Blind Adaptive Multiuser Detection for DS-CDMA Utilizing a Sinusoidally-Distributed DSE-CMA

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Abstract—The use of adaptive filtering to mitigate the multiple access interference (MAI) in the direct-sequence code division multiple access (DS-CDMA) systems is studied in this paper. Blind adaptive algorithm based on our recently proposed sinusoidally-distributed dithered signed-error constant modulus algorithm (S-DSE-CMA) is introduced to adapt the filter coefficients. This algorithm retains the averaged transient behavior of the constant modulus algorithm (CMA). We evaluate the performance of an adaptive multi-user detector utilizing the S-DSE-CMA scheme against the existed uniformly-distributed DSE-CMA (U-DSE-CMA). It is shown that the new scheme converges faster than the conventional scheme. Simulation results of averaged mean-squared error (MSE) trajectories for synchronous and asynchronous DS-CDMA are presented.

I. INTRODUCTION

Multiple access wireless communication systems employ different methods to multiplex different users for transmission over wireless channels. There are some existing methods, for instance, frequency division multiple access (FDMA) and time division multiple access (TDMA), which assign each user with a distinct orthogonal frequency band and a time slot, respectively. On the other hand, in code division multiple access (CDMA), users are spread across frequency and time using distinct orthogonal codes, where their data rate (chip rate) designed to be much higher than that of the information signal (symbol rate). In this way, it is expected that the detrimental effects of intentional jamming and interference arising from inner-cell or outer-cell users can be suppressed.

However, multi-path propagation and filtering of bandlimited channels in wireless communication systems, which produce the sum of superimposed delayed copies of the signal, cause another kind of distortion to the transmitted signal [1], known as inter-chip interference (ICI). Therefore, the receiver has to be able detect the transmitted symbols (with a certain delay) for one particular user and equalize the effects of ICI at the same time. Moreover, multiple access interference (MAI) occurs when the spreading code waveforms are not completely orthogonal. It is widely known that MAI limits the performance and capacity of DS-CDMA communication systems significantly [2].

As conventional detectors, i.e., RAKE receivers and zero-forcing detectors, did not provide optimal solutions for multi-user detection, the progress of digital signal processing techniques has considered the adaptive multi-user detection methods for their possibility to be implemented in next generation mobile communications, in [3] and [4]. It involves the development of blind adaptive systems, where training sequences are not required by the receiver. For example, in [5], the uniformly-distributed dithered signed-error constant modulus algorithm (U-DSE-CMA) has been implemented for DS-CDMA multiuser detection. It was shown that the algorithm was able to lock each user to converge to their specific set of minima, while retaining the averaged transient behavior of the constant modulus algorithm. In this paper, we employ the recently proposed sinusoidally-distributed DSE-CMA (S-DSE-CMA) [6] for the purpose of blind adaptive multiuser detection. While providing a faster convergence as compared to the U-DSE-CMA in blind equalization cases, it is expected that the same performance will be achieved by implementing the algorithm in the multiuser detection scheme with DS-CDMA.

II. SYSTEM MODEL

Fig. 1 depicts the transmitter and receiver system model of a baseband DS-CDMA communication system with $K$ users. Each user transmits binary symbols $s(n) \in \{-1,+1\}$ using BPSK modulation. The $k^{th}$ user of the source symbol sequence with $T_b$ symbol period, denoted by $s_k(n)$, is spread by a short code pseudo-noise sequence of length $L$ with a chip duration of $T_c$. Thus, the spreading gain of the system can be expressed as $L = T_b/T_c$. It can also be seen in the figure that the sampling rate of the symbol sequence is increased by a factor of $P$ before passing it through the channel. This scheme is derived from the multirate model of fractionally-spaced receiver [7]. The spreading sequence of $k^{th}$ user can be written in a vector $c_k = [c_k(0), c_k(1), c_k(\ell), \ldots, c_k(L-1)]^T$. 

![Fig. 1. Multirate DS-CDMA system model.](image-url)
where \(c_k(\ell) \in \{-1, +1\}\) and \((\cdot)^T\) is a transpose operator. The coefficients of the \(k\)th user channel are summarized in the vector \(h_k = [h_k(0), h_k(1), h_k(\ell T_c/P), \ldots, h_k(PN_h - 1)]^T\), where \(N_h\) denotes the channel length. The additive Gaussian noise, \(w(\ell T_c/P)\), is independent of the source symbols and has zero mean and variance \(\sigma_n^2\).

The transmitted message signal for the \(k\)th user at time \(\ell T_c/P\) is then expressed as:

\[
u_k(\ell T_c/P) = H_k C_k s_k(n),
\]

where \(H_k\) denotes the channel convolution matrix:

\[
H_k = \begin{bmatrix}
    h_k(0) & h_k(1) & \cdots & h_k(PN_h - 1) \\
    \vdots & \ddots & \vdots & \vdots \\
    h_k(0) & h_k(1) & \cdots & h_k(PN_h - 1)
\end{bmatrix},
\]

with dimension \(N_f \times (N_f + N_h - 1); N_f\) being the equalizer length. The spreading codes matrix \(C_k\) of dimension \((N_f + N_h - 1) \times N_s\) is defined as:

\[
C_k = \begin{bmatrix}
    \mathbf{c}_k \\
    \mathbf{c}_k \\
    \vdots \\
    \mathbf{c}_k
\end{bmatrix},
\]

where \(\mathbf{c}_k\) represents column vectors of oversampled spreading codes that may be upper or lower truncated, respectively. The truncation mainly due to finite observation time. On the other hand, the column vector \(\mathbf{c}_k\), is an oversampled chip sequence of length \(PL\). Thus, the number of source symbols from the \(k\)th user that are considered to estimate the output symbol at the time-index \(n\) may be given as:

\[
N_s = \left\lceil \frac{N_f + N_h - 1}{PL} \right\rceil.
\]

Clearly, the source symbol vector follows as:

\[
s_k(n) = [s_k(0), s_k(1), \ldots, s_k(n - N_s + 1)]^T.
\]

Finally, the received signal vector \(r(\ell T_c/P)\) at the input of the filter can be expressed as:

\[
r(\ell T_c/P) = \sum_{k=1}^{K} u_k(\ell T_c/P) + w(\ell T_c/P)
\]

\[
= \sum_{k=1}^{K} H_k C_k s_k(n) + w_k(\ell T_c/P)
\]

\[
= \left[ \begin{array}{c}
    H_1 C_1 \\
    H_2 C_2 \\
    \cdots \\
    H_K C_K
\end{array} \right]
\begin{bmatrix}
    s_1(n) \\
    s_2(n) \\
    \vdots \\
    s_K(n)
\end{bmatrix}
\]

\[+ w(\ell T_c/P).\]

The soft linear detector output for each user at symbol rate is computed from the received vector \(r(\ell T_c/P) = [r(1), r(2), \ldots, r(\ell T_c/P - N_f + 1)]^T\) can be represented as follows:

\[
\hat{y}_k(n) = f_k^T r(\ell T_c/P).
\]

III. THE SINUOSIDALLY DISTRIBUTED DSE-CMA (S-DSE-CMA)

The S-DSE-CMA algorithm that has been developed in [6] will be reproduced here for convenient and adapted for the case of DS-CDMA systems.

A. The Sinusoidal Distribution

A real-valued random variable \(V\) said to have a sinusoidal distribution if \(V\) obeys the following pdf:

\[
p_V(\nu) = \left\{ \begin{array}{ll}
    A \cos \left( \frac{\pi}{2} \frac{\nu}{\alpha} \right) & \nu < \alpha, \\
    0 & \text{elsewhere},
\end{array} \right.
\]

where \(A\) is the amplitude of the sinusoidal distribution. The value of \(A\) is set to satisfy the condition that \(p_V(\nu)\) must be non-negative and the area under it must be 1; as such we have \(A = \pi/(4\alpha)\).

The cumulative distribution function (cdf) of \(V\) is given by:

\[
P_V(\nu) = \left\{ \begin{array}{ll}
    1 & \nu \geq \alpha, \\
    \frac{1}{2} \sin \left( \frac{\pi}{2} \frac{\nu}{\alpha} \right) + \frac{1}{2} & -\alpha \leq \nu < \alpha, \\
    0 & \nu < -\alpha.
\end{array} \right.
\]

The first and second moments of the above \(V\) are given, respectively, as \(E\{V\} = 0\) and \(E\{V^2\} = (1 - \frac{8}{\pi^2})\alpha^2\). For instance, with \(\alpha = 1\) (hence \(A \approx 0.78\)), we have \(E\{V\} = 0\) and \(\sigma_v^2 = 0.19\). On the other hand, for the uniform distribution with \(\alpha = 1\), a bigger variance is obtained \(\sigma_v^2 = 0.33\). It can be shown that the sinusoidally-distributed random processes \(\nu^r(\alpha)\) and \(\nu^s(\alpha)\) can be generated via \(\nu(\alpha) = \frac{2\alpha}{\pi} \sin^{-1}[2(z - 0.5)]\), where \(z\) is drawn from the uniform distribution on \([0, 1]\).

B. The S-DSE-CMA

In blind systems utilizing S-DSE-CMA, adaptation of filter coefficients using the gradient descent method can be expressed as follows:

\[
f(n + 1) = f(n) + \mu r(n) \psi_{\text{s-dse-cma}}(y_n),
\]

where \(\mu\) is a small positive step-size. The error function \(\psi_{\text{s-dse-cma}}(y_n)\), which incorporates sinusoidally-distributed dither processes for the real-valued case can be written as:

\[
\psi_{\text{s-dse-cma}}(y_n) = \alpha \text{sign}(\psi_{\text{cma}}(y_n) + \nu_n(\alpha)),
\]

where \(\alpha\) is a dither amplitude, \(\nu_n(\alpha)\) is real-valued i.i.d processes distributed sinusoidally on \([-\alpha, \alpha]\). In (10), the CMA error function \(\psi_{\text{cma}}(y_n)\) may be formulated as \(\psi_{\text{cma}}(y_n) = y_n^* (\gamma - |y_n|^2)\), where \(\gamma\) is a dispersion constant defined as \(\gamma \equiv E[|s_n|^4]/E[|s_n|^2]\).

C. Transient Behavior

To ensure that the behavior of the proposed S-DSE-CMA resembles that of the conventional DSE-CMA, the theorems of the average transient behavior in [8] are imposed. The dither amplitude (\(\alpha\)) is selected based on the following criteria:

\[
\alpha > \alpha_c \equiv 2(\gamma/3)^{3/2}, \quad \alpha > \alpha_{df} \equiv \max_{s \in S} |\psi_{\text{cma}}(s)|, \quad \text{where} \quad S \text{ denotes all possible source vectors } s, \quad \text{and} \quad \alpha > \alpha_{oe} \equiv \max_{y \in Y_{oe}} |\psi_{\text{cma}}(y)|, \quad \text{where} \quad Y_{oe} \text{ is a set of open-eye equalizer outputs defined as } Y_{oe} \equiv \{y : \min_{s \in S} |y - s| < \Delta_s/2\}.
\]
and $\triangle_a$ denotes minimum distance between two symbols in $S$. Clearly, these parameters ($\alpha_c, \alpha_{zf}, \alpha_{oe}$) are constellation and modulation dependent. It can be summarized that $\alpha$ is selected large enough to satisfy $\alpha > \max\{\alpha_c, \alpha_{zf}, \alpha_{oe}\}$.

Since the CMA (hence the DSE-CMA) cost-surface has multi-modal properties [7], a set of minimum points exists. Therefore, in a multiuser system with $K$ users, $K$ sets of minima exist. Each minimum point of a specific set of minima relates to a different delay. Depending on the channel characteristics and noise distortion, their depth can also vary widely. In this point of view, adaptive multi-user detection refers to the algorithms capability to lock one user to its set of minima and converge to those points. If the algorithm leads to the wrong set of minima, it directs the decision to the wrong user. The following simulation results show the algorithm behavior in those multiuser environments.

IV. Simulation Results

In this section, we present simulation results of multiuser detection in DS-CDMA environments utilizing adaptive filter controlled by S-DSE-CMA and U-DSE-CMA. In the down-link mode, $K = 15$ users transmitted symbol sequences from the base station (BS) to the mobile equipments with the same channel impulse response for all users. In this scheme, synchronous DS-CDMA is considered. The source symbol sequences of each user were spread by Pseudo-Noise (PN) and Gold sequences of length $L = 31$. The $T/2$ fractionally-spaced filter length $N_f$ was set to $2L$.

On the other hand, bit asynchronous DS-CDMA was simulated to represent the up-link mode, where $K = 10$ users transmitted symbol sequences from different mobile equipments in the same cell to the same BS with different channel impulse response for each user. The source symbol sequences of each user were spread by Pseudo-Noise (PN) and Gold sequence of length $L = 31$. The $T/2$ fractionally-spaced filter length $N_f$ was set to $4L$ (larger than the fractionally-spaced filter length for detection of synchronous DS-CDMA). For both cases (the synchronous and the asynchronous DS-CDMA), the oversampled factor ($P$) was set to 2.

In all simulations, the dither amplitude ($\alpha$) and dispersion constant $\gamma$ were set to 1, and the algorithm step-size ($\mu$) was $1 \times 10^{-4}$. Along the way from transmitter to receiver, white Gaussian noise is added and it was assumed that SNR = 40 dB. The mean-squared error trajectories in all cases were averaged over 100 iterations.

A. Multiuser Detection in Synchronous DS-CDMA

In synchronous DS-CDMA, the bits of each user signal are aligned in time. Fig. 2 compares the averaged MSE trajectories of particular users that were detected with DSE-CMA utilizing uniform and sinusoidal dithering, where the symbol sequence spread using Gold sequence with $L = 31$, while in Fig. 3 the symbol sequence spread using PN sequence with $L = 31$. It can be seen in the two figures that the S-DSE-CMA provides faster convergence as compared to the U-DSE-CMA. However, it is noted that additional of dithering process in eq. 10 results in the increase of the steady-state MSE for both algorithms by nearly the same amount. Moreover, Fig. 2 and 3 show that the proposed adaptation scheme is capable of locking each user to its minimum point. Since most of the blind adaptive schemes have a multimodal cost-surface, the locking capability can be considered as an important property of a blind adaptive algorithm in multiuser detection systems.

B. Multi-user detection in asynchronous DS-CDMA

In bit-asynchronous DS-CDMA, the bits of each user are not aligned in time, where the bits of one user may superimpose on other users as well. Thus, detection becomes more difficult as compared to the synchronous DS-CDMA. Hence, it took a longer time for the filter to lock the user to its specific set of minima, as depicted in Fig. 4 and Fig. 5. Notice that in this simulation we used a large the number of filter coefficients ($N_f = 124$). It can be seen that the DSE-CMA using sinusoidally-distributed dithering outperforms the uniformly-distributed dithering in terms of convergence speed.

V. Conclusion

In this paper the recently proposed sinusoidally-distributed signed-error constant modulus algorithm has been implemented for multiuser detection in synchronous and asynchronous DS-CDMA wireless communication systems. It has been shown that the algorithm has properties similar to the conventional DSE-CMA in terms of performance in multiuser systems but demonstrates a faster convergence. This algorithm is expected to be useful for applications with multiuser detectors in the next generation wireless networks.
Fig. 3. Averaged MSE trajectories of S-DSE-CMA and U-DSE-CMA for 4 out of 15 different users simulated on synchronous DS-CDMA, with: a. User-1, b. User-6, c. User-12, d. User-15. The transmitted symbol sequences were spread using PN sequences, with $L = 31$. The line of * represents the minimum MSE of each user.

Fig. 4. Averaged MSE trajectories of S-DSE-CMA and U-DSE-CMA for 4 out of 10 different users simulated on asynchronous DS-CDMA, with: a. User-1, b. User-3, c. User-6, d. User-8. The transmitted symbol sequences were spread using Gold sequences with $L = 31$. The line of * represents the minimum MSE of each user.

Fig. 5. Averaged MSE trajectories of S-DSE-CMA and U-DSE-CMA for 4 out of 10 different users simulated on asynchronous DS-CDMA, with: a. User-1, b. User-3, c. User-6, d. User-8. The transmitted symbol sequences were spread using PN sequences with $L = 31$. The line of * represents the minimum MSE of each user.

REFERENCES


