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A New Joint Multiuser Iterative Decision-feedback Equalizer in the Frequency Domain

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Abstract: In this study, for a multiuser multi-code CDMA system under multipath fading channel, a new Iterative Block Decision-feedback Equalizer (IB-DFE) is proposed, in which the correlation between users is took into consideration. The dispersive channel will weaken the orthogonal between users which induces the following worse effect that the pre-cursor and/or post-cursor Inter-symbol Interference (ISI) from each user will leak to the present symbol. These previous papers, related the multi-user detection with the DFE method, only consider themselves' feed-back signal without the other users' feed-back signals. Since these feed-back signals of other users have also effect on the desired user, the correlation factor between users will improve the performance compared with the conventional DFE. Generally, the DFE co-exists with the MMSE but the MMSE is biased estimation. In order to keep feedback signal the same scaling with the received signal, the output of the MMSE-DFE must be un-biased. Therefore, the un-biased MMSE-DFE is also considered in this study. Furthermore, the IB-DFE has less complexity compared with the conventional DFE, so this study also extends the IB-DFE with single user to multi-user. The simulation results show that the proposed IB-DFE method, based on correlation between users, outperforms more than 2dB compared with the conventional IB-DFE on a wireless dispersive fading channel.

Key words: DFE, iterative algorithm, MUD, frequency domain

INTRODUCTION

The Code Division Multiple Access (CDMA) transmission scheme has been adopted in 3G standards such as Wideband CDMA (WCDMA), Time Division-Synchronous CDMA (TD-SCDMA) and CDMA2000 Evolution-Data and Voice (CDMA2000 1xEV-DV) for high-speed communications. The receiver of the CDMA system is operated in the time domain (TD), such as RAKE receiver, Generalized RAKE (G-RAKE) receiver, Minimum Mean-Square Error (MMSE) receiver, MMSE-DFE receiver, Parallel Interference Cancellation (PIC)/Successive Interference Cancellation (SIC) receiver jointed with these above algorithms and so on. Some of these above receivers aren't suit to the high-speed scenario and others require a very high complexity. However, by performing various operations in the Frequency Domain (FD), through the Discrete Fourier Transform (DFT), the complexity of processing can be reduced. Indeed, performance may also increase, due to the possibility of selecting longer filters. In this regard, references propose the block-based DFE, where the Feedback (FB) filter is optimized for each detected symbol; however, the complexity of the structure is still quite high.

A considerable reduction of complexity has been achieved by the FD linear equalizer and by the DFE (Benvenuto and Tomasin, 2005), where the Feed-forward (FF) filter and the FB filter are realized in the FD. This algorithm (Benvenuto and Tomasin, 2005), an Iterative Block DFE (IB-DFE), having a computational complexity lower than existing TD-or H-DFE. In particular, as an extension of the study (Benvenuto and Tomasin, 2002), transmitted data are arranged according to a format that allows the use of DFT both for the FF and FB filters, i.e., cancellation is performed in the FD. Moreover, by using an iterative configuration similar to that proposed in study of Chan and Wornell (2001), also the filter design is performed directly in the FD.

Generally, the IB-DFE method is only applied on each single user which can cancel the precursors of the inter-symbol interference and further improve the performance of each single user. Since the feed-back signal of other user has also effect on the desired user,

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the correlation factor between users will improve the performance compared with the conventional IB-DFE. Furthermore, in order to improve the accuracy of the feedback signal, an unbiased MMSE-DFE method is also proposed in this study. The simulation results show that the proposed IB-DFE method, based on correlation between users, outperforms more than 2dB compared with the conventional IB-DFE on a wireless dispersive fading channel.

SYSTEM MODEL

In the following description, a wideband CDMA transmission is considered in downlink. For each cell, the multipath propagation can be described by a filter whose Channel Impulse Response (CIR) is the sum of delayed paths with different attenuations and phases and the CIR of the discrete time baseband equivalent model of the channel for the cell p as $h^{(p)}(l)$, l = 0, 1,..., L-1 where the L is the discrete-time channel path length.

In order to describe simply the system, this study assumes that each cell has one user with multi-codes in a slot (Take EVDO system for example, there is only one user with 16 codes in a certain slot in a cell). Each cell/user has the K active codes that spread the information data with codes having a spreading factor S_F. For the pth user/cell, the transmitted signal can be expressed as:

$$s^{(p)}(i) = PN^{(p)}(i) \cdot \sum_{k=1}^{K} s^{'(p,k)}(i) \tag{1}$$

$$s^{'(p,k)}(m + n \cdot S_F) = c^{(p,k)}(m) \cdot d^{(p,k)}(n) \tag{2}$$

where, $c(p, k)^{(m)}$, m = 0, 1,..., S_{f-1} is the spreading code and $d(p, k)^{(n)}$ is the nth data signal after modulation and $S'^{(p,k)}$ is spread signal of the kth code of the pth user/cell and $PN^{(p)}(I)$ is the pseudo-random sequence of the pth user/cell.

The received discrete-time signal of the User Equipment (UE) can be obtained as:

$$r(i) = \sum_{p=0}^{P-1} \sum_{l=0}^{L-1} s^{(p)}(l - i) \cdot h^{(p)}(i) + w(i) \tag{3}$$

where, w(i) is the complex additive white Gaussian noise (AWGN) term, having zero mean and variance N_0.

The Frequency Domain (FD) of the received signal can be transferred as:

$$R_q(i) = \sum_{p=0}^{P-1} S_q^{(p)}(i) \cdot H_q^{(p)} + W_q(i) \tag{4}$$

where, the q is the index of the sub-carrier.

TRADITIONAL DFE

For a single user, the Eq. 4 can be rewritten as:

$$R = S.H+E \tag{5}$$

The equalizer includes two parts:

- The Forward Filter (FF) coefficients $\{F_q\}$, q = 1, 1,..., Q-1, in the FD which partially equalizes for the interference, where the Q is the FFT size
- The Feedback Filter (FB) coefficients $\{B_q\}$, q = 1, 1,..., Q-1 and the output $\{Y_q\}$ in the FD which removes part of the residual interference

The proposed method Iterative Block DFE (IB-DFE), in the reference Benvenuto and Tomasin (2005), iterates the equalization and data detection for N_I times. At iteration j, the vector $F^{(j)}$ containing the FF filter coefficients is element-wise multiplied with R to yield the vector signal $Z^{(j)}$, with elements:

$$Z_q^{(j)} = F_q^{(j)} \cdot R_q \tag{6}$$

The FB output vector signal $Y^{(j)}$ has components:

$$Y_q^{(j)} = B_q^{(j)} \cdot \hat{S}_q^{(j-1)} \tag{7}$$

where, $\hat{S}^{(j-1)}$ is the output FD detected data of the j-1 iteration.

At the detection point, we obtain the vector signal:

$$\begin{aligned} U^{(j)} &= Z^{(j)} + Y^{(j)} \\ &= F^{(j)} \cdot R^{(j)} + B^{(j)} \cdot \hat{S}^{(j-1)} \end{aligned} \tag{8}$$

The MSE at the detection point is given by:

$$J^{(j)} = \frac{1}{Q^2} \sum_{q=0}^{Q-1} E\left[\left| F_q^{(j)} \cdot R_q + B_q^{(j)} \cdot \hat{S}_q^{(j-1)} - S_q \right|^2 \right] \tag{9}$$

At application of gradient method to minimize Eq. 9 with respect to the FB and FF filter coefficients, yields the solution:

$$B_q^{(j)} = -\frac{\gamma^{(j-1)}}{M_{\hat{S}_q^{(j-1)}}} \left[H_q F_q^{(j)} - HF^{(j)} \right] \tag{10}$$

$$F_q^{(j)} = \frac{H_q^*}{N_0 + M_{S_q} \left(1 - \frac{\left|\gamma^{(j-1)}\right|^2}{M_{S_q} M_{\hat{S}_q^{(j-1)}}} \right) \left|H_q\right|^2} \tag{11}$$

where, M_{S_q} and $M_{\hat{S}_q^{(j-1)}}$ is the power of the transmitted and the detected signal in FD, respectively. $\gamma^{(j-1)}$ represents the correlation between transmitted and detected data sequences. Their mathematic formats can be written as:

$$M_{S_q} = E\left[\left|S_q\right|^2\right] \quad (12)$$

$$M_{\hat{S}_q^{(j-1)}} = E\left[\left|\hat{S}_q^{(j-1)}\right|^2\right] \quad (13)$$

$$\gamma^{(j-1)} = E\left[S_q \hat{S}_q^{(j-1)*}\right] \quad (14)$$

$$HF^{(j)} = \frac{1}{Q}\sum_{q=0}^{Q-1} H_q F_q^{(j)} \quad (15)$$

The reference Stamoulis *et al.* (2001) extends this algorithm to the uplink system, where the Base Station (BS) has the multiuser scenario. In this study, the BS equalizes the received signal from each user by using the DFE method but don't consider the correlation between these users. Namely, only calculate the FF and FB filter of each user, respectively.

$$B_q^{(p,j)} = -\frac{\gamma^{(p,j-1)}}{M_{\hat{S}_q^{(j-1)}}}\left[H_q^{(p)} F_q^{(p,j)} - HF^{(p,j)}\right] \quad (16)$$

$$F_q^{(p,j)} = \frac{H_q^{(p)*}}{N_0 + M_{S_q}\left(1 - \frac{\left|\gamma^{(p,j-1)}\right|^2}{M_{S_q} M_{\hat{S}_q^{(j-1)}}}\right)\left|H_q^{(p)}\right|^2} \quad (17)$$

This study only simple applies the single user DFE in the multiuser system and don't care the correlation between users. We take this correlation between these users into consideration in our present study to improve the system performance.

JOINT MULTIUSER DFE

Here, the two users are considered in the following derivation. The LMMSE-DFE signal model is described as following:

$$\begin{bmatrix} U_1^{(j)}(q) \\ U_2^{(j)}(q) \end{bmatrix} = \begin{bmatrix} F_1^{(j)}(q) \\ F_2^{(j)}(q) \end{bmatrix} R(q) + \begin{bmatrix} B_{11}^{(j)}(q) & B_{12}^{(j)}(q) \\ B_{21}^{(j)}(q) & B_{22}^{(j)}(q) \end{bmatrix} \begin{bmatrix} \hat{S}_1^{(j-1)}(q) \\ \hat{S}_2^{(j-1)}(q) \end{bmatrix} \quad (18)$$

The matrix expression of the Eq. 18 can be rewritten as:

$$U^{(j)}(q) = F^{(j)}(q) \cdot R^{(j)}(q) + B^{(j)}(q) \cdot \hat{S}^{(j-1)}(q) \quad (19)$$

The above equation is similar to the Eq. 8 in the single user model. The cost function of the LMMSE-DFE is:

$$J^{(j)} = \frac{1}{Q^2}\sum_{q=0}^{Q-1} E\left[\left|F^{(j)}(q) \cdot R(q) + B^{(j)}(q) \cdot \hat{S}^{(j-1)}(q) - S(q)\right|^2\right] \quad (20)$$

The FF and FB filter coefficients can be obtained as:

$$B^{(j)}(q) = -\left(F^{(j)}(q) \cdot H(q) - I\right) \cdot \eta \quad (21)$$

$$F^{(j)}(q) = \frac{\begin{bmatrix} M_{S_1} \cdot H^{(1)*}(q) \\ M_{S_2} \cdot H^{(2)*}(q) \end{bmatrix}}{N_0 + \sum_{p=1}^{2} M_{S_p}\left(1 - \frac{\left|\gamma^{(p,j-1)}\right|^2}{M_{S_p} M_{\hat{S}_p^{(j-1)}}}\right)\left|H^{(p)}(q)\right|^2} \quad (22)$$

UN-BIASED MMSE-DFE

The unbiased MMSE notion has been proposed in the study of Rainfield (2009). This study applies unbiased MMSE in the joint multi-user MMSE-DFE, then the feedback and forward filter coefficients can be re-written as following:

$$B_{unbiased}^{(j)}(q) = -\left(F_{unbiased}^{(j)}(q) \cdot H(q) - I\right) \cdot \eta \quad (23)$$

$$F_{unbiased}^{(j)}(q) = \frac{F^{(j)}(q)}{HF^{(j)}} \quad (24)$$

PERFORMANCE COMPARISON

The CDMA2000-EVDO system is considered in the following simulation, whose slot structure is illustrated as following Fig. 1. An EVDO frame, 80/3 msec, includes 16 slots, in which there is two half slots. And each half slot is divided into two data parts, two MAC parts and one pilot part. Each data part applies WALSH code 16, namely Spreading Factor (SF) equating to 16 and full codes are employed. Without loss of generality, the two cells, only one user in each cell, is considered.

In order to evaluate the convergence of our proposed algorithm, the simulation result is shown in the Fig. 2. And the simulation result shows that the proposed algorithm has good convergence and the performance of the 4-th iteration outperforms about 3 dB compared with no iteration at 10% raw BER. Another, the ideal correlation factor is considered in the Fig. 2. The effect of the

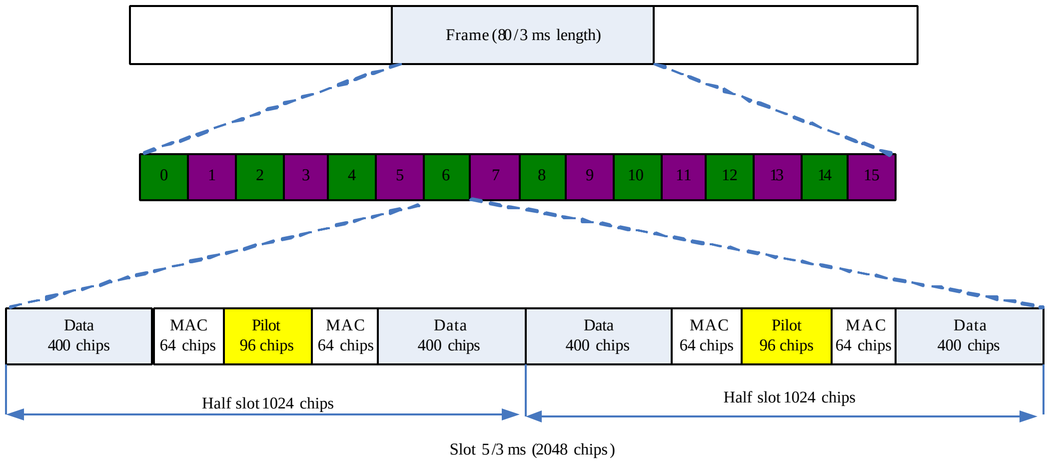

Fig. 1: Slot structure of the CDMA2000-EVDO

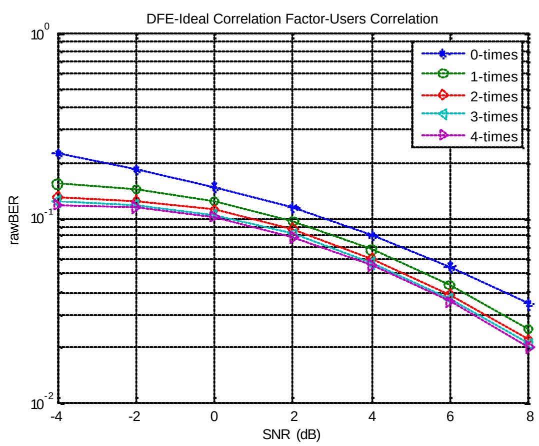

Fig. 2: Performance comparison between different iteration times of proposed algorithm under ideal correlation factor

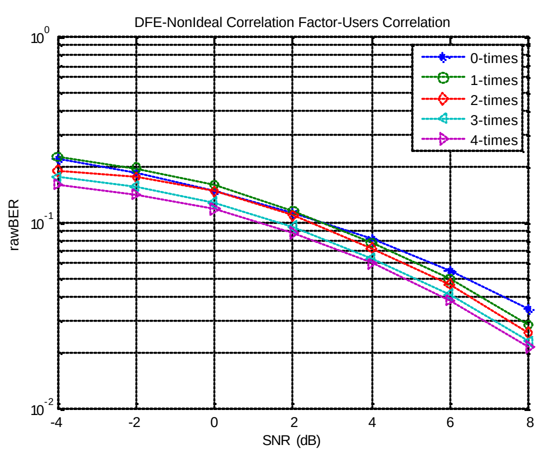

Fig. 3: Performance comparison between different iteration times of proposed algorithm under estimated correlation factor

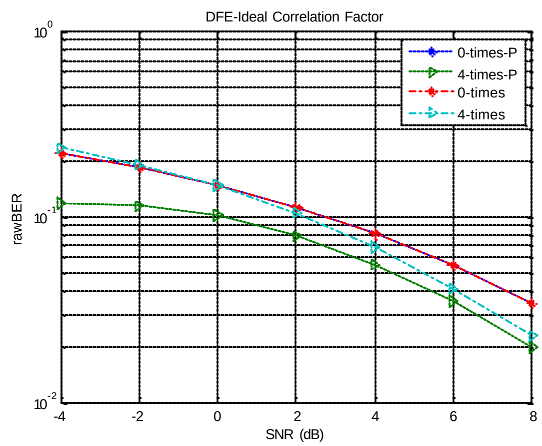

Fig. 4: Performance comparison between proposed algorithm and general DFE algorithm under ideal correlation factor, label 'i-times-P' means the performance of the i-th times iteration of proposed algorithm

correlation factor on the iteration DFE algorithm is evaluated in Fig. 3 and the simulation result shows that the estimated correlation factor has worse effect on the performance compared with the ideal correlation factor, especially at the low SNR scenario.

Compared to the reference paper (Stamoulis *et al*., 2001), our proposed algorithm takes the correlation between users during the iteration DFE into consideration. To illuminate the advantage of this modified item, the simulation is shown in the Fig. 4 which shows that the proposed algorithm outperforms about 2 dB gain compared with the algorithm mentioned in the study of Stamoulis *et al*. (2001) at the raw BER 10%. Especially, the more gain is obtained at low SNR.

CONCLUSION

A joint multiuser iteration-block DFE using a frequency domain FF and FB filter has been proposed. The IB-DFE method (Benvenuto and Tomasin, 2005) is only applied on each single user which can cancel the precursors of the inter-symbol interference and further improve the performance of each single user. Since the feed-back signal of other user has also effect on the desired user, the correlation factor between users will improve the performance compared with the conventional IB-DFE. The simulation results show that the proposed IB-DFE method, based on correlation between users, outperforms more than 2 dB compared with the conventional IB-DFE on a wireless dispersive fading channel.

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