A BLOCK FACTOR ANALYSIS BASED RECEIVER FOR BLIND MULTI-USER ACCESS IN WIRELESS COMMUNICATIONS

We present a technique for the blind separation of DS-CDMA signals received on an antenna array, in the context of multi-path propagation with Inter Symbol Interference (ISI).
Our method relies on a new third-order tensor decomposition, which is a generalization of the parallel factor (PARAFAC) model.

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Communication System

- Blind Signal Separation: Why? Estimation of the data relative to each user without prior knowledge of the learning sequence.
  - Get higher communication rate.
  - Eavesdropping.
  - Source localisation.
  - Case of learning sequence unavailable or partially received.

- Parameters and propagation model:
  - R: Nb of users, transmitting at the same time within the same bandwidth.
  - I: Spreading Factor of CDMA codes.
  - J: Duration of the observation window (in Symbol Periods).
  - $I \times J$ samples collected at the receiver.
  - K: Nb of receiving Antennas.
  - P: Nb of reflected paths per user (Multipath Propagation).
  - L: Nb of interfering symbols (Inter Symbol Interference, ISI).

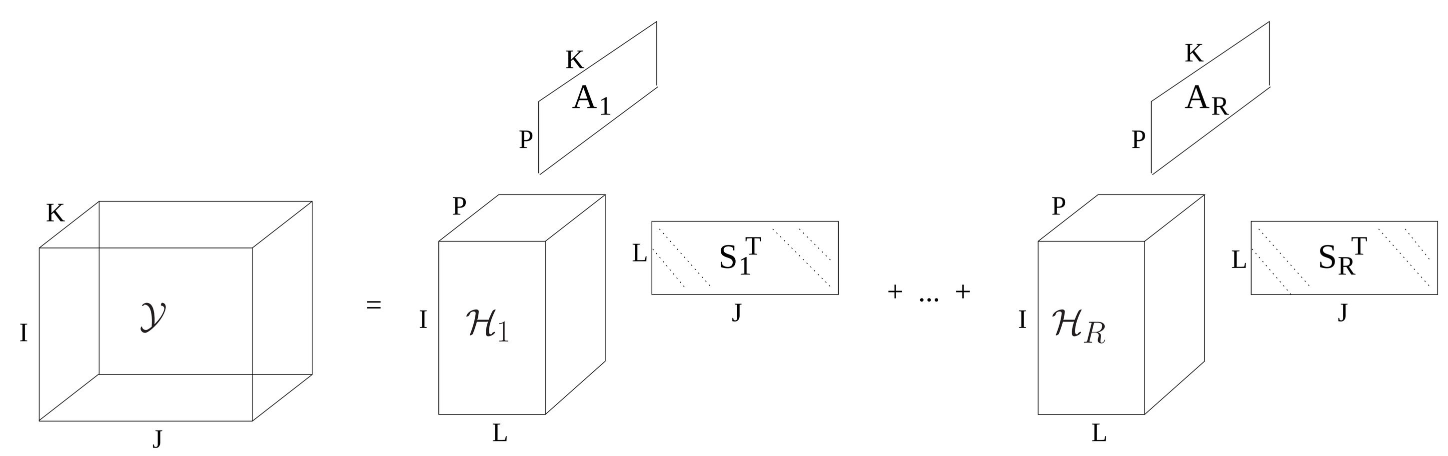
- Over-Sampled Received Signal: Analytic Form

Antenna Response — Channel Effect — Transmitted Symbol

$$y_{ijk} = \sum_{r=1}^{R} \sum_{p=1}^{P} a_k(\theta_{rp}) \sum_{l=1}^{L} h_{rp}(i + (l-1)I)\, s_{j-l+1}^{(r)}$$

Contribution of R users — Contribution of P paths — Contribution of L ISI

- Over-Sampled Received Signal: Algebraic Form



Block Factor Model (BFM)

- The Problem consists of the decomposition of the observation tensor in a sum of R terms.
- Each Term contains the information related to one particular user (channel, antenna response and symbols).
- The Toeplitz structure of each $\mathbf{S}_r$ is exploited.

Uniqueness of the Decomposition

- If BFM unique (up to some trivial indeterminacies): separation of the different user signals and estimation of the transmitted sequences are possible.
- Sufficient condition for uniqueness:

$$min\left(\left\lfloor\frac{J}{L}\right\rfloor, R\right) + min\left(\left\lfloor\frac{K}{P}\right\rfloor, R\right) + min\left(\left\lfloor\frac{I}{max(L,P)}\right\rfloor, R\right) \geq 2R+2, \quad (1)$$

- Upper bound on the number of users = maximal value of R that satisfies this equation.

I	J	K	L	P	R max
4	50	4	2	2	2
6	50	6	2	2	4
12	50	4	2	2	6

More users (R=6) than antennas (K=4)

Computation of the Decomposition

- Objective: Given only $\mathcal{Y}$, estimate $\mathcal{H}_r$, $\mathbf{S}_r$ and $\mathbf{A}_r$ for each user.
- Matrix Representation of the unknowns:
  $\mathbf{A}$ ($K \times RP$ matrix), $\mathbf{H}$ ($RLP \times I$ matrix), $\mathbf{S}$ ($J \times RL$ matrix).
- Optimization Problem to Solve: Minimize the cost function

$$\begin{aligned}\phi_{ALS} &= \left\|\mathcal{Y} - \mathcal{Y}^{(n)}\right\|_2^2 \\ &= \left\|\mathbf{Y}^{(JK\times I)} - (\mathbf{S}^{(n)} \odot_R \mathbf{A}^{(n)})\mathbf{H}^{(n)}\right\|_2^2,\end{aligned} \quad (2)$$

where the superscript n denotes the estimation at the n^{th} iteration.

- Solution: Alternating Least Squares Algorithm (ALS)
  Exploit the multilinearity of the model to alternate between conditional least-squares updates of the unknowns.

Summary of the ALS algorithm

1- Initialize $\mathbf{S}^{(n-1)}$, $\mathbf{H}^{(n-1)}$, $n=1$.

2- ALS Steps:

- Find $\mathbf{A}^{(n)}$ from $\mathbf{S}^{(n-1)}$ and $\mathbf{H}^{(n-1)}$.

- Find $\mathbf{S}^{(n)}$ from $\mathbf{A}^{(n)}$ and $\mathbf{H}^{(n-1)}$.

- Find $\mathbf{H}^{(n)}$ from $\mathbf{A}^{(n)}$ and $\mathbf{S}^{(n)}$.

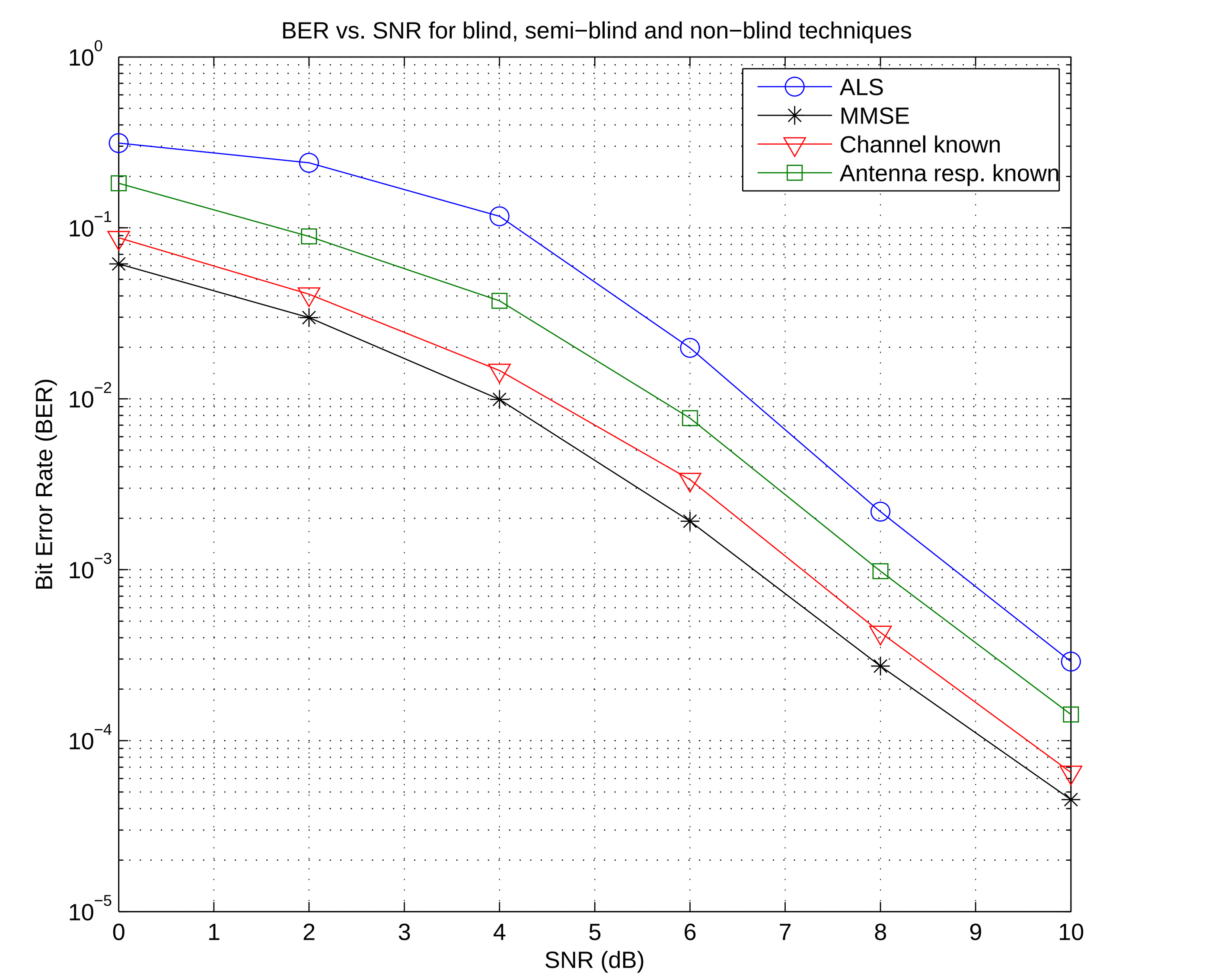
3- Repeat from 2 until $c(n) < \epsilon$ (e.g. $\epsilon = 10^{-5}$),

where $c(n) = \left\|\mathcal{Y}^{(n)} - \mathcal{Y}^{(n-1)}\right\|_2^2$.

- Increase n to $n+1$

Experimental Results

- Performance in presence of AWGN. Noisy tensor of observation: $\mathcal{Y}_{obs} = \mathcal{Y} + \mathcal{N}$.
- Parameters: $I = K = 6$, $J = 30$ QPSK symbols, $L = P = 2$, $R = 4$ (On the uniqueness bound).
- Comparison between performance of BFM Blind Receiver, MMSE (Non-Blind) Receiver, and Semi-Blind Receivers (either $\mathbf{H}$ or $\mathbf{A}$ known).



Conclusion

The Block Factor Model leads to a powerful blind receiver for multi-user access in wireless communications, with performance close to the MMSE receiver.
Both ISI and multi-path propagation are taken into account.
Other methods [1,2] have been developed to improve the convergence speed of the ALS (Levenberg-Marquardt, Line Search,...).

[1] Dimitri Nion and Lieven De Lathauwer, "Line Search Computation of the Block Factor Model for Blind Multi-User Access in Wireless Communications", SPAWC 2006, July 2-5, Cannes, France, accepted.

[2] Dimitri Nion and Lieven De Lathauwer, "Levenberg-Marquardt Computation of the Block Factor Model for Blind Multi-User Access in Wireless Communications", EUSIPCO 2006, September 4-8, Florence, Italy, accepted.

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