EM-based Iterative Channel Estimation, 
Interference Cancellation and Data Decoding 
for DS-CDMA

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State-of-the-art: AAU
**SYSTEM MODEL FOR CODED DS-CDMA**

The complex baseband representation of the received signal

\[ r(t) = \sum_{l=0}^{L-1} \sum_{k=1}^{K} a_k d_k[l] s_k(t - lT_s) + n(t) \]

- BPSK modulation, i.e. \( d_k[l] \in \{+1, -1\} \);
- \( K \) users; Frame length \( L \);
- AWGN and flat Rayleigh fading channels;
- Convolutional codes;
- Rectangular chip waveform for \( s_k(t) \).
SYSTEM MODEL FOR CODED DS-CDMA

Optimal receiver structure:

\[ r(t) \xrightarrow{} \text{Matched Filter User 1} \xrightarrow{[1/T_s]} \text{Buffer} \xrightarrow{z} \text{Whitening Filter } (F^T)^{-1} \xrightarrow{y} \text{Optimal multiuser decoder} \xrightarrow{\hat{b}_{ML}} \]

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SAGE Algorithm (cont’d)

Maximum a posteriori (MAP) estimation of $\mathcal{D}$ given the observation $\mathcal{Z}$ is defined by

$$\hat{D}_{\text{MAP}} = \arg \max_{D \in \mathcal{D}} \log p(\mathcal{D} | \mathcal{Z})$$

- Objective function: $\log p(\mathcal{Y} | \mathcal{D})$

EM algorithm:
- $\mathcal{Y}$: Incomplete data;
- $\mathcal{X}$: Complete data;
- $\mathcal{D}[^i]$: Estimate of $\mathcal{D}$ at iteration $i$.
- Objective function: $Q \left( \mathcal{D} | \mathcal{D}[^i] \right) = E \left\{ \log p(\mathcal{X} | \mathcal{D}) | \mathcal{Y}, \mathcal{D}[^i] \right\}$.

SAGE algorithm: Estimate a parameter subset of $\mathcal{D}$ at each iteration:
- $\mathcal{D}_S$: Parameter subset;
- $\mathcal{X}_S$: Admissible hidden data for $\mathcal{D}_S$ (complete data if $\mathcal{D}_S$ is known;
- Objective function $Q_S \left( \mathcal{D}_S | \mathcal{D}[^i] \right) = E \left\{ \log p(\mathcal{X}_S | \mathcal{D}_S, \mathcal{D}_S[^i]) | \mathcal{Y}, \mathcal{D}[^i] \right\}$. 
Traditional Applications of the EM/SAGE Algorithms for Multiuser Soft-Decoding

- Swap role of nuisance parameter and parameter of interest; i.e. $D = a$ and $X = (z, d)$ [BEM algorithm] as in [Chiavaccini and Vitetta 2001]:
  - E-step: update code soft-symbols $d^{[z]} = E[d|z, a] \rightarrow \text{complexity } \mathcal{O}\{2^K\}$
  - M-step: re-estimate the channel vector $a$.

- Keep role of nuisance parameter and parameter of interest; but modify SAGE algorithm [Hu et al. 2004]
  - E-step: estimate channel vector $a$
  - D-step: estimate soft estimate of code symbols $d$
THE ITERATIVE SISO-SAGE BASED RECEIVER ARCHITECTURE

$z$

Channel Estimation

$\tilde{a}^i$

Soft MAI Cancellation for user $k$

$\lambda^e_{SAGE}(d'_k)^{[i+1]}$

$\lambda^e_{SAGE}(d_k)^{[i+1]}$

$\Pi_k^{-1}\lambda^e_{SAGE}(d_k)^{[i+1]}$

SISO SU Decoder for user $k$

$\lambda^e_{dec}(d_k)^{[i+1]}$

$\tilde{b}_k$

Update $\tilde{d}_k^{[i]}$ only $i + 1 \rightarrow i$

$\Pi_k$

APPs

APPs

EXT values

APP or EXT values

APP or EXT values

$\Pi_k$

SD

$\Sigma$

$\Sigma$

APPs

EXT values

APP or EXT values

$\tilde{d}_k^{[i]}$

$\tilde{d}_k^{[i]}$

$\tilde{d}_k^{[i]}$

$\tilde{d}_k^{[i]}$

$d_0^{[0]}$

$k = \kappa[i] \mod K + 1$

APP or EXT values
State-of-the-art: ftw.
THE ITERATIVE PIC RECEIVER ARCHITECTURE

Channel Estimation

Soft MAI Cancellation

\( z^{[i]} \) → \( a^{[i]} \)

Update \( \hat{d}^{[i]} \)

Channel
Estimation

Soft MAI Cancellation

Update \( \hat{d}^{[i]} \)

SISO SU Decoder for user 1

\( \Pi_1^{-1} \)

\( \hat{d}_1 \)

SISO SU Decoder for user \( K \)

\( \Pi_K^{-1} \)

\( \hat{d}_K \)

Update \( \hat{d}^{[i]} \)

\( i + 1 \rightarrow i \)

\( d^{[0]} \)

\( z^{[i]} \) → \( d' \)

\( d' \)

\( \Pi_1 \)

SD

\( \Pi_1 \)

SD

\( \Pi_K \)

SD

\( \Pi_K \)

SD

APPs

EXT values

APPs

EXT values
Comparison of the two schemes
SIMULATION SCENARIOS

- Rate=1/2 convolutional codes \((5_8 7_8)\);
- 320 information bits per frame;
- 6 pilot symbols and 80 code symbols per block;
- Random spreading sequences, processing gain \(N_c = 8\);
- AWGN channel (known/unknown to the receiver);
- Initial MMSE channel estimator and multiuser detector based on pilot symbols;
- Different types of soft information \((SI_{CE}/SI_{IC})\) fed to channel estimator (CE)/interference cancellation device (IC);
- Channel is updated per user.
Settings: known channel, (5,7) conv. codes, $N_c = 8$, $E_b/N_0 = 5$ dB, AWGN.
Settings: *known* channel, (5,7) conv. codes, $N_c = 8, \frac{E_b}{N_0} = 5$ dB, AWGN.
**SIMULATION RESULTS**

PIC with APP feedback

Settings: *known* channel, (5,7) conv. codes, $N_c = 8$, $E_b/N_0 = 5$ dB, AWGN.
SIMULATION RESULTS

Pic with EXT feedback

Settings: known channel, (5,7) conv. codes, $N_c = 8$, $E_b/N_0 = 5$ dB, AWGN.

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SIMULATION RESULTS

Settings: unknown AWGN, (5,7) conv. codes, Nc = 8, Eb/N0 = 5 dB.

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SIMULATION RESULTS

Settings: unknown AWGN, (5,7) conv. codes, $N_c = 8$, $E_b/N_0 = 5$ dB.
OPEN ISSUES AND OUTLOOK

Why does the system load and convergence speed of different receiver architectures depend on different kind of soft information fed back to the

- interference cancellation device,

- and channel estimator?

A theoretical framework is under construction.