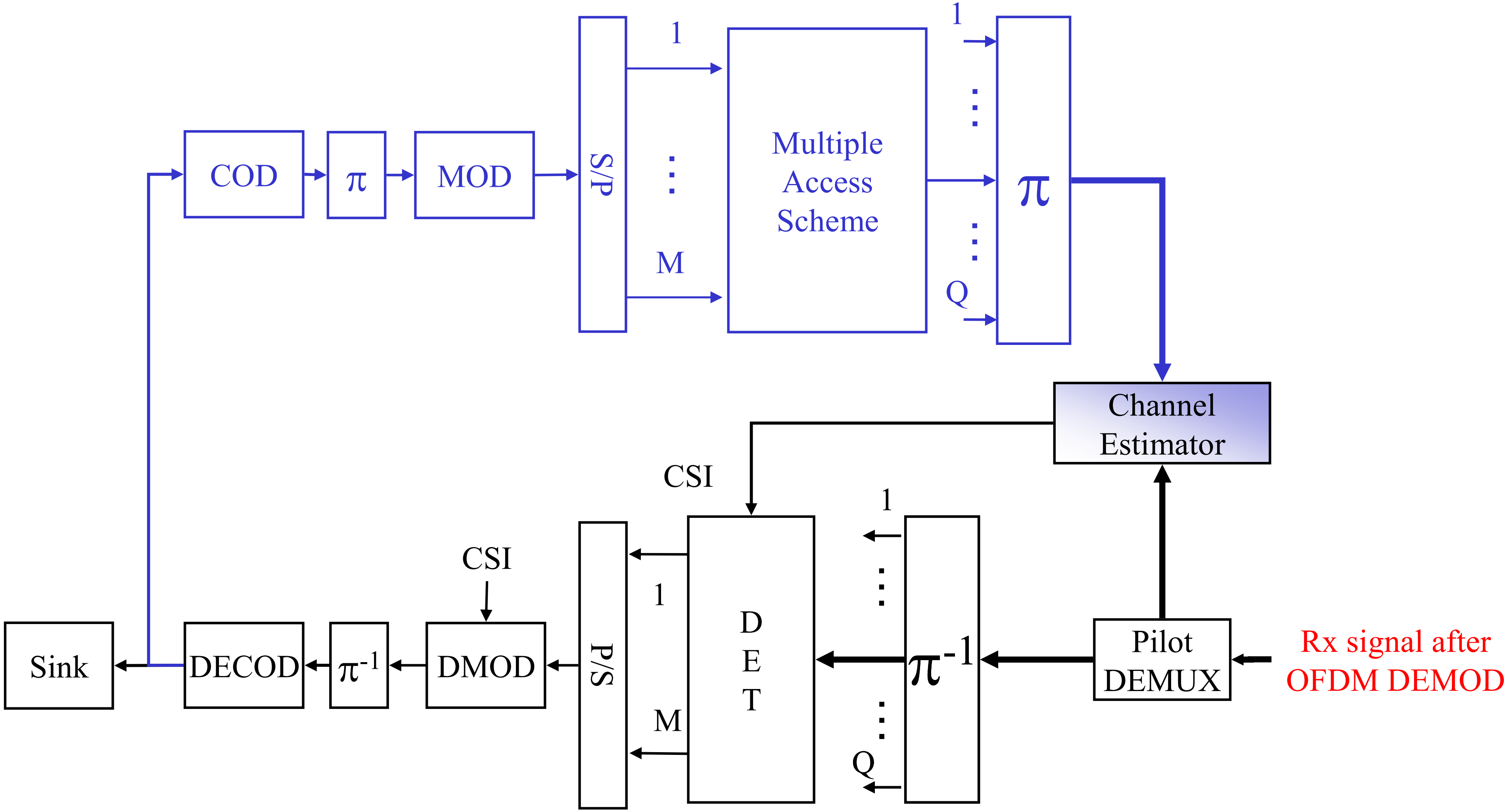
Outline

- ➢ System model
  - Downlink MC-CDMA
  - Iterative Channel Estimation (ICE)
  - Frame structure
- ➢ Pilot aided channel estimation (PACE)
- ➢ Spreading problem & solution
- ➢ Simulation results
- ➢ Conclusions & outlook

System Model: Downlink MC-CDMA



System Model: Iterative Channel Estimation (ICE)

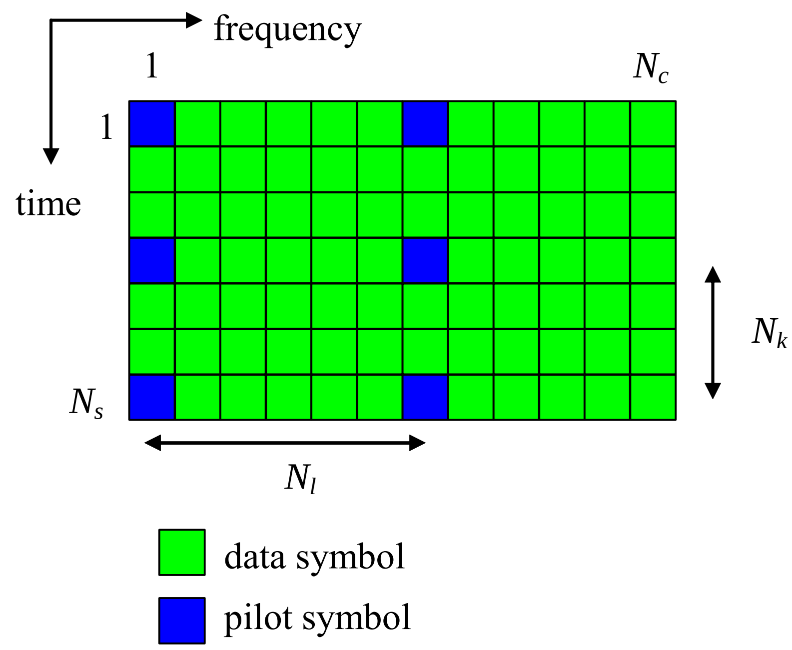


System Model: Frame Structure

- Rectangular grid, starting point (1,1)
  - Pilot distance in frequency direction: N_l
  - Pilot distance between OFDM symbols: N_k
- $2 \times$ oversampling
  - Pilot distance in frequency direction:

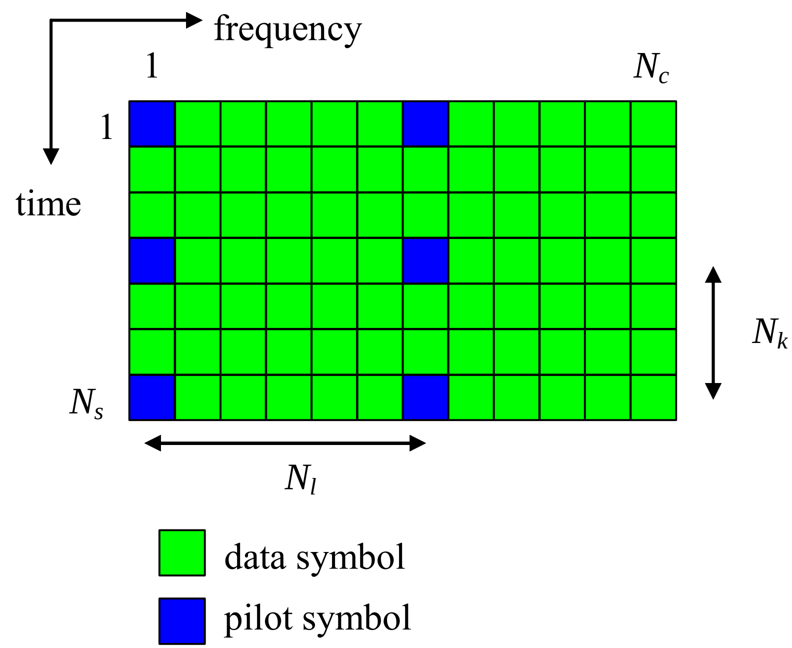
    $N_l \approx 1/2/(2\ \tau_{\max} \Delta F)$
  - Pilot distance between OFDM symbols:

    $N_k \approx 1/2/(4\ f_{D\max} T_s)$



System Model: Frame Structure

- Rectangular grid, starting point (1,1)
  - Pilot distance in frequency direction: N_l
  - Pilot distance between OFDM symbols: N_k
- Example: $T_s = 9.5\ \mu s$
  - f_{Dmax}=20 Hz (4km/h @ 5GHz):
    $N_k \approx 1/2/(4\ f_{Dmax} T_s) \approx 650$
  - f_{Dmax}=1500 Hz (300km/h @ 5GHz):
    $N_k \approx 1/2/(4\ f_{Dmax} T_s) \approx 9$



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:

$$\breve{H}_{n',k'} = \frac{R_{n',k'}}{S_{n',k'}} = H_{n',k'} + \frac{N_{n',k'}}{S_{n',k'}}, \qquad \forall \{n',k'\} \in \Re,$$

    where $\Re$ denotes the set of reference symbols.

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

$$\hat{H}_{n',k'} = \sum_{\{n',k'\} \in \Im_{n,k}} \omega_{n',k',n,k} \breve{H}_{n',k'}, \qquad \Im_{n,k} \in \Re, \qquad n = 1,\ldots,N_c, k = 1,\ldots,N_s,$$

    where $\omega_{n',k',n,k}$ is the shift-variant 2-D impulse response of the filter.
    $\Im_{n,k}$ 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

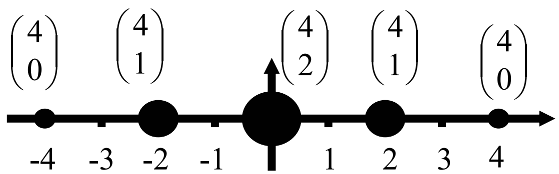
- SNR for the Wiener filter design can be fixed

  ⇒ no further information about the actual SNR needed during channel estimation

⇒ Only maximum Doppler frequency, maximum time delay, and average expected SNR need to be known to design robust Wiener filter

Spreading Problem & Solution

- MC-CDMA:
  - Walsh-Hadamard spreading code:
    zero-valued subcarriers can occur during transmission
  - Example : Walsh-Hadamard spreading code, N=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?

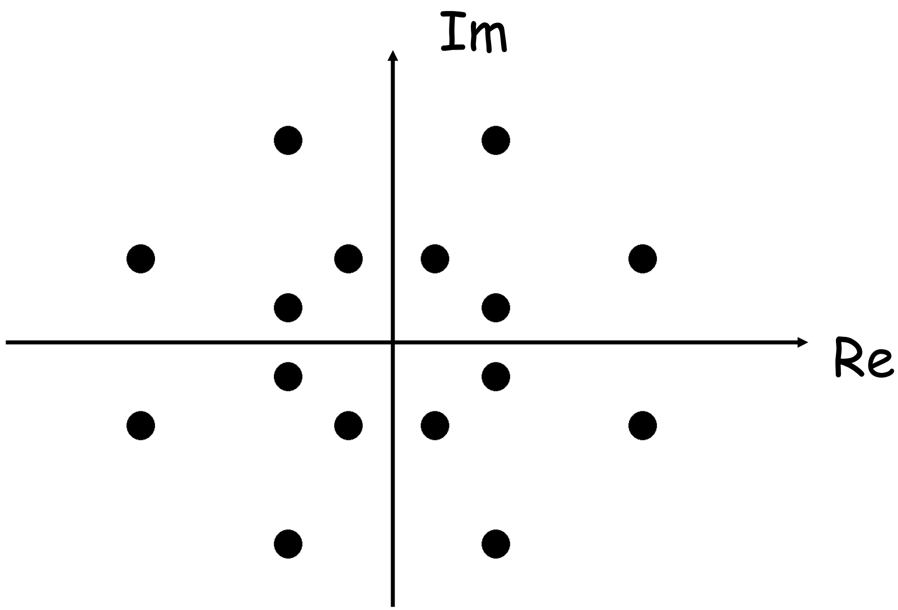
$$\breve{H}_{n',k'} = \frac{R_{n',k'}}{\hat{S}_{n',k'}}$$

Spreading Problem & Solution

- Rotated Transform and WH spreading code:

  no zero-valued subcarriers, no ambiguity

Rotated Constellation
after spreading



Spreading Problem & Solution

- MMSE channel estimation method:

$$\breve{H}_{n',k'} = \begin{cases} \dfrac{R_{n',k'}}{S_{n',k'}} & \text{if reference symbol } S_{n',k'} \\[2ex] \dfrac{\hat{S}^{*}_{n',k'} R_{n',k'}}{\left|\hat{S}_{n',k'}\right|^{2} + \rho_{th}} & \text{if estimated data symbol } \left|\hat{S}_{n',k'}\right| \end{cases}$$

  - Good approximation: ρ_{th}=1/SNR
  - For low SNR: no division by zero can occur and no noise enhancement

Spreading Problem & Solution

- Modified LS Method:

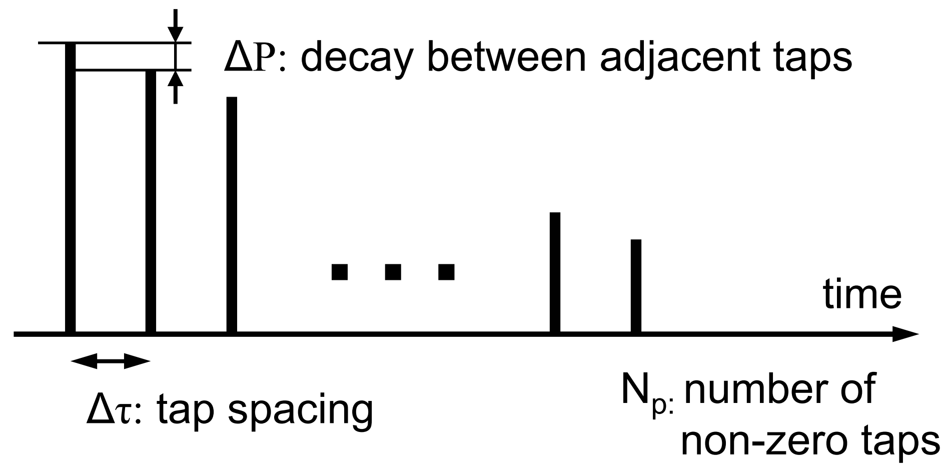
  If the reconstructed subcarrier is zero or below a certain threshold, set the LS channel estimates to zero:

$$\breve{H}_{n',k'} = \begin{cases} \dfrac{R_{n',k'}}{S_{n',k'}} & \text{if reference symbol } S_{n',k'} \\ \dfrac{R_{n',k'}}{\hat{S}_{n',k'}} & \text{if estimated data symbol } \left|\hat{S}_{n',k'}\right| > \rho_{th} \\ 0 & \text{if estimated data symbol } \left|\hat{S}_{n',k'}\right| \leq \rho_{th} \end{cases}$$

Simulation Results: Scenario

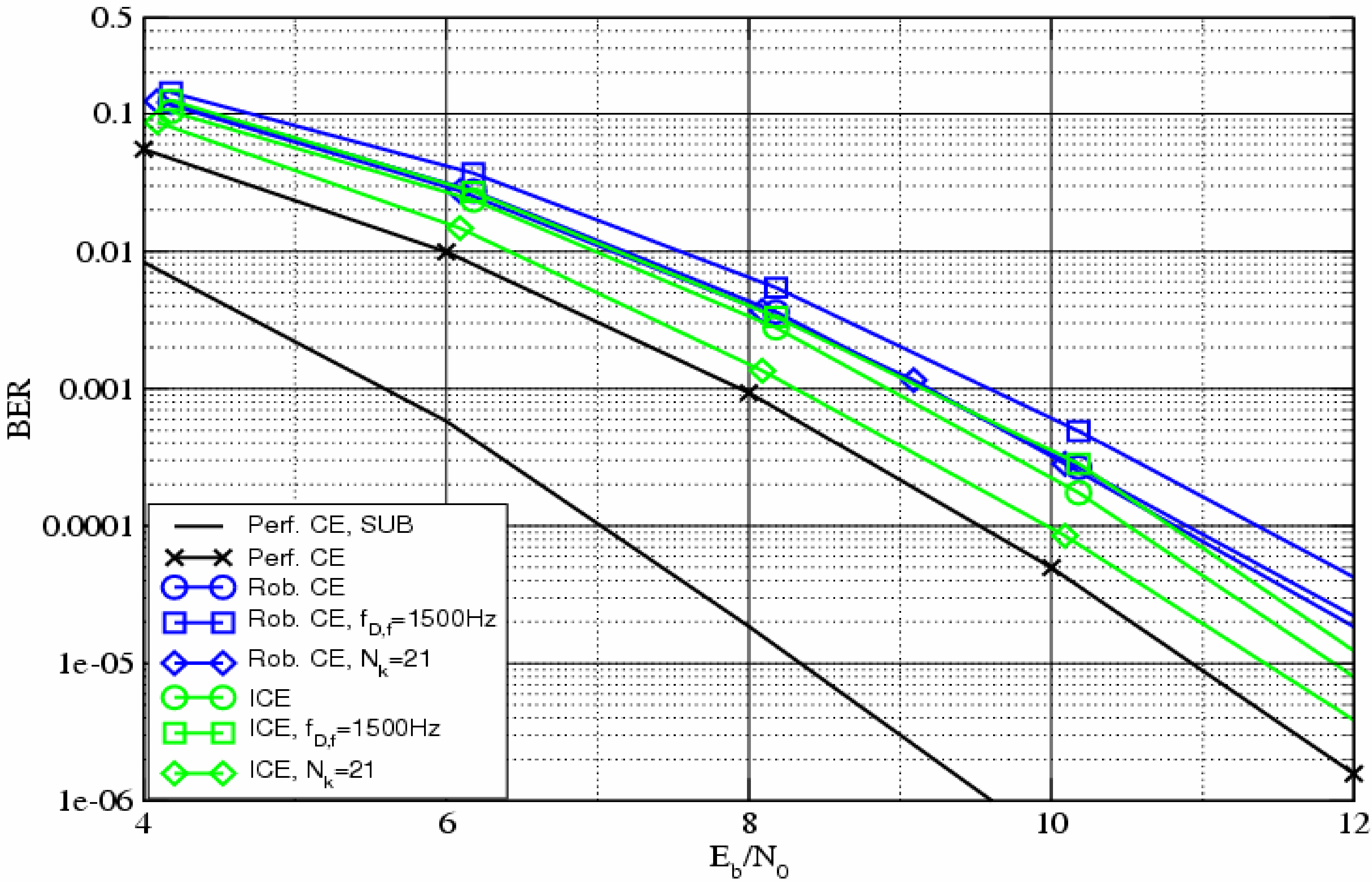
Bandwidth	101.5 MHz
Subcarriers	768
FFT length	1024
Sampling duration T_{spl}	7.4 ns
Guard interval T_{GI}	226 T_{spl}
Subcarrier spacing Δf	131.836 kHz
OFDM symbols / Frame	64
Modulation	4-QAM
Coding	Conv. code, R=1/2
Detection	MRC, MMSE
Pilot spacing frequency	3
Pilot spacing time	9,21
Max delay channel estimator	T_{GI} =226 T_{spl}
Max Doppler channel estimator	0.01*, 0.00013*Δf
LS-Estimation	Modified LS

Channel model



$f_{D,max}$	0.01*, 0.00013*Δf
T_{max}	176 T_{spl}
N_p	12
ΔP	1dB
$\Delta \tau$	16 T_{spl}

Simulation Results: f_D=20Hz (4km/h @ 5GHz)



Default Values:

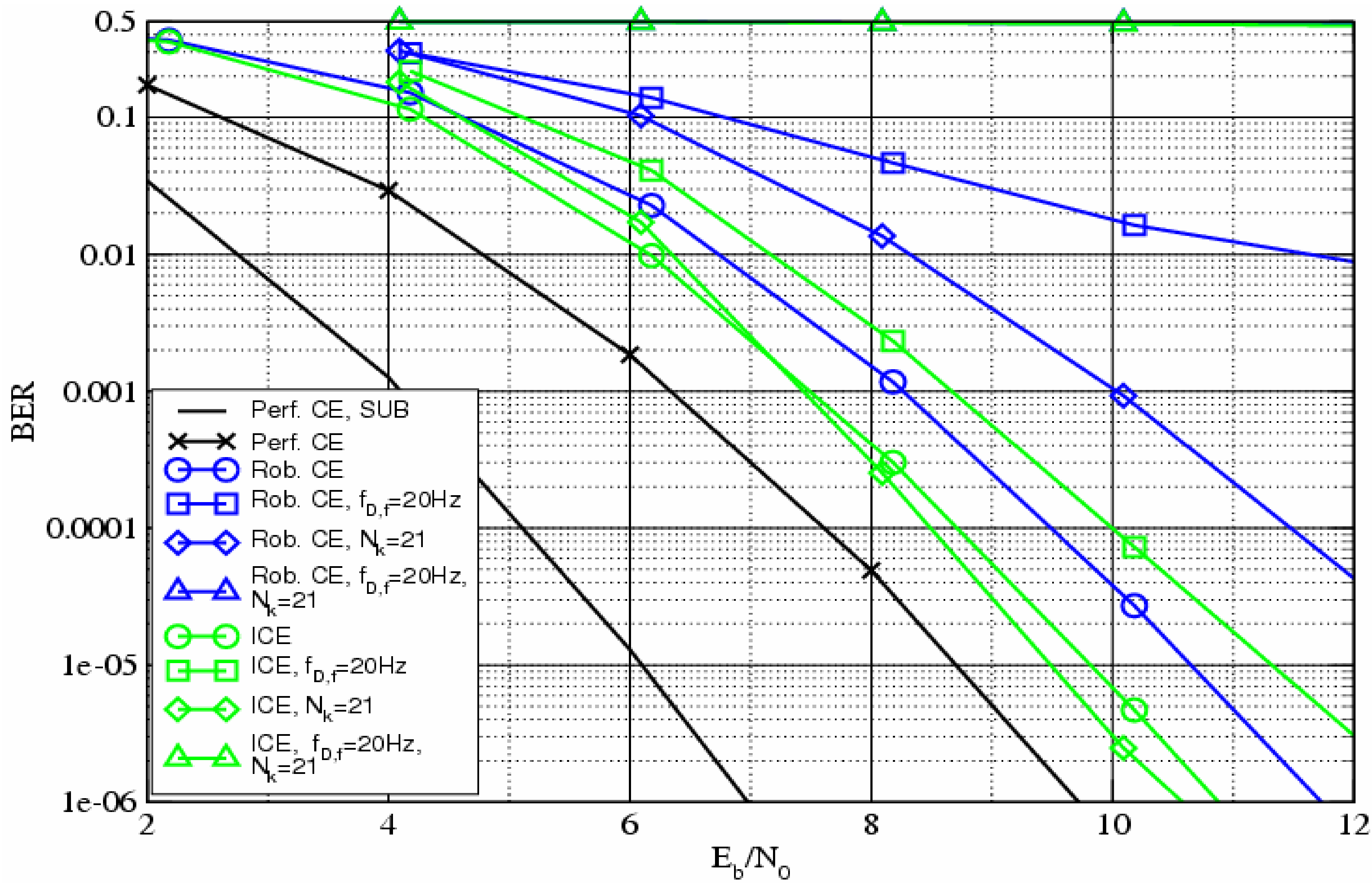
Detection:
SU MMSE

Pilot spacing:
N_k=9

Doppler freq. of CE:
$f_{D,f}$=20Hz

ICE:
Rob. Wiener filt.,
1 Iteration,
All users det. in user group

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



Default Values:

Detection:
SU MMSE

Pilot spacing:
N_k=9

Doppler freq. of CE:
$f_{D,f}$=1500Hz

ICE:
Rob. Wiener filt.,
1 Iteration,
All users det. in user group

Conclusions & Outlook

- ICE with Walsh-Hadamard spreading: zero-valued subcarriers
- Rotated transform & Walsh-Hadamard spreading
- MMSE channel estimation method
- Modified LS Method
- Simulation results indicate:
  - Robust ICE always improves robust PACE
  - Performance gains with robust ICE even for scenarios optimized for robust PACE
- Outlook:
  - Soft feedback in ICE to improve convergence
  - MIMO ICE to reduce pilot overhead