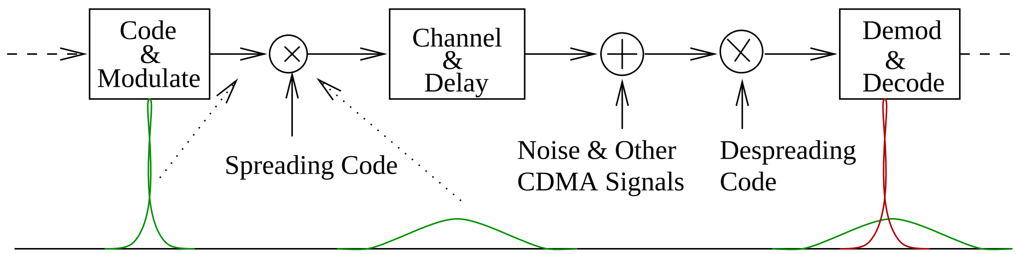
Code division multiple access (CDMA)

- Uses available bandwidth efficiently
- Distinguishes users by codewords
- A simple CDMA transmitter and receiver

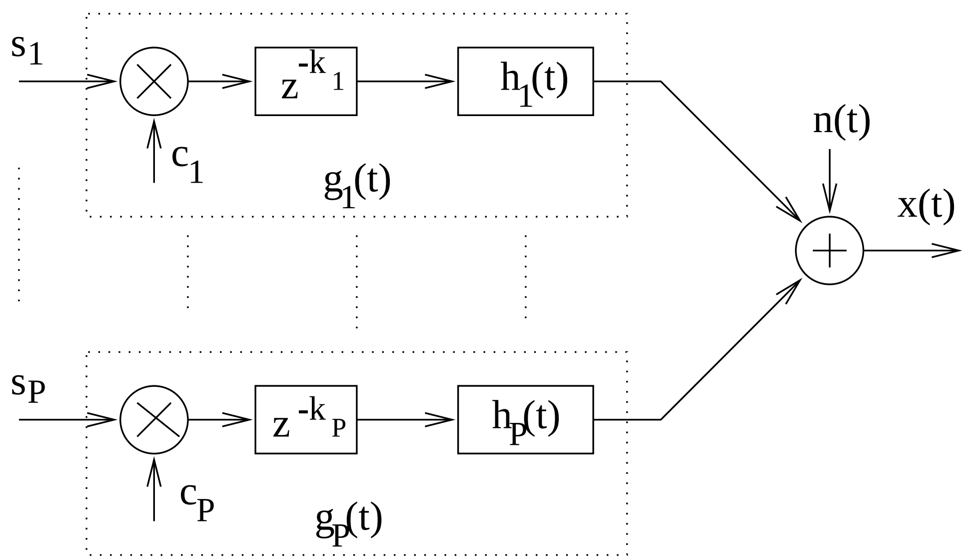


☞ Chip period for spreading code is T_c

CDMA Systems

- Synchronous CDMA
  - ☞ All signals are synchronized to within T_c (200 ns)
  - ☞ Orthogonal codewords
  - ☞ destroyed by multipath fading
- Narrowband Asyncronous CDMA
  - ☞ IS-95
  - ☞ RAKE receiver coherently resolves multipath fading
- Wideband Asynchronous CDMA (A-CDMA)
  - ☞ Emerging third-generation standards
  - ☞ Estimate (vector) FIR channel parameters for symbol estimation

A-CDMA System with P Users



- ☞ Blindly estimate $h_1(t), \ldots, h_P(t)$
- ☞ Assume knowledge of spreading codes $c_1, \ldots, c_P$
- ☞ Assume knowledge of propagation delays $k_1, \ldots, k_P$.

A-CDMA Model and Data Formulation

- Baseband signal, single receiver, P users:

$$x(t) = \sum_{i=1}^{P} \sum_{n=-\infty}^{\infty} s_i(n) g_i(t - nT_s)$$

  - ☞ i denotes the user index
  - ☞ P is the number of users
  - ☞ $\{s_i(n)\}$ are the information symbols
  - ☞ T_s is the symbol duration
  - ☞ $g_i(t)$ is a signature waveform

$$g_i(t) = \sum_{k=1}^{2L_c} c_i(k - k_i) h_i(t - kT)$$

  - ☞ $\{c_i(1),\ c_i(2), \cdots, c_i(L_c);\ \ c_i(k) = \pm 1\}$ is the preassigned spreading code of i^{th} user
  - ☞ L_c is the code length
  - ☞ $\{h_i(t)\}$ are the channels

Multi-User Channel Estimation

- Estimate signature vectors $\{\mathbf{g}_i\}$ $\Longleftrightarrow$ determine the channel vectors $\{\mathbf{h}_i\}$
- Data model when including additive white noise

$$\mathbf{X} + \mathbf{N} = \mathbf{G}\mathbf{S} + \mathbf{N}.$$

- Perform subspace decomposition on $\mathbf{X}$ by a singular value decomposition (SVD)

$$\mathbf{X} + \mathbf{N} = \begin{pmatrix} \mathbf{U}_s & \mathbf{U}_o \end{pmatrix} \begin{pmatrix} \Sigma_s & \mathbf{0} \\ \mathbf{0} & \Sigma_o \end{pmatrix} \begin{pmatrix} \mathbf{V}_s^H \\ \mathbf{V}_o^H \end{pmatrix}$$

☞ Vectors in $\mathbf{U}_s$ span the *signal subspace*, $\mathbf{G}$.

☞ Vectors in $\mathbf{U}_o$ span the *noise subspace*.

Multi-User Channel Estimation

- Estimate $\{\mathbf{G}_i\}$ from $\mathbf{X}$ without knowledge of $\mathbf{S}$
- Orthogonality between noise and signal subspace

$$\mathbf{U}_o \perp \mathbf{G} \Rightarrow \mathbf{U}_o^H \mathbf{G}_i = \mathbf{0}, \quad i = 1, \cdots, P$$

- Using $\mathbf{G}_i = \mathbf{C}_i \mathbf{h}_i$ yields

$$\mathbf{U}_o^H \mathbf{C}_i \mathbf{h}_i = \mathbf{0}, \quad i = 1, \cdots, P$$

☞ $\mathbf{C}_i$ is a Toeplitz matrix of spreading codes

☞ $\mathbf{h}_i$ is in the null space of $\mathbf{U}_o^H \mathbf{C}_i$

Blind Channel Estimation Algorithm for a Single Receiver

1. Construct data matrix $\mathbf{X}$
2. Apply SVD to $\mathbf{X}$, or eigenvalue decomposition (EVD) of $\mathbf{X}\mathbf{X}^H$, to obtain orthogonal subspace $\mathbf{U}_o$.
3. For each user, estimate the channel vector $\mathbf{h}_i$
4. Reconstruct signature vectors $\{\mathbf{g}_i\}$ and $\{\mathbf{G}_i\}$

☞ This algorithm exploits the important fact that each signature vector is a *linear* function of a unique spreading code [Torlak & Xu, IEEE-TSP Jan. 1997]

Capacity Increase Using Smart Antennas

- A-CDMA system with code length L_c cannot accommodate more than L_c users [Viterbi].
- Fundamental limit for a single antenna $P < L_c$
- Goal: Manage an overloaded system ($P \geq L_c$)
- Proposed algorithm breaks in an overloaded system (dimension of the orthogonal subspace $\mathbf{U}_o$ reduces)
- Additional orthogonal vectors are required to guarantee more equations than unknowns
- This can be achieved by spatially oversampling by means of multiple receivers

Capacity Increase Using Smart Antennas

- Assume M receivers at the base-station

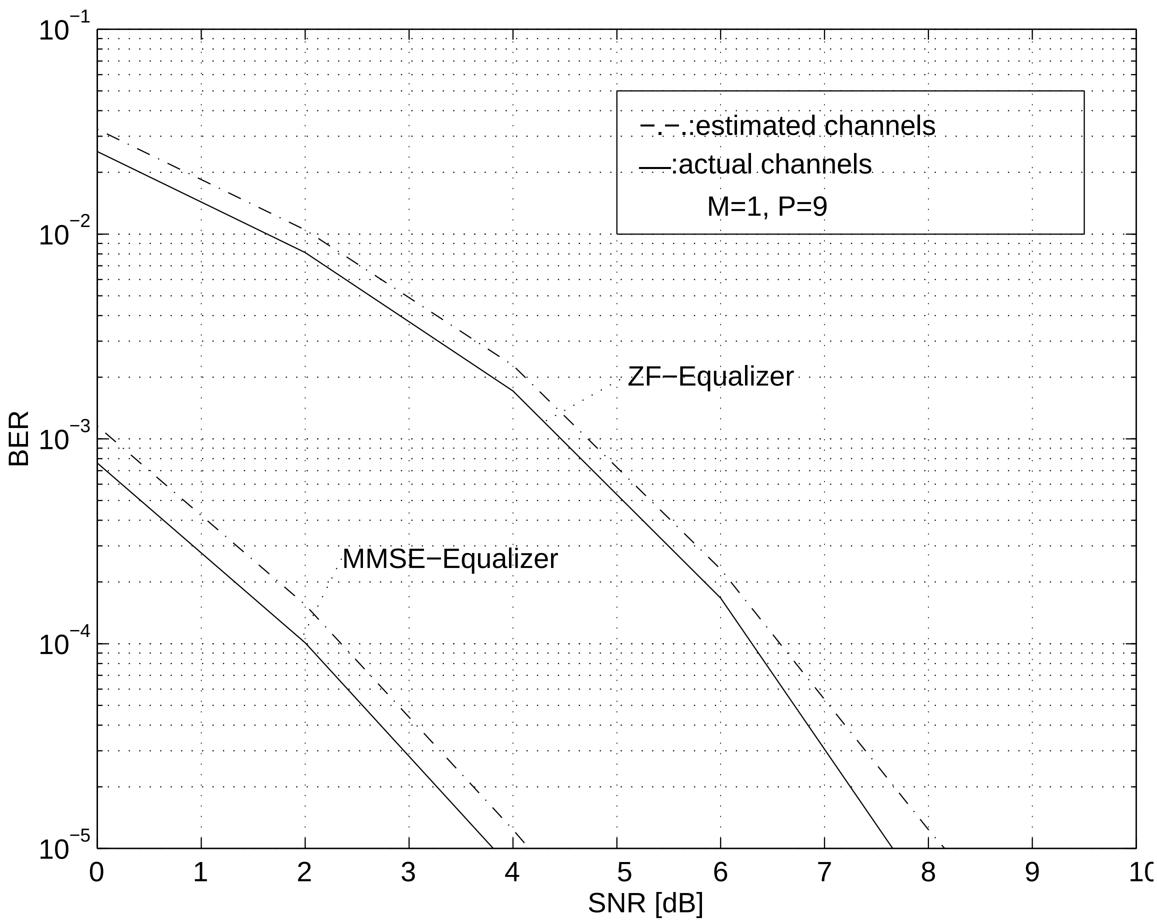
$$\mathbf{X} = \begin{bmatrix} \mathbf{X}^1 \\ \vdots \\ \mathbf{X}^M \end{bmatrix} = \sum_{i=1}^{P} \underbrace{\begin{bmatrix} \mathbf{G}_i^1 \\ \vdots \\ \mathbf{G}_i^M \end{bmatrix}}_{\mathbf{G}_i} \mathbf{S}_i(K+1)$$

where K is the integer smoothing factor of $\mathbf{X}$

- $\mathbf{X} = \mathbf{G}\mathbf{S}$ still holds, so does the subspace space relation between $\mathbf{X}$ and $\mathbf{G}$
- Orthogonal vectors in $\mathbf{U}_o$ increases from $KL_c - (K+1)P$ to $MKL_c - (K+1)P$
- Signal space fixed while noise space increases
- Extend our proposed algorithm to handle $P \geq L_c$

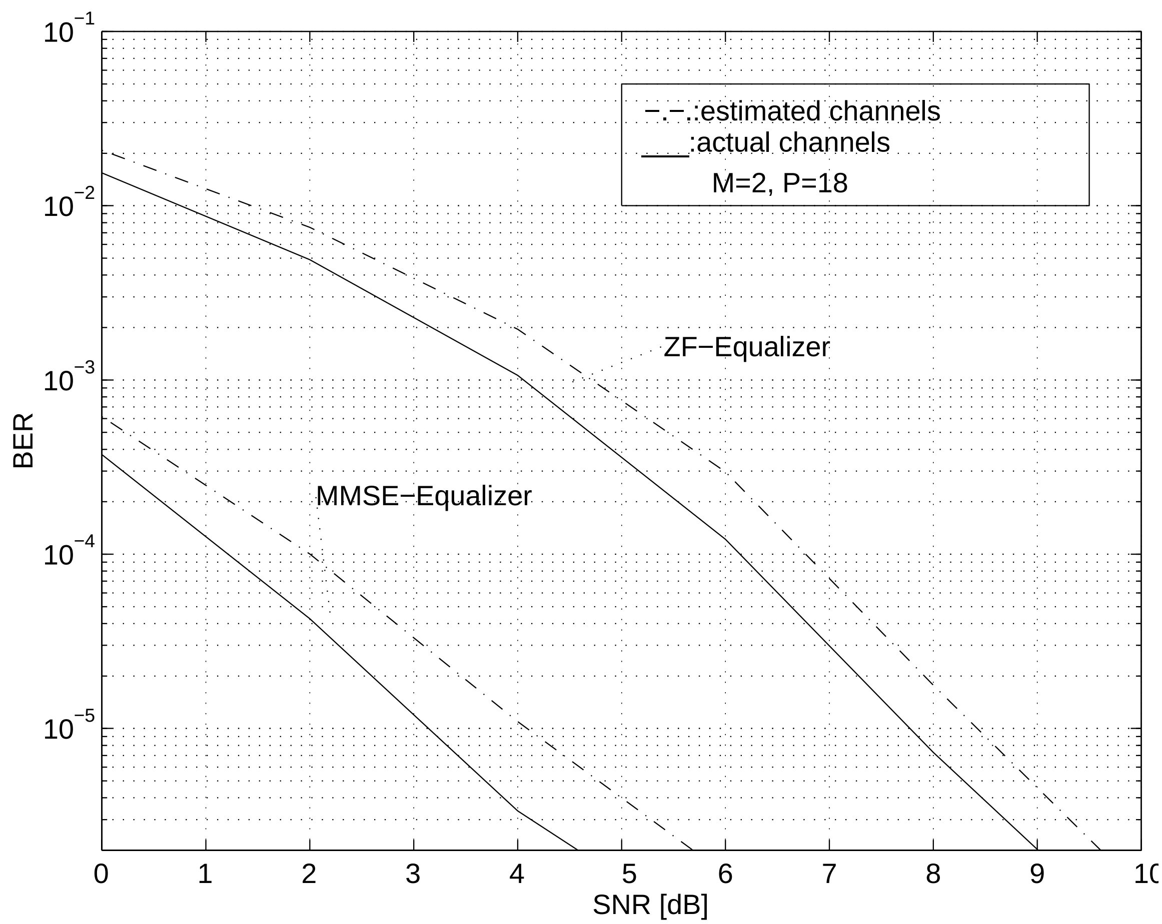
Non-Overloaded A-CDMA System Simulation

☞ Average bit error rate (BER) for different receivers with estimated and actual channels



Overloaded A-CDMA System Simulation

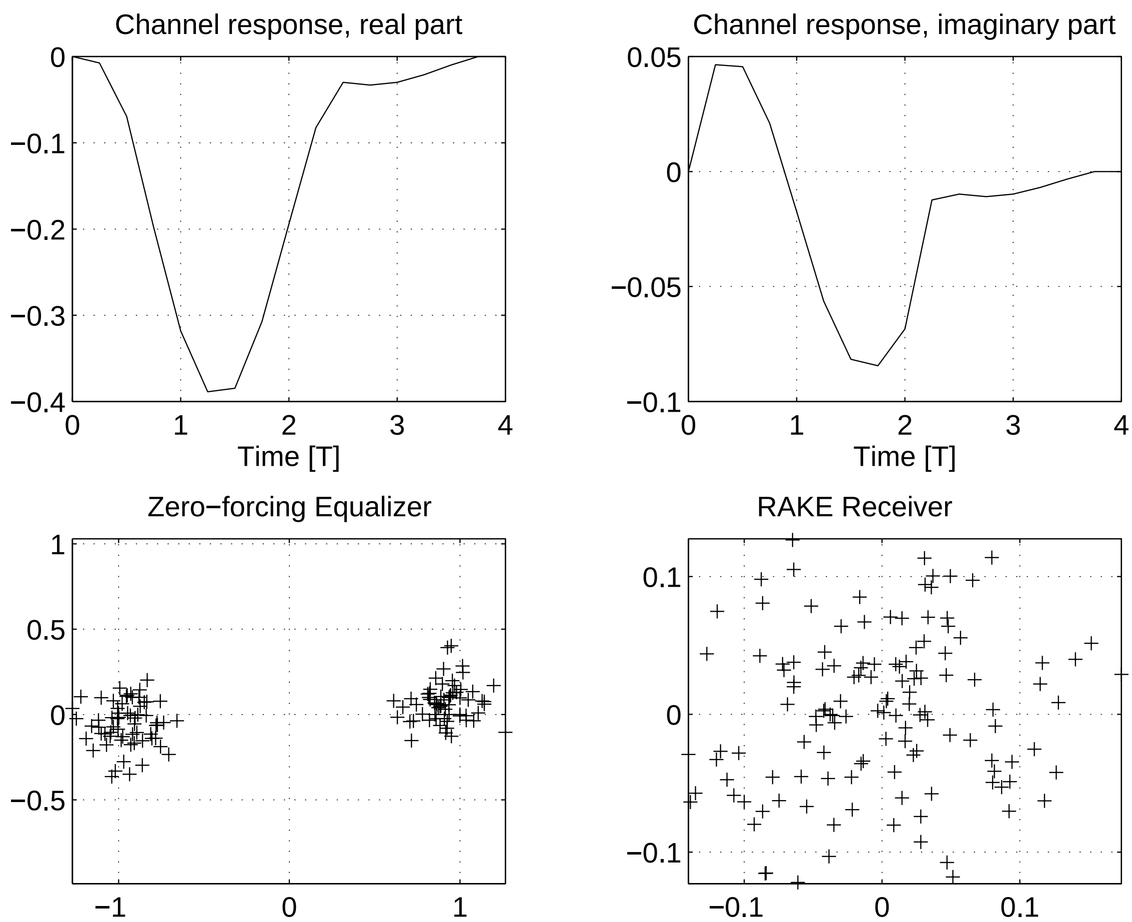
☞ Average BER for different receivers with estimated and actual channels



Computer Simulations

- A single receiver A-CDMA system with $L_c = 16$, $P = 11$, $K = 4$ and SNR$=$ 10 dB.

☞ Signal Constellations for user #1



Computer Simulations

- Two receiver antennas with a 22-user system.