Blind widely linear adaptive MMSE criterion for Multicarrier CDMA

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Abstract— **This paper proposes a novel multiuser detection in multicarrier code-division multiple-access (MC-CDMA) system by using adaptive widely linear MMSE structures. They jointly elaborate the received signal and its complex conjugate. Computer simulations show that widely linear MMSE algorithm is capable of both wideband multiple-access and narrowband interference that affects the MC-CDMA systems.**

Index Terms – **Multiuser detection**

I. Introduction

Multiuser detection (MUD) techniques for demodulation of Multicarrier CDMA signals have received a great deal of attention. This is because the pioneering work by Verdu [1] demonstrated that the near-far problem suffered from the conventional matched-filter detector. The difficulty can be overcome by resorting to more sophisticated structure, which accounts for the presence of the other users.

In the future, wireless communication system must support the demand of a large number of users and high data rate transmission such as multimedia data. The DS-CDMA (Direct Sequence Code-Division Multiple-Access) technique can meet the above requirement. However, it suffers from InterSymbol Interference (ISI) due to multipath signal and interference from other users in the system. In DS-CDMA receiver system, the ISI can be reduced by using a RAKE receiver, but the complexity of the receiver will increase exponentially as the data transmission rate increases. To overcome this problem, the multicarrier CDMA (MC-CDMA) scheme has been proposed in [1] - [3]. The MC-CDMA is the combination of CDMA scheme and Orthogonal Frequency Division Multiplexing (OFDM) technique, therefore the ISI can be reduced when data is transmitted at higher rate.

In this paper, we propose an adaptive widely linear MMSE algorithm, called adaptive WL-MMSE, for receiver applied to the MC-CDMA systems. In the proposed algorithm, the weight vector is first update by short training process.The approach of LCL time-varying filtering has already been applied in the CDMA context, to mitigate the effects of narrowband interference (NBI). In this paper, by applying WL estimation concepts to MC-CDMA multiuser detection, we propose a class of WL-MUD's, aimed at improving the suppression of both wideband multiple-access interference (MAI) and NBI. The performance advantage of WL-MUD's over conventional L-MUD's is motivated theoretically and can be substantiated by computer simulation examples.

II. Data Model of MC-CDMA

The transmitted signal of the MC-CDMA system can be describe as

$$y(t)=\sum_{n=-\infty}^{\infty}\sum_{m=0}^{M-1}b[n]c_m e^{j2\pi f_m t}g\left(t-nT'\right) \qquad (1)$$

where $b[n]$ is the signal symbol at nT' ; $\{c_m\}_{m=0}^{M-1}$ is a random spreading sequence, M is the spreading gain ; T' is the symbol duration, f_m is the carrier frequency of the m^{th} sub-carrier and $f_m = f_0 + \frac{m}{T'}$. Since this paper focuses on the baseband analysis, without loss of generality, let $f_0 = 0$ and $g(t)$ is the impulse response of the pulse shaping filter: so the discrete form of transmitted signal can be described as

$$y[Mi+u]=b[i]\tilde{c}_u \quad u=0,1,2,...,M-1 \qquad (2)$$

The channel is a multipath fast fading channel. For the discrete-time domain representation with the sample interval $T_s = T'/M$, the channel impulse sequence can be written as

$$h[n]=\sum_{l=0}^{L-1}h_l[n]\delta[n-1] \qquad (3)$$

where $h_l[n]$ is the complex amplitude of path l at time n with variance σ_l^2 .

III. Widely Linear Adaptive MMSE Algorithm

Significant quantities: n_B is the index of bit, n_C is the index of carrier, n_D is the index of time delay.

Let us consider the output $\hat{y}[n_B]=w^H[n_B]x[n_B]$ where $\hat{y}[n_B]\in C^{1\times 1}$ denotes the output signal, $w[n_B]\in C^{N_C\times 1}$ signifies the weight vector, $x[n_B]\in C^{N_C\times 1}$ designates the received signal.

Base on the MSE criterion, we propose a new cost function for MC-MMSE algorithm applied to the MC-CDMA system as follows

$$J(N_B)=\sum_{i=0}^{N-1}E\left[\left|w^H(N_B)x(N_B)-y(N_B)\right|^2\right] \qquad (4)$$

The gradient of equation (4) with respect to the weight vector $w[N_B]$ is given by

$$\nabla J = \sum\left[2R_{xx}[N_B]w[N_B - 2r_{xy}]\right] \quad (5)$$

where,

$R_{xx}[N_B] = E\left[x[N_B]E^H[N_B]\right]$ is the correlation matrix of the symbol of the N_B bit

$r_{xy}[N_B] = E[x[N_B]y^*[N_B]]$ is the cross-correlation vector between receive signal at the receiver and symbol sequence.

An adaptive solution that minimizes the cost function is [5];

$$w[N_B] = w[N_B - 1] - \frac{1}{2}\mu\nabla J[N_B] \quad (6)$$

where μ is the step size parameter.

From equation (6) we see that in order to update the weight vector we must know the correlation matrix $R_{xx}[N_B]$ and the cross-correlation matrix $r_{xy}[N_B]$.

In proposed algorithm, the correlation matrix $R_{xx}[N_B]$ and the cross-correlation matrix $r_{xy}[N_B]$ are computed by using the moving-average (MA) produced as follows:

$$R_{xx}[N_B] = F.R_{xx}[N_B - 1] + x[N_B]x^H[N_B] \quad (7)$$

$$r_{xy}[N_B] = F.r_{xy}[N_B - 1] + x[N_B]y^*_{N_u}[N_B] \quad (8)$$

where $0 \le F \le 1$ is called the forgetting factor.

However, when considering the complex-valued received signal $x[n_B]$, the widely linear (WL) criterion with better performance is in such a way that [4]

$$\hat{y}_{WL}[n_B] = w^H_{WL}[n_B]z[n_B] \quad (9)$$

$$= w_1^H[N_B]x[N_B] + w_2^H[N_B]x^*[N_B] \quad (10)$$

where the weight vector $w_{WL}[n_B]$ is chosen to minimize the MSE

Let us introduce the concatenated vector $z[n_B] \in C^{2N_C \times 1}$

$$z[n_B] \overset{\Delta}{=} \begin{bmatrix} x[n_B] \\ x^*[n_B] \end{bmatrix} \quad (11)$$

$$J(N_B) = \sum_{i=0}^{N-1} E\left[\left|w^H_{WL}[N_B]z[N_B] - y[N_B]\right|^2\right] \quad (12)$$

Solving (12) by the orthorgonality principle yields [6] $w_{WL}(n_B) = R^{-1}_{ZZ}(n_B)r_{zy_1}(n_B)$,with $R_{ZZ}(n_B) \overset{\Delta}{=} E\left[z(n_B)z^H(n_B)\right]$ and $r_{zy_1} \overset{\Delta}{=} E\left[z(n_B)y_1^*(n_B)\right]$. An alternative expression is readily obtained by partitioning $R_{ZZ}(n_B)$ according to the structure of $z(n_B)$, and applying inverson rules for partitioned matrices, as [6]

$$w_1(n_B) = \left[R_{xx}(n_B) - R_{xx^*}(n_B)R^{-1*}_{xx}(n_B)R^*_{xx^*}(n_B)\right]^{-1} \times \left[r_{xy_1}(n_B) - R_{xx^*}(n_B)R^{-1*}_{xx}(n_B)r^*_{xy_1^*}(n_B)\right]$$

$$w_2(n_B) = \left[R^*_{xx}(n_B) - R^*_{xx^*}(n_B)R^{-1*}_{xx}(n_B)R_{xx^*}(n_B)\right]^{-1} \times \left[r^*_{xy_1^*}(n_B) - R^*_{xx^*}(n_B)R^{-1}_{xx}(n_B)r_{xy_1^*}(n_B)\right]$$

where

$$R_{xx}(n_B) \overset{\Delta}{=} E\left[x(n_B)x^H(n_B)\right] \quad (13)$$

$$R_{xx^*}(n_B) \overset{\Delta}{=} E\left[x(n_B)x^T(n_B)\right] \quad (14)$$

$$r_{xy_1} \overset{\Delta}{=} E\left[x(n_B)y_1^*(n_B)\right] \quad (15)$$

and

$$r_{xy_1^*} \overset{\Delta}{=} E\left[x(n_B)y_1(n_B)\right] \quad (16)$$

which do not depend on n_B^{th} if the symbol sequence $y_1(n_B)$ is stationary.

Thus in the symbol period the adaptive widely linear MC-MMSE algorithm is summarized as follows:

1.Initialize $w_{WL}[0] = 0$

2.Update the weight vector, $n = n + 1$

- Receive a new received signal matrix $x[N_B]$
- Calculate the correlation matrix and cross-correlation vector by equation (7) and (8)
- Calculate the gradient

$$\nabla J = \sum_{i=1}^{N}\left[2R_{xx,i}[N_B]w[N_B - 1] - r_{xy,i}[N_B]\right]$$

Update the weight vector

$$w_{WL}[N_B] = w_{WL}[N_B - 1] - \frac{1}{2}\mu\nabla J[N_B]$$

3. Iterate step until the weight vector converges

When both $r_{xy_1^*}(n_B)$ and $R_{xx^*}(n_B)$ are zero, a condition is referred to in [6] as joint circularity of $x[n_B]$ and $y_1[n_B]$. One has that $w_1(n_B) = R_{xx}^{-1}(n_B)r_{xy_1}(n_B)$ and $w_2(n_B) = 0$ that is, the WL-MUD reduces to the conventional L-MUD. However, there are situations of practical interest where joint circularity is not verified. For example, when the MC/CDMA system employs BPSK modulation, in which case $y_1[n_B]$ is real.Hence, $r_{xy_1^*}(n_B) = r_{x_{y1}}(n_B)$, $\hat{y}_1(n_B) = 2\,\mathrm{Re}\left[w_1^H(n_B)x(n_B)\right]$,and $w_1(n_B) = w_2^*(n_B)$, that is, also the WL-estimate is necessarily real; or else when the MC/CDMA system employs QPSK modulation and the interfering signal is noncircular, in which case $r_{xy_1^*}(n_B) = 0$ but $w_2(n_B) \ne 0$. In such cases, the WL-MUD is expected to outperform the conventional L-MUD

IV. Numerical Results

In this section, we provide some numerical results obtained by Monte Carlo computer simulations, aimed at comparing the performance of the proposed adaptive WL-MUD with that of the L-MUD. We focused our attention on the simple case where both the L-MUD and WL-MUD are time-invariant, in order to avoid the unnecessary complications inherent to time-

varying implementation. In the considered experiments, the MC-CDMA system employs BPSK modulation, spreading length code N=15, numbers of carrier n_C =16 , numbers of data bits n_B =1000, the white Gaussian circularly symmetric with power spectral density $2N_0$ and the interference-to-signal ratio is set to 30 dB.

In the first experiment, we considered K = 8 users. In Fig. 1, we evaluated the bit-error rate (BER) of the first user versus its energy constant $\frac{E_b}{N_0}$, for a fixed valued of $\frac{E_b}{N_0}$ = 16 dB for each MAI signal. The results show that, as expected, in the presence of strong NBI the conventional receiver (match filter) performs very poorly, and that the WL-MUD significantly outperforms the L-MUD.

In second experiment investigates the BER performance when the number of MC-CDMA users is increased from 1 to 12, with $\frac{E_b}{N_0}$ held constant at 10 dB, for the desired user, and at 16 dB for each MAI signal. These results show from the channel is time-varying and simulated in four cases area , rural, urban, bad-urban and hilly with both doppler frequency 50 Hz and 110 Hz

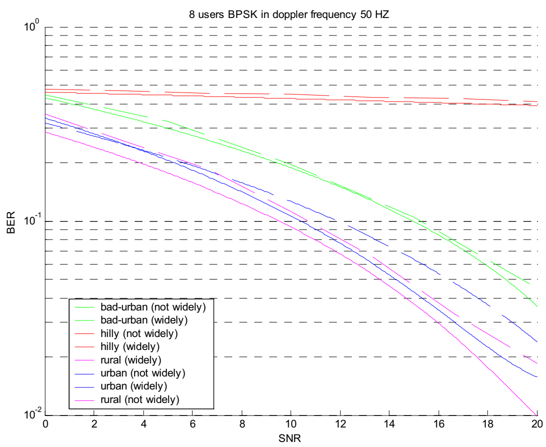

Fig.1. BER versus SNR in channel time-varying at doppler frequency 50 Hz

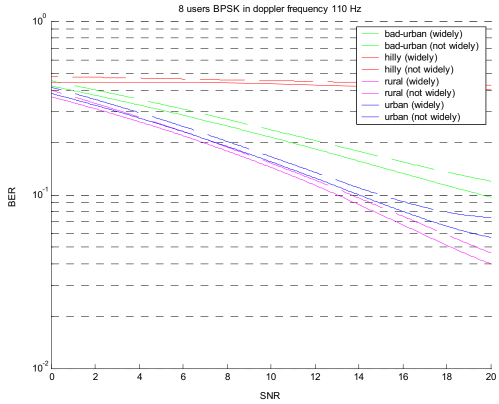

Fig.2. BER versus SNR in channel time-varying at doppler frequency 110 Hz

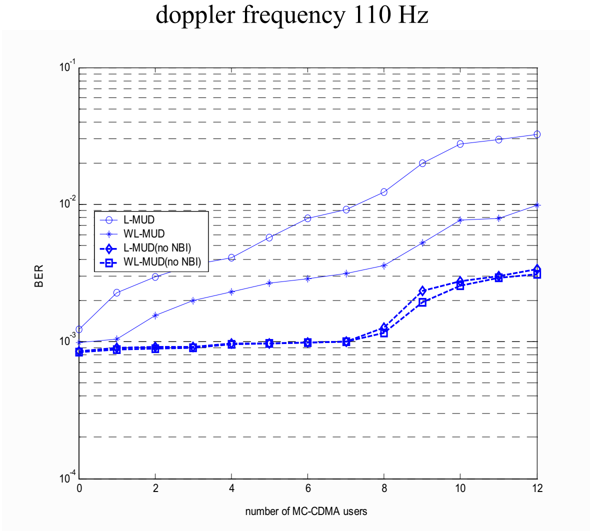

Fig.3. BER versus number of MC-CDMA users

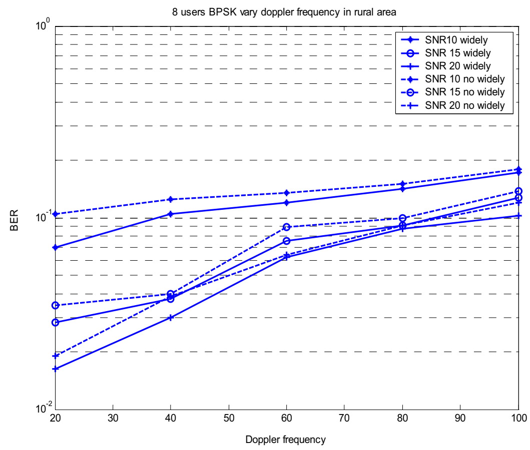

Fig.4. BER versus Doppler frequency

V. CONCLUSION

In this paper, the adaptive widely linear MMSE algorithm, for the MC-CDMA system is proposed. The adaptive WL-MUD has a vey good capability of suppressing MAI and NBI, resulting in a MC-CDMA system with very high BER performances in multi-path Rayleigh fading channel. Our performance analysis and simulation results show in good agreement that the WL-MUD stochastic gradient algorithm has important advantages over their linear counterparts. It has been demonstrated that WL-MUD, in the presence strong NBI, yields better bit-error-rate than L-MUD. In addition, in $\frac{E_b}{N_0}$ limited MC-CDMA systems, the capacity in the case of increasing CDMA users, shown that the WL-MUD achieves a much higher bit-error-rate than L-MUD; however, when no NBI is present, the performance of two receivers are practically undistinguishable, since for a MC-CDMA system with QPSK modulation, and in the absence of NBI, the joint circularity condition holds, and hence the WL-MUD and L-MUD are theoretically coincident. We believe that these desirable features make WL adaptive algorithms a favorable choice for MC-CDMA receiver designers.

Finally, In Fig 4. can show that the WL-MUD can be more flexible than L-MUD in MC-CDMA which has high doppler frequency

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