A New Blind Receiver for Downlink DS-CDMA Communications

Kemin Li and Hui Liu

***Abstract*— A linear receiver is proposed for downlink DS-CDMA communications over unknown frequency-selective fading channels. The new receiver exploits the fact that all synchronized downlink signals go through the same channel and recovers the desired signal with a constrained channel equalizer followed by a despreader. Such a scheme allows the receiver to operate blindly in a time varying environment for both periodic CDMA and aperiodic CDMA systems.**

***Index Terms*—Channel equalization, spread spectrum communication.**

I. Introduction

IN direct-sequence (DS) code-division-multiple-access (CDMA) communications, multiple users share the same media by using pre-assigned spreading codes. Multiple access interference (MAI) is the main cause of performance degradation in a multipath environment. For uplink communication, multiuser detection has been shown to be an effective way to combat interfering signals in CDMA systems [1]–[3]. However, these solutions are generally expensive, either computationally (for blind reception), or in bandwidth (for training sequence based reception). Although downlink can be regarded as a special case of the uplink, it is often impractical to apply the existing multiuser detectors directly to downlink due to resource constraints.

The commonly used downlink receiver consists of a linear channel equalizer followed by a despreader [4], [5]. The decoupling of equalization and despreading allows the receiver to handle IS-95 types of CDMA signals with mask codes. The channel equalizer often has to be trained using a pilot sequence in a fading environment. In this letter, we propose a novel downlink receiver which is comprised of a blind linear equalizer and despreader. The development of the proposed receiver is based on the following simple observations.

1) Downlink signals are perfectly synchronized at the transmitter.
2) All downlink signals go through the same fading channel.
3) Users' spreading codes can be chosen to be orthogonal, even when mask sequences are employed.

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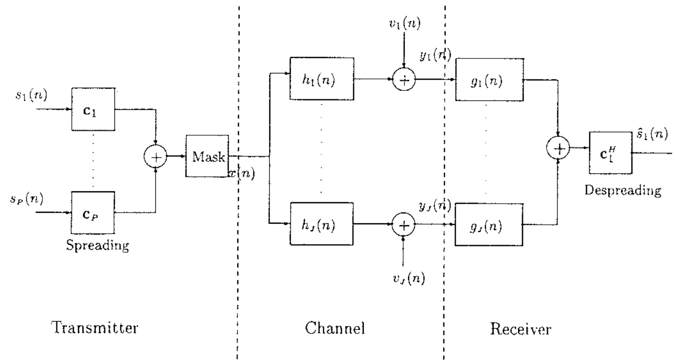

Fig. 1. CDMA downlink over multiple FIR channels.

Unlike uplink where different users are subject to different fading channels the orthogonality between users' signals can be restored in downlink by equalizing one common channel. This allows a simple code matched filter (despreader) to eliminate MAI from intracell users. The proposed equalizer exploits these structures using a minimum output energy (MOE) criterion and achieves blind downlink reception without introducing undue complexity.

In Section II, the data model for downlink CDMA is presented. Section III proposes the new receiver structure based on a constrained Minimum Output Energy (C-MOE) criterion. Adaptive implementation is also presented. The relative performance of the new method and an existing approach is shown in Section IV. Section V concludes this paper.

II. Data Model

We consider a multiple FIR channel model for CDMA downlink shown in Fig. 1. The signals are represented by their chip-rate complex baseband equivalent. The base station transmits P synchronized signals to the mobile stations. Each user's data sequence $s_i(n)$ is spread with a user specific spreading code of length M.

The transmitted signal $x(n)$ can be expressed conveniently in a vector form by stacking chip rate samples within one symbol period:

$$\begin{bmatrix} x(nM+1) \\ \vdots \\ x(nM+M) \end{bmatrix} = \begin{bmatrix} c_1(1) & \cdots & c_P(1) \\ \vdots & & \vdots \\ c_1(M) & \cdots & c_P(M) \end{bmatrix} \begin{bmatrix} s_1(n) \\ \vdots \\ s_P(n) \end{bmatrix} = \boldsymbol{Cs}(n). \quad (1)$$

Here $s_i(n)$ the ith user's information bearing sequence, and $c_i(j)$ is the ith user's spreading code. $\{c_i(j)\}$ may vary from symbol to symbol when mask codes are employed. For presentational simplicity we assume no mask codes in the following derivation, although the proposed method can handle time-varying spreading codes without difficulty.

For generality we let $x(n)$ from the base station go through J FIR channels, obtained either through over-sampling or multiple receiving antennas. Each channel has a composite impulse response $h_j(n)$ with maximum length L. The received signal through the jth channel is thus $y_j(l) = h_j(l) * x(l)$. The nth symbol will span $M+L-1$ chips. Collecting $M+L-1$ chips in vector form and defining $K = M+L-1$, we have

$$\boldsymbol{y}_j(n) = \mathcal{T}(\boldsymbol{h}_j)\boldsymbol{x}(n) + \boldsymbol{v}(n) \tag{2}$$

where

$$\begin{aligned}\boldsymbol{y}_j(n) &= [y_j(nM+1)y_j(nM+2)\cdots y_j(nM+K)]^H\\ \boldsymbol{x}(n) &= [x(nM-L)x(nM-L+1)\cdots x(nM+1)\\ &\quad \cdots x(nM+K)]^H\\ \boldsymbol{v}_j(n) &= [v_j(nM+1)v_j(nM+2)\cdots v_j(nM+K)]^H\end{aligned}$$

and

$$\mathcal{T}(\boldsymbol{h}_j) = \begin{bmatrix} h_j(L) & \cdots & h_j(1) & 0 & \cdots & 0\\ 0 & h_j(L) & \cdots & h_j(1) & \cdots & 0\\ \vdots & \vdots & \vdots & & \ddots & \vdots\\ 0 & \cdots & 0 & h_j(L) & \cdots & h_j(1)\end{bmatrix}$$

is a block Toeplitz convolutional matrix.

Our objective is to find a set of blind equalizers $\{g_i(l)\}_{i=1}^{J}$, when combined with despreader, will suppress the MAI and ISI as much as possible.

III. Linear Equalizer

The structure of the downlink receiver we consider is also shown in Fig. 1. The outputs of the channel equalizers are first combined and then despread to form a symbol estimate. Since the despreading operation is fixed, we should focus our discussion on the equalizer.

The input to the despreader can be conveniently expressed as

$$\boldsymbol{z}(n) = \sum_i \mathcal{T}(\boldsymbol{g}_i)\boldsymbol{y}_i(n) = \sum_i \mathcal{T}(\boldsymbol{y}_i(n))\boldsymbol{g}_i = \boldsymbol{Y}(n)\boldsymbol{g} \tag{3}$$

where

$$\begin{aligned}\boldsymbol{Y}(n) &= [\mathcal{T}(\boldsymbol{y}_1(n))\cdots\mathcal{T}(\boldsymbol{y}_J(n))],\\ \boldsymbol{g} &= [\boldsymbol{g}_1^H\cdots\boldsymbol{g}_J^H]^H.\end{aligned}$$

When the channel information is available, MMSE equalizer can be constructed,

$$\min_{\boldsymbol{g}} E\|c_1^H\boldsymbol{Y}(n)\boldsymbol{g} - s_1(n)\|^2. \tag{4}$$

For an equalizer to demodulate the signal without knowledge of channel or the data sequence being sent, we notice that the original signal $x(n)$ is the sum of different users' sequences spread by the orthogonal codes. Thus in the absence of noise, the output of a perfect equalizer will be orthogonal to subspace $\boldsymbol{C}_o$, formed by the unused spreading codes. In practice the number of active downlink users is far less than the spreading gain, e.g., in the IS-95 system, so that $\boldsymbol{C}_o$ is not empty. This suggests that the equalizer can be found by forcing the projection of its output on $\boldsymbol{C}_o$ to be zero. More specifically, the equalizer should be the solution that minimizes the output energy below,

$$\hat{\boldsymbol{g}} = \arg\min_{\boldsymbol{g}} E\|\boldsymbol{C}_o^H\boldsymbol{Y}(n)\boldsymbol{g}\|^2. \tag{5}$$

To prevent trivial solution and signal cancelation, we add on a constraint which forces the projection of the equalizer output onto the desired user's spreading code to be fixed. We formulate our cost function as

$$\begin{aligned}\hat{\boldsymbol{g}} = \arg\ &\min_{\boldsymbol{g}}\ E\|\boldsymbol{C}_o^H\boldsymbol{Y}(n)\boldsymbol{g}\|^2,\\ &\text{subject to } E\|\boldsymbol{c}_1^H\boldsymbol{Y}(n)\boldsymbol{g}\|^2 = 1.\end{aligned} \tag{6}$$

Upon defining

$$\begin{aligned}\boldsymbol{R}_o &= E[\boldsymbol{Y}^H(n)\boldsymbol{C}_o\boldsymbol{C}_o^H\boldsymbol{Y}(n)]\\ \boldsymbol{R}_s &= E[\boldsymbol{Y}^H(n)\boldsymbol{c}_1\boldsymbol{c}_1^H\boldsymbol{Y}(n)].\end{aligned} \tag{7}$$

The minimization problem as shown in (6) can be converted into

$$\hat{\boldsymbol{g}} = \arg\ \min_{\boldsymbol{g}}\ \frac{\boldsymbol{g}^H\boldsymbol{R}_o\boldsymbol{g}}{\boldsymbol{g}^H\boldsymbol{R}_s\boldsymbol{g}}. \tag{8}$$

Clearly, the desired equalizer is an eigenvector corresponding to the minimal generalized eigenvalue of matrix pair $(\boldsymbol{R}_o, \boldsymbol{R}_s)$.

The above solution also leads to an adaptive receiver using the LMS algorithm. The adaption rules are summarized as follows:

1) initialize parameters;
2) $\boldsymbol{R}_o(n) = \boldsymbol{Y}^H(n)\boldsymbol{C}_o\boldsymbol{C}_o^H\boldsymbol{Y}(n)$, $\boldsymbol{R}_s(n) = \boldsymbol{Y}^H(n)\boldsymbol{c}_1\boldsymbol{c}_1^H\boldsymbol{Y}(n)$;
3) $\nabla(n) = \alpha\boldsymbol{R}_o(n)\boldsymbol{g} - \lambda\alpha\boldsymbol{R}_s(n)\boldsymbol{g}(n)$;
4) $\boldsymbol{g}(n+1) = \boldsymbol{g}(n) - \mu\nabla(n)$;
5) $\alpha = (\boldsymbol{g}^H(n+1)\boldsymbol{R}_s\boldsymbol{g}(n+1))^{-1}$, $\lambda = (\boldsymbol{g}^H(n+1)\boldsymbol{R}_o\boldsymbol{g}(n+1))/(\boldsymbol{g}^H(n+1)\boldsymbol{R}_s\boldsymbol{g}(n+1))$;
6) $\boldsymbol{g}(n+1) = \boldsymbol{g}(n+1)/\|\boldsymbol{g}(n+1)\|$.

IV. Simulations

In this section, we provide some simulation results to illustrate the performance of the proposed receiver.

In the first example, we simulate a ten-user CDMA system with spreading gain of 16. We assume two FIR channels of length 3 and set the SNR at 10 dB. The length of equalizers for both channels is 3. We randomly generate 10 sets of channels, and plot the normalized MSE's of the MMSE receiver outputs and the proposed constrained MOE receiver in Fig. 2. It is seen that their performance is quite close in all cases, indicating that the proposed blind receiver achieves almost optimum performance.

In the next example, we measure the bit-error rate (BER) of the MMSE and proposed downlink receiver using a fixed channel. The configuration is similar to that of the above example. DQPSK signals are used. Differential decoding can

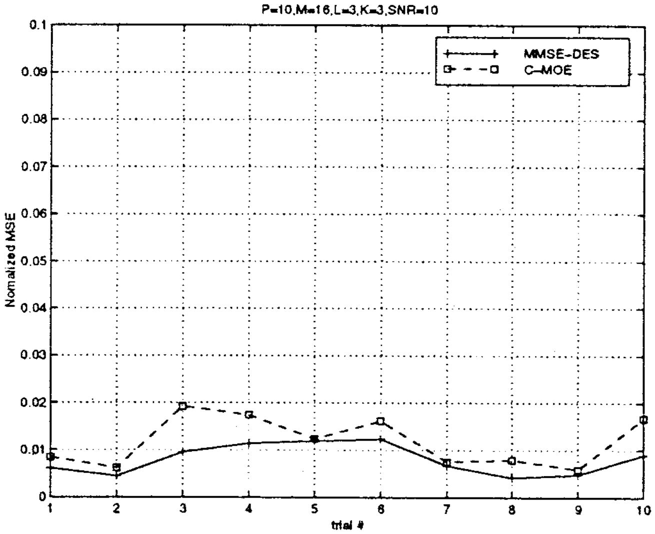

Fig. 2. MSE's for ten trials.

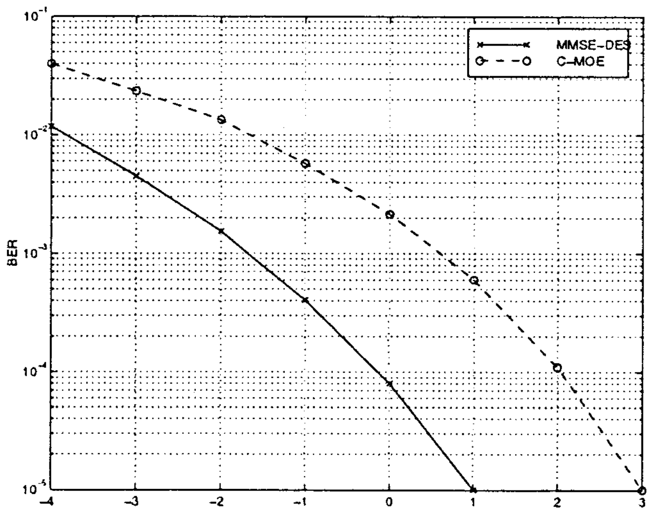

Fig. 3. BER versus SNR.

resolve the scalar ambiguity of equalizer obtained from solving (8). We plotted the BER of the two receivers in Fig. 3. Again their BER performance is close over a wide range of SNR values.

In the last experiment, the adaptive version of the proposed receiver was implemented (se Fig. 4). We track the normalized MSE of the adaptive algorithm in blocks of data of size 100 and compar it with the MSE reached by the batch method. The

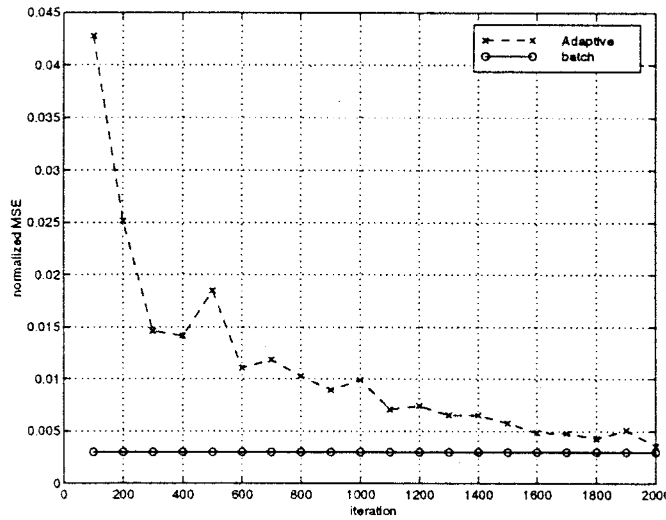

Fig. 4. Performance of the adaptive implementation.

step size μ is set at 5×10^{-3}. Results show that the adaptive algorithm can converge to the desired equalizer with a small amount of excess MSE.

V. Conclusion

We presented a linear equalizer based on a constrained MOE principle for downlink CDMA communications. The advantage of the proposed receiver is that it does not rely on training sequence or channel information. Its performance is shown to be close to the nonblind MMSE/despreading receiver. More thorough studies on the performance and requirement of the proposed receiver and its adaptive implementation remain to be done.

References

[1] S. Verdú, "Minimum probability of error for asynchronous Gaussian multiple access channels," *IEEE Trans. Inform. Theory*, vol. IT-32, pp. 84–96, Jan. 1986.

[2] H. Liu and G. Xu, "A subspace method for signature waveform estimation in synchronous CDMA systems," *IEEE Trans. Commun.*, vol. 44, pp. 1346–1354, Oct. 1996.

[3] S. E. Bensley and B. Aazhang, "Subspace-based channel estimation for code division multiple access communications," *IEEE Trans. Commun.*, vol. 44, pp. 1009–1020, Aug. 1996.

[4] A. Klein, "Data detection algorithms specially designed for the downlink of CDMA mobile radio systems," in *Proc. VTC97*, Phoenix, AZ, May 1997, pp. 203–207.

[5] I. Ghauri and D. T. M. Slock, "Linear receiver for the DS-CDMA downlink exploiting orthogonality of spreading sequences," in *Proc. 32nd Asilomar Conf. on Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 1998.