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An Efficient Joint Data Detection and Channel Estimation Technique for Uplink MC-CDMA Systems Based on SAGE Algorithm

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Outline

- Introduction
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- Uplink MC-CDMA systems
- Signal Model
- EM algorithm
- Simulations
- Conclusion

Introduction

Multicarrier (MC) and Code Division Multiple Access (CDMA) have gained considerable interest due to their considerable performance

OFDM (Orthogonal Frequency Division Multiplexing)

- Robust against multi-path propagation effects
- Reduced system complexity due to equalization in the frequency domain
- Increase of spectral efficiency
- Efficient modulation algorithm available (IFFT, FFT)
- No continuous spectrum required
- The capability of narrow-band interference rejection

Introduction

Code Division Multiple Access (CDMA)

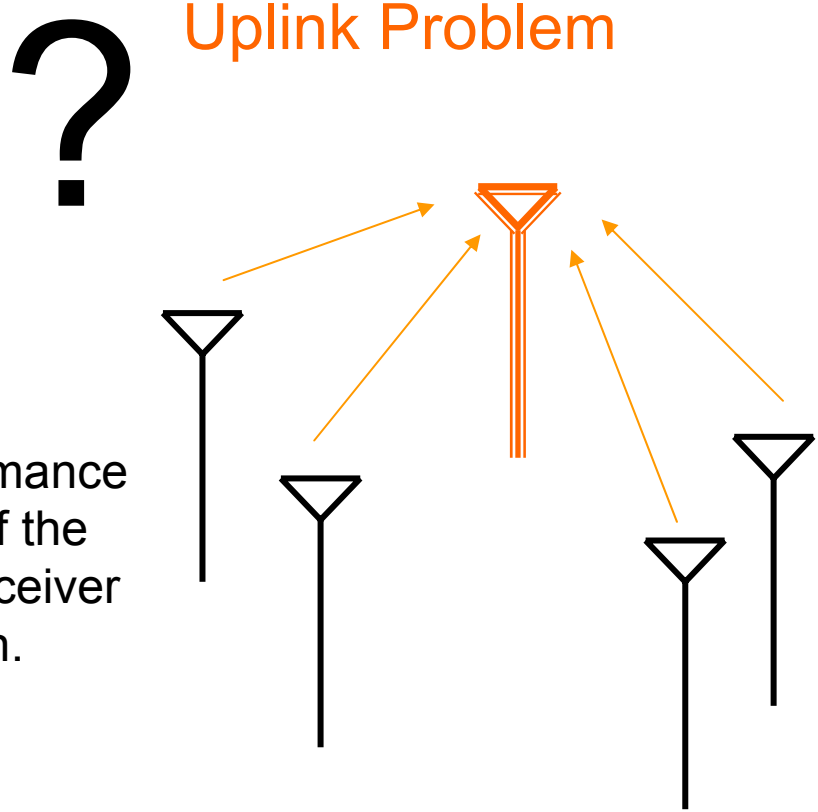
- Allows multiple users to share same bandwidth at the same time
- An ability to reduce user's signal power during transmission using a power control algorithm
- Extended battery life because of effective power control
- No guard bands or guard times are typically required relative to TDMA and FDMA

MC-CDMA

As a combination of OFDM and CDMA techniques, it combines the advantages of both OFDM and CDMA

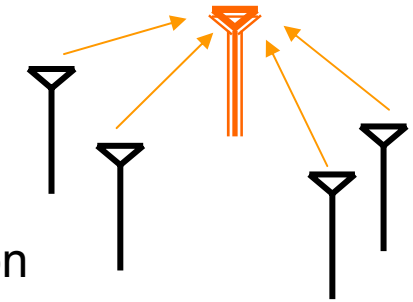
Objective of this work

Uplink Problem



- MC-CDMA transmission through the frequency-selective fading channels causes the SNR degradation and the occurrence of the multiple-access interference (MAI).
- To eliminate or reduce the resulting performance degradations, equalization and detection of the received signal can be performed at the receiver based on the complete channel information.
- In conventional MC-CDMA systems, MAI mitigation is accomplished at the receiver using single user or multi-user detection schemes

Objective of this work



- It is necessary to make excellent joint data and channel estimation for initialization of the interference cancelation detector

- We consider an efficient iterative algorithm based on the **SAGE technique** for multi-user data detection and channel estimation, jointly for uplink MC-CDMA systems in the presence of frequency selective fading channels.

Objective of this work

- The work is an extension of [R1] in which joint data detection and channel estimation of uplink DS-CDMA systems were considered based on an EM algorithm in the presence of flat Rayleigh channels.

R1: A. Kocian and B. H. Fleury, "EM-based joint data detection and channel estimation of DS-CDMA signals,"IEEE Trans. Commun., vol. 51, no. 10, pp. 17091720, Oct. 2003.

- We extend their results for the uplink MC-CDMA systems with frequency selective channels.

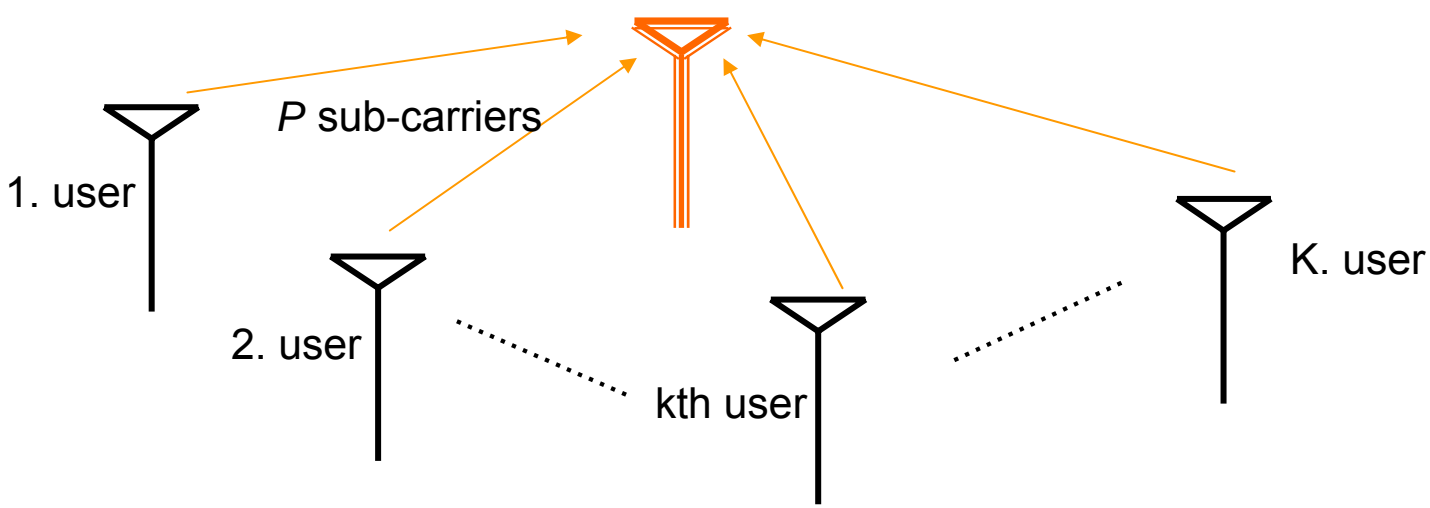
Uplink MC-CDMA systems

K mobile users are simultaneously active.

For the *k*th user, each transmit symbol is modulated in the frequency domain by means of a $P \times 1$ specific spreading sec$\mathbf{c}_k$nce .

After transforming by a *P*-point IDFT and parallel-to-serial (P/S) conversion, a cyclic prefix (*CP*) is inserted of length equal to at least the channel memory (*L*).

the signal is transmitted through frequency selective channel



Signal Model

At receiver, the received signal is first serial-to-parallel (S/P) converted, CP is removed and DFT is then applied to the received discrete time signal to obtain the received vector expressed as

$$\mathbf{y}(m) = \sum_{k=1}^{K} b_k(m)\mathbf{C}_k\mathbf{F}\mathbf{h}_k + \mathbf{w}(m) \quad , m = 1, 2, ..., M$$

$b_k(m)$ denotes data sent by the user k within the mth symbol time

$\mathbf{C}_k = \mathrm{diag}(\mathbf{c}_k)$ $\quad \mathbf{c}_k = [c_{k1}, c_{k1}, ..., c_{kP}]^T$ $\quad \mathbf{F} \in \mathbb{C}^{P\times L}$ denotes the DFT matrix

$\mathbf{w}(m)$ is the $P \times 1$ zero-mean, i.i.d. Gaussian vector

We stack $\mathbf{y}(m)$ as $\mathbf{y} = [\mathbf{y}^T(1), ..., \mathbf{y}^T(M)]^T$

$$\mathbf{y} = \begin{bmatrix} b_1(1)\mathbf{C}_1\mathbf{F} & \cdots & b_K(1)\mathbf{C}_K\mathbf{F} \\ \vdots & \ddots & \vdots \\ b_1(M)\mathbf{C}_1\mathbf{F} & \cdots & b_K(M)\mathbf{C}_K\mathbf{F} \end{bmatrix} \begin{bmatrix} \mathbf{h}_1 \\ \vdots \\ \mathbf{h}_K \end{bmatrix} + \begin{bmatrix} \mathbf{w}(1) \\ \vdots \\ \mathbf{w}(M) \end{bmatrix}$$

SAGE algorithm

Estimate the transmitted symbols $\mathbf{b} = \{b_k(m)\}_{k=1,m=1}^{K,M}$ for each user *k*.

Based on observed data **y**

nuisance parameters

$$\mathbf{h} = [\mathbf{h}_1, \mathbf{h}_2, \cdots, \mathbf{h}_K]^T$$

incomplete data $\mathbf{y}$

"hidden-data" set $\chi = (\mathbf{y}, \mathbf{h})$

- At each iteration *i* $\longrightarrow$ $\mathbf{b}_k = [b_k(1), b_k(2), \cdots, b_k(M)]$ $\quad k = k(i) = i \bmod K$

  is updated while keeping the data sequences in the complement set fixed $\mathbf{b}_{\tilde{k}}$

- $\mathbf{b}_{\tilde{k}}$ is the vector obtained by canceling the components of $\mathbf{b}_k$ in $\mathbf{b}$

SAGE algorithm

Problem

The SAGE algorithm

Expectation(E) step

Maximization(M) step

At the *i*th iteration the E-step computes

$$Q_k\left(\mathbf{b}_k|\mathbf{b}^{(i)}\right) = E\left\{\log p(\boldsymbol{\chi}|\mathbf{b}_k, \mathbf{b}_{\tilde{k}}^{(i)}|\mathbf{y}, \mathbf{b}^{(i)}\right\}$$

In the M-step,only $\mathbf{b}_k$ is updated as

$$\begin{aligned}\mathbf{b}_k^{(i+1)} &= \arg\max_{\mathbf{b}} Q_k(\mathbf{b}_k|\mathbf{b}^{(i)}) \\ \mathbf{b}_{\tilde{k}}^{(i+1)} &= \mathbf{b}_{\tilde{k}}^{(i)}.\end{aligned}$$

SAGE algorithm

successive interference cancellation

$$b_k^{i+1}(m) = \mathrm{sgn}\left[\Re\left\{\boldsymbol{\mu}_h^{(i)}[j]\boldsymbol{\Psi}_k^T\left[\mathbf{y}(m) - \sum_{j=1, j\neq k}^{K} b_j^{(i)}(m)\boldsymbol{\Psi}_j\boldsymbol{\mu}_h^{(i)}[j]\right]\right\}\right]$$

Channel estimation

$$(\mathbf{h}_k)^{(i)} \triangleq E\{\mathbf{h}_k|\mathbf{y}, \mathbf{b}^{(i)}\} = \boldsymbol{\mu}_h^{(i)}[k].$$

$$\boldsymbol{\Psi}_j \triangleq \mathbf{C}_j\mathbf{F}$$

Simulations

The orthogonal Walsh sequences selected as spread code and processing gain equals to the number of subcarriers

The number of users is selected as U=16 and each user send frame ,that is composed of T preamble bits, and F data bits, over mobile fading channel.

Wireless channels between mobiles antennas and receiver antenna are assumed to be TU channel channel of length L and it has distribution $N(0, Ch)$

Simulations

Compared Receivers

MMSE separate detection and estimation (SDE)

At the receiver, initial MMSE channel estimate is obtained by using T preamble bits while channel covariance matrix *Ch* is assumed to be know. Initial MMSE estimate of F data bits is computed from the observation of y while assuming we have estimated channel coefficients.

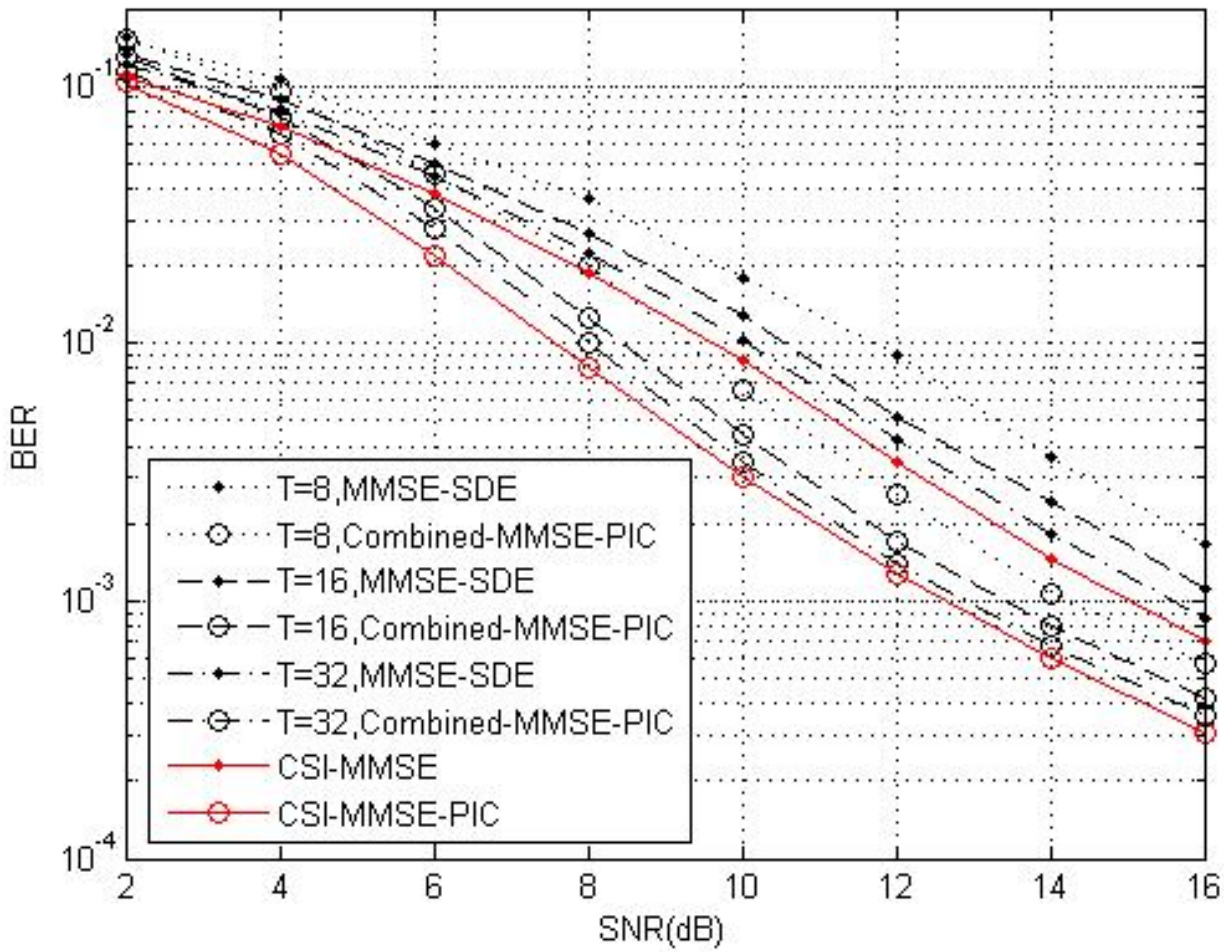
Perfect channel state information cases **CSI-MMSE**

Combined MMSE-PIC

If the output of the (MMSE-SDE) is applied to paralel interference cancellation (PIC) receiver

Perfect channel state information cases **CSI-Combined MMSE-PIC**

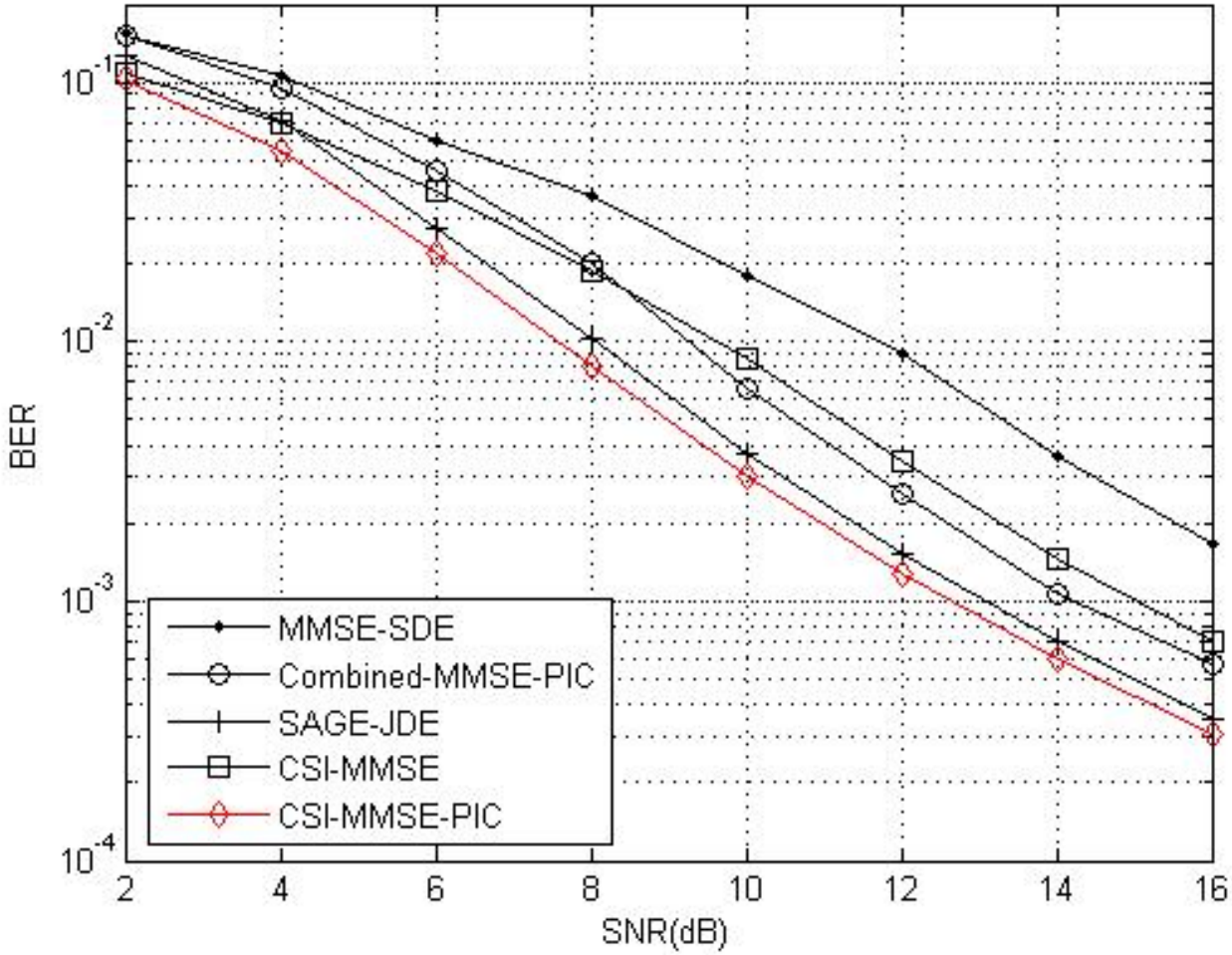
Simulations



- Performance of the seperate estimation and detection methods have been investigated
- We need T=32 to approach CSI case

Too many pilot---unefficient bandwith usage

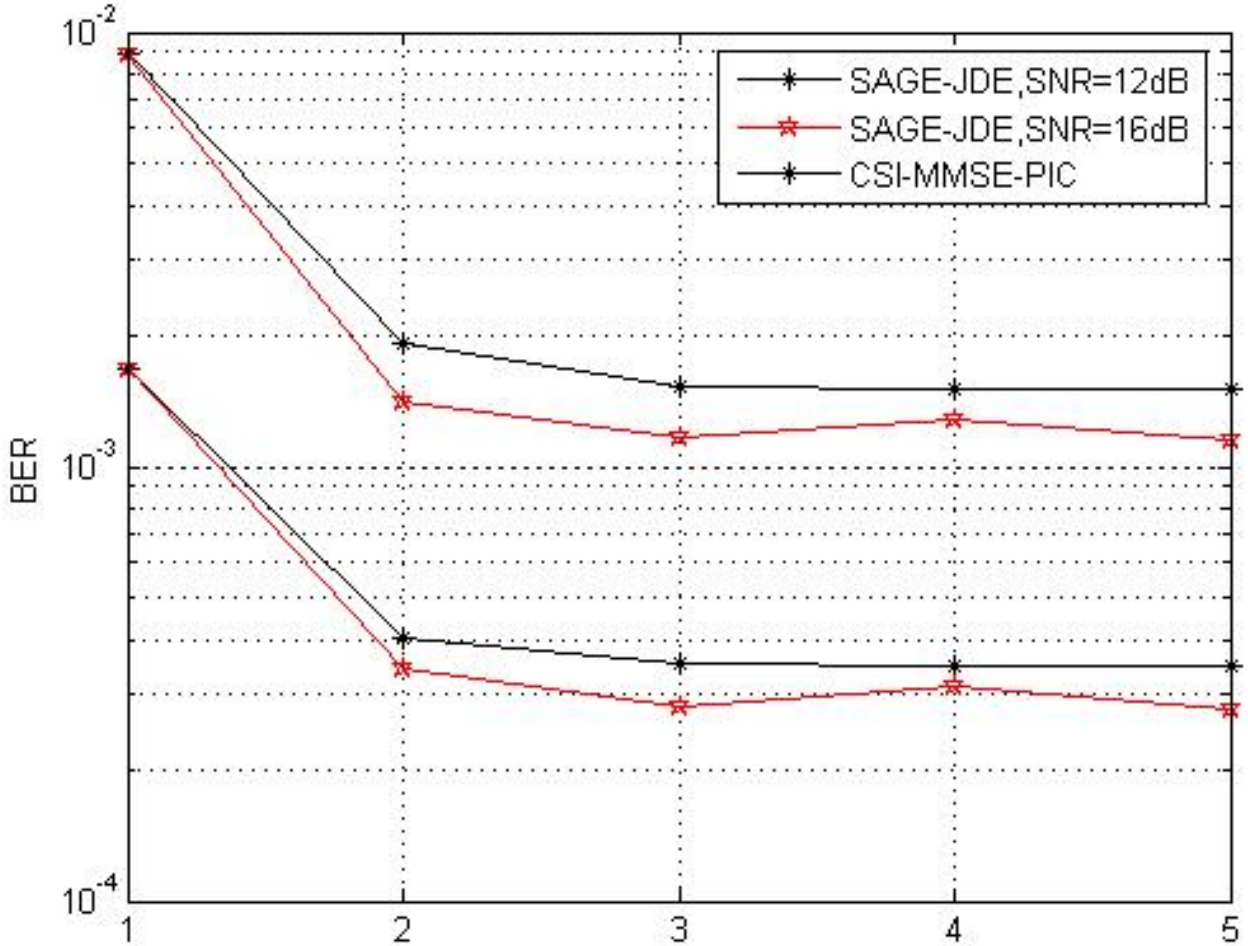
Simulations



T=8

Proposed SAGE-JDE outperforms the MMSE-SDE, Combined- MMSE-PIC as well as CSI-MMSE and approaches the CSI-Combined MMSE-PIC for higher Eb/No values

Simulations



Conclusion

The problem of joint data detection and channel estimation for MC-CDMA systems operating in the presence of frequency selective fading channels was investigated in this work.

We presented an iterative approach based on a version of the SAGE algorithm suitable for superimposed signals. A closed form expression was derived for the data detection which incorporates the channel estimation as well as the partial interference cancelation steps in the algorithm.

Computer simulations were presented to demonstrate the effectiveness of the proposed algorithm in terms
of BER performances.

Thanks for your attention

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