A Self-Recovering RAKE Receiver for Asynchronous CDMA Systems

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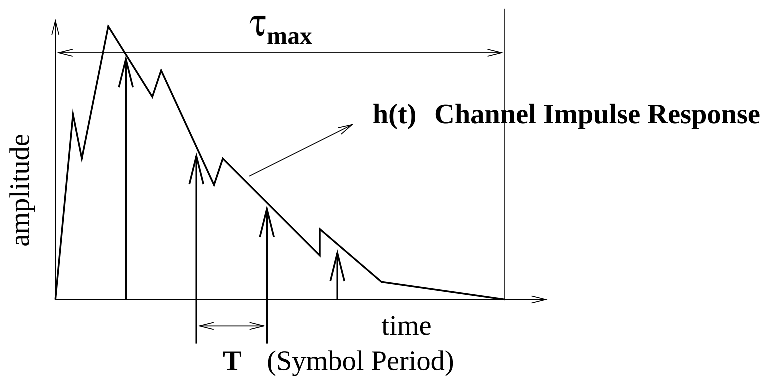
INTRODUCTION

- Advanced CDMA Receivers
  - ☞ Multiuser Reception $\Longrightarrow$ Enhance the worst-case performance
  - ☞ Self-Recovery $\Longrightarrow$ Blind reception; increase survivability, and robustness
  - ☞ Adaptive Implementation $\Longrightarrow$ Fast convergence, and reduced complexity
- Problem
  - ☞ Design an advanced CDMA receiver which converges faster than existing receivers
- Solution
  - ☞ Adapt constant modulus algorithm to CDMA signals

Background: Wideband Channels

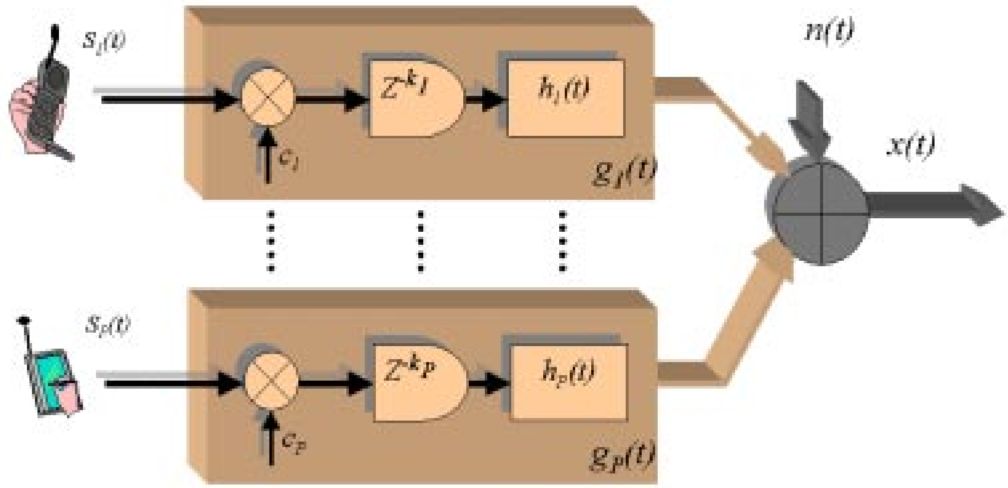
- Wideband CDMA signals suffer from frequency selective fading
- The symbol period, T, is close in value to multipath spread, τ_{max}



- Single-user case with L paths to receiver

$$\mathbf{x}(t) = \sum_{k=1}^{L} \alpha_k s(t - \tau_k) = \mathbf{h}(t) \otimes s(t)$$

ASYNCHRONOUS-CDMA SYSTEMS WITH PERIODIC SPREADING



- Baseband signal with *P* users and the code waveform distorted by the channel

$$x(t) = \sum_{i=1}^{P} \sum_{n=-\infty}^{\infty} s_i(n) g_i(t - nT_s) \quad \text{and} \quad g_i(t) = \sum_{k=1}^{2L_c} c_i(k - k_i) h_i(t - kT)$$

  - ☞ Asynchronous operation due to user signals' propagation delays, k_i
  - ☞ i is the user index; $\{s_i(n)\}$ are data symbols; T_s is the symbol duration
  - ☞ c_i is the spreading code; L_c is the code length; $h_i(t)$ are channels

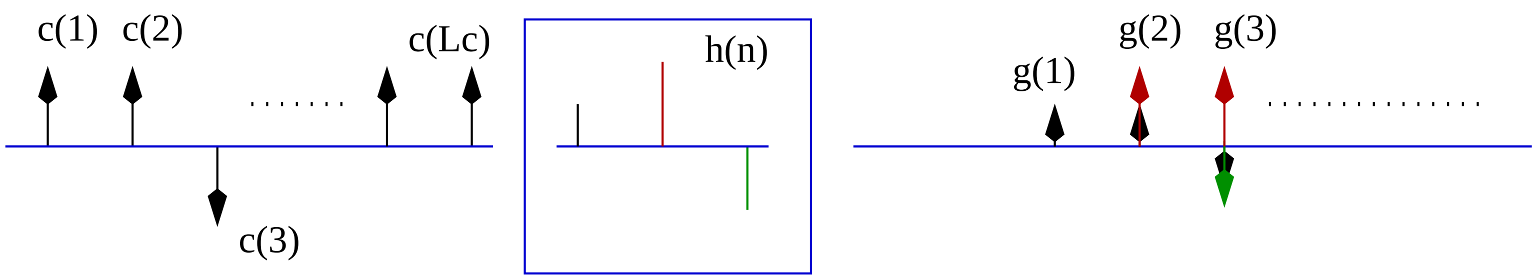
DISCRETE DISTORTED CODE WAVEFORM OF THE DESIRED USER

- Spreading code is distorted by the channel

$$\mathbf{g}_i = \begin{bmatrix} \mathbf{g}(1) \\ \mathbf{g}(2) \end{bmatrix} = \mathbf{c}_i \mathbf{h}_i$$

- Filtering effect leads to Hankel code matrix

$$\mathbf{c}_i = \begin{bmatrix} \mathbf{c}_i(1) \\ \mathbf{c}_i(2) \end{bmatrix}, \ \ \mathbf{c}_i(j) \ is \ L_c \times L, \ j = 1, \ 2$$



VECTOR REPRESENTATION OF A-CDMA SIGNALS

- Stack data samples for two symbols period

$$\mathbf{X}(l) = \mathbf{g}_1 s_1(n) + \mathbf{O}(n)$$

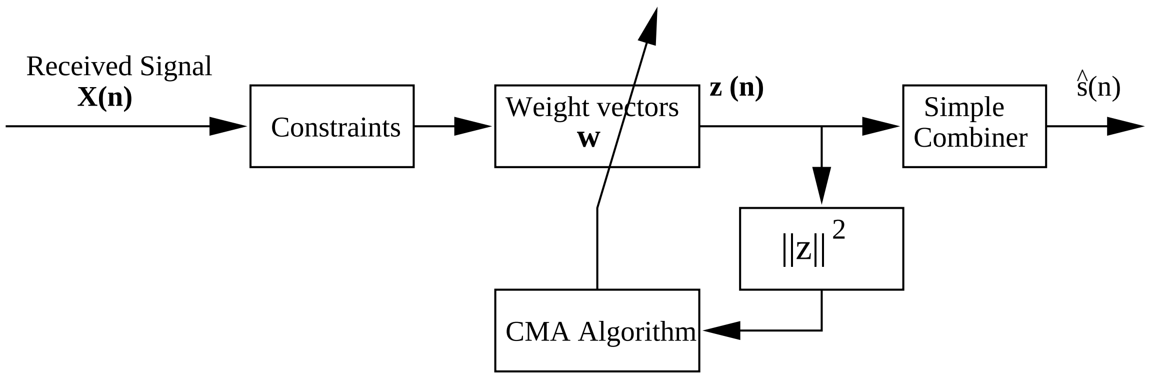
- $\mathbf{O}(n)$ contains intersymbol interference, multiuser interference, and noise

$$\begin{bmatrix} \mathbf{g}_1(2) & \mathbf{0} \\ \mathbf{0} & \mathbf{g}_1(1) \end{bmatrix} \begin{bmatrix} s_1(n-1) \\ s_1(n+1) \end{bmatrix} + \sum_{i=2}^{P} \mathbf{G}_i \mathbf{S}_i(n) + \mathbf{V}(n).$$

Self-Recovering RAKE Receiver

- Conventional RAKE receiver uses code correlators $\Longrightarrow$ Fingers
- Exploit constant modulus property of transmitted symbols (BPSK, QPSK, . . .)
- Propose self-recovering RAKE receiver based on constant modulus algorithm
- Fingers are jointly adapted to suppress intersymbol interference and multiuser interference

RAKE RECEIVER BASED ON CMA



- Adapt correlators at each finger

$$z_l(n) = \mathbf{w}_l^H \mathbf{X}(n)$$

- Correlators $\mathbf{w}_l$ are subject to a set of constraints

$$\mathbf{w}_l^H \mathbf{c}_i = \mathbf{e}_l, \quad \mathbf{e}_l = [0, \cdots, 1, \cdots, 0]^T$$

- Search direction is constrained by Hankel code matrix

Modified CMA Cost Function

- Noncoherently combine RAKE fingers to produce the desired signal power

$$J(\mathbf{w}_l) = E\left[\left(\sum_{1}^{L} \|z_l\|^2 - \delta\right)^2\right]$$

- Adapt each finger according to CMA and constraints

$$\mathbf{w}_l(n+1) = \mathbf{w}_l(n) - \mu \Pi_{\mathbf{c}_i}^{\perp} \mathbf{X}(n)\mathbf{z}^H(n)e_l(n)$$

  ☞ $e_l(n) = \sum_{l=1}^{L} |z_l(n)|^2 - \delta$ is the error signal

  ☞ δ sets the gain of the proposed RAKE receiver

  ☞ $\Pi_{\mathbf{c}_i}^{\perp} = \mathbf{I} - \mathbf{c}_i^H(\mathbf{c}_i\mathbf{c}_i^H)\mathbf{c}_i$ is the orthogonal projection matrix

- Coherently combine finger outputs to demodulate desired user signal

Simple Coherent Combining Algorithm

- Finger outputs can be rewritten as

$$\mathbf{z}(n) = \begin{bmatrix} z_1(n) \\ \vdots \\ z_L(n) \end{bmatrix} = \begin{bmatrix} a_1 \\ \vdots \\ a_L \end{bmatrix} \mathbf{s}_1(n) + \mathbf{v}(n)$$

☞ $\mathbf{v}$ contains residual interference and noise

- For N samples, estimate the power of each finger output

$$A_l = \frac{1}{N} \sum_{n=1}^{N} |z_l(n)|^2 \quad l = 1, \ldots, L$$

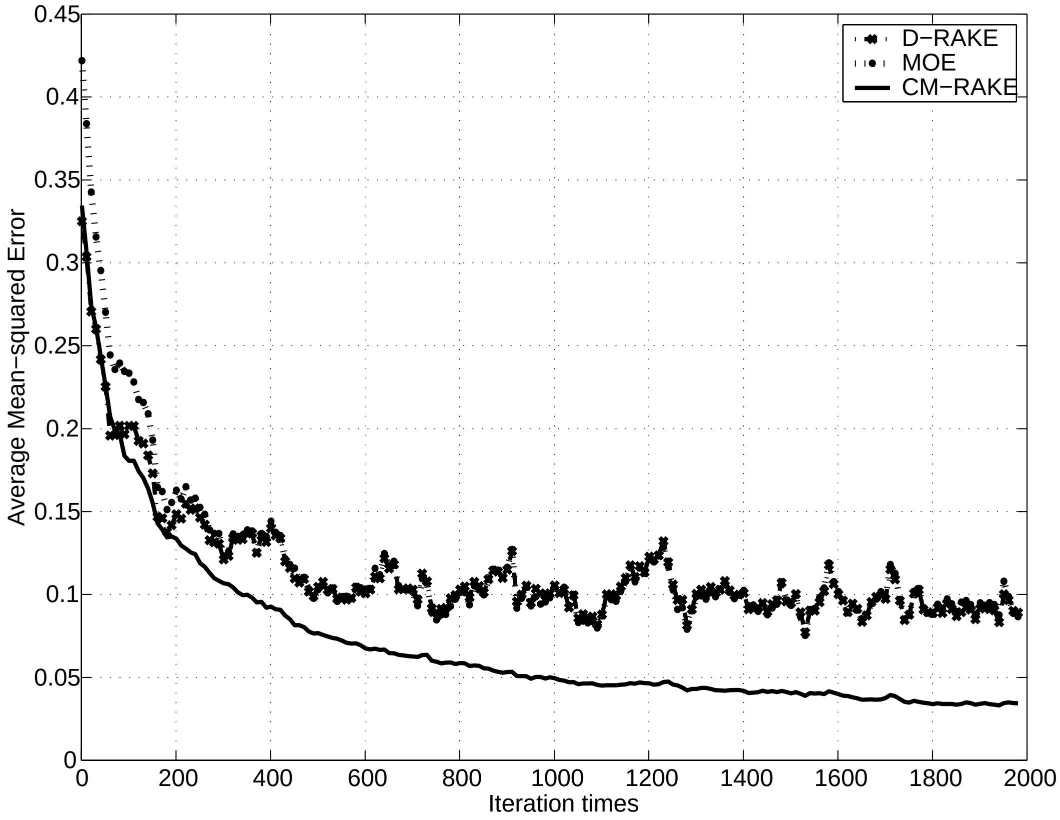
- Construct an estimator by multiplying the finger outputs by the complex conjugated of the kth finger whose output power is the maximum

$$\hat{\mathbf{a}} = \frac{1}{N} \mathbf{z}(n) z_k^*(n).$$

SIMULATION RESULTS

- Convergence of proposed CM-RAKE, adaptive D-RAKE and MOE receivers.

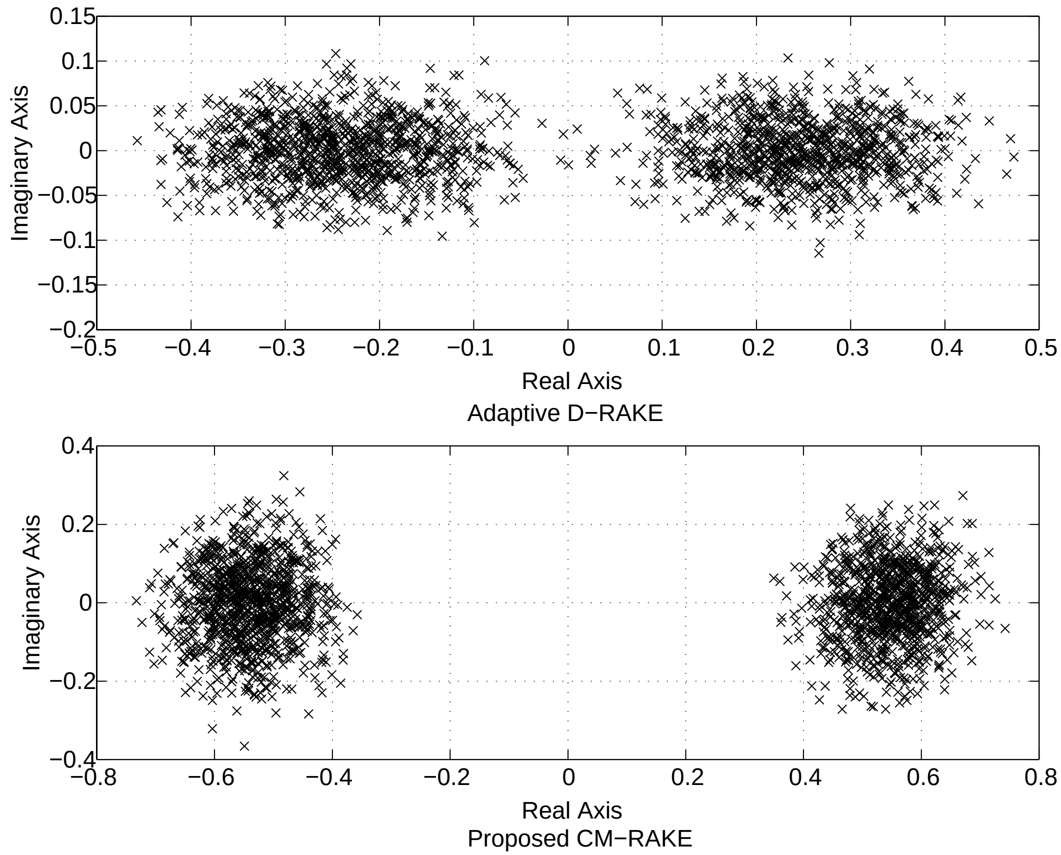
  ☞ Spreading gain=16, M=1, SNR=20 dB, $\mu = 0.05$, and 8 users



Simulation Results

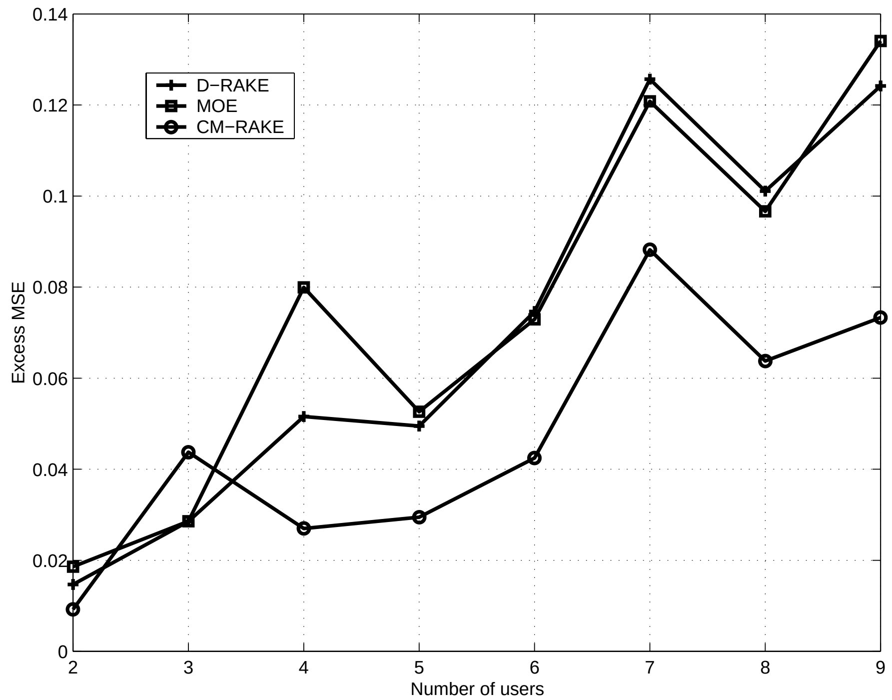
- Signal constellations after convergence.

  ☞ Spreading gain=16, M=1, SNR=20 dB, $\mu = 0.05$, and 8 users



SIMULATION RESULTS

- Averaged MSEs for the different adaptive receivers with varying number of users
  - ☞ Spreading gain=16, M=1, and SNR=20 dB



CONCLUSIONS

- Self-recovering RAKE receiver based on constant modulus algorithm
  - ☞ Better convergence rate that other blind adaptive receivers
  - ☞ Directly operate on the combined output powers without obtaining the demodulated signal
  - ☞ The signal can be demodulated after convergence using a coherent combining algorithm.
- Future directions
  - ☞ Performance and convergence analysis
  - ☞ Real-time implementation