Soft-PIC multiuser detection in MC-CDMA uplink system

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Abstract: It is necessary for an MC-CDMA uplink receiver to employ MUD (multiuser detection) in a frequency selective fading channel. After analyzing the algorithm of PIC (parallel interference cancellation) MUD, a novel MUD scheme, Soft-PIC (soft parallel interference cancellation) is proposed. Based on the reliability of each detected user signal in the former stage, this Soft-PIC detection scheme substitutes a soft decision of the variable for the hard decision in PIC scheme. Compared with the PIC scheme, it can reconstruct the interference signals more accurately and eliminate MAI (multiple access interference) in a more efficient way. PIC is one of the most practical schemes in numerous multiuser detection technologies. However, Soft-PIC as an improved PIC scheme deserves further study.

Keywords: multi-carrier code division multiple access; multiuser detection; soft parallel interference cancellation

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1 INTRODUCTION

The MC-CDMA scheme is characterized by a good spectrum efficiency and ISI suppression. In addition, its modulator and demodulator can be realized by digital signal processing technology using Discrete Fourier Transforms (DFT), which correspond to the developmental trend of soft radio technology [1][2][3]. Thus it has been one of the hottest research topics in recent years.

For the MC-CDMA system, different users are recognized by different Walsh sequences. However, the orthogonality of spreading codes would be corrupted because the attenuation over each subcarrier is different. Also, in the uplink, the attenuation over the same subcarrier for different users is not the same [4]. In this situation, multiuser detection (MUD) must be employed to avoid MAI and improve receiver performance. Parallel Interference Cancellation (PIC) is a very popular approach for MUD [5].

2 PIC SCHEME IN MC-CDMA

PIC in MC-CDMA is very similar to PIC in CDMA system. When the PIC algorithm is introduced in MC-CDMA, interference signals are achieved using single user detection technology, i.e. combining detection [2] is applied for each user. Another important difference is that channel equalization is employed besides spreading when reconstructing the interference signals. Generally it can get good performance via 2-stage detection, such as EGC-MRC MUD, MMSE-MRC MUD [8][9][10].

As shown in Fig. 1, equal gain combining (EGC) is used in stage 1 to get the estimation signal of each user. After reconstructing the interference signal, PIC is applied. Finally maximum ratio combining is employed as the 2nd stage of detection.

In this example, EGC is used in stage 1, and the decision variable is

\[ D_v^{(2)} = \sum_{n=0}^{\sigma_{\text{MC}-1}} y(m) C_n^v h_m^* \left| h_m^v \right| \] (1)

The estimation of each user comes out as

\[ \hat{h}_v^{(1)} = \text{sgn} (D_v^{(1)}) = \text{sgn} \left[ \sum_{n=0}^{\sigma_{\text{MC}-1}} y(m) C_n^v \left| h_m^v \right| \right] \] (2)
This is the output of stage 1. It can be observed that MAI is present here, due to the fact that this is just a single user detection technology, and thus it is not reliable. Assuming that $\hat{b}_{u}^{(1)}$ is exactly what each user sends, after spreading, the output of the transmitters is

$$r \neq \sum \ldots$$

First estimation by EGC

Reconstruction

Second estimation by MRC

**Fig. 1** 2-Stage PIC Multiuser Detection

From the diagram, we use the PIC algorithm, where $C_u = [C_{u,0}, C_{u,1}, \ldots, C_{u,GMC-1}]$ is the $u^{th}$ user's spreading code vector, $h_u = [h_{u,0}, h_{u,1}, \ldots, h_{u,GMC-1}]^T$ the $u^{th}$ user's channel coefficient vector, and $\cdot$ here denotes the product of two vectors, still a vector.

Therefore, the $u^{th}$ user's reconstructed signal is obtained. For the $u^{th}$ user, any other user signal is interference. All interference has been estimated in stage 1. By using the PIC algorithm, the desired signal $\hat{y}_u$ can be detected by subtracting $(N-1)$ interferences

$$\hat{y}_u = y - \sum_{j \neq u}^{N} \hat{y}_j = y - \sum_{j \neq u}^{N} \hat{b}_j^{(1)} C_j \cdot h_j.$$  (4)

In the 2nd stage, detecting $\hat{y}_u$ using MRC combining gives the decision variable

$$D_u^{(2)} = (C_u \cdot h_u)^H [y - \sum_{j \neq u}^{N} \hat{b}_j^{(1)} C_j \cdot h_j].$$  (5)

The decision output of stage 2 is

$$\hat{b}_{u}^{(2)} = \text{sgn}(D_u^{(2)}).$$  (6)

3 THE IMPROVED PIC SCHEME-SOFT-PIC

During reconstruction in PIC, a hard decision is used for the decision variable $D_u^{(1)}$ in stage 1, and the output is $\hat{b}_{u}^{(1)}$. The next step reconstructs all interference signals using $\hat{b}_{u}^{(1)}$ and subtracts the interference instantaneously to get the desired signal. However, the decision output $\hat{b}_{u}^{(1)}$ in stage 1 cannot be perfectly correct, so it cannot reconstruct all users' interference precisely. Some new interference would be introduced when using PIC. Therefore, some users' signals, which are correct after the 1st stage detection, become wrong after the application of PIC. To avoid error propagation, we can use soft decision on $D_u^{(1)}$ based on its reliability to reconstruct interference. The reliability is introduced shortly below.

Output after the combining detection can be expressed as

$$D_u^{(1)} = a_u \sum_{i=0}^{\text{GMC}-1} C_{u,i} h_{u,i} C_{u,i} b_{u,i} + \sum_{j=1}^{N} a_j \sum_{i=0}^{\text{GMC}-1} C_{u,i} h_{j,i} C_{u,i} b_{u,i} + \text{MAI} + \ldots$$

where $D_u^{(1)}$ is the decision variable for user $u$, $a_u$ is the desired symbol, $C_{u,i}$ is the spreading code of user $u$ for the $i^{th}$ spreading code, $h_{u,i}$ is the channel coefficient of user $u$ for the $i^{th}$ spreading code, $b_{u,i}$ is the decision output of stage 1 for user $u$ for the $i^{th}$ spreading code, and $\text{MAI}$ is the multi-access interference. The reliability is introduced shortly below.

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where $D_u^{(1)}$ is the decision variable for user $u$, $a_u$ is the desired symbol, $C_{u,i}$ is the spreading code of user $u$ for the $i^{th}$ spreading code, $h_{u,i}$ is the channel coefficient of user $u$ for the $i^{th}$ spreading code, $b_{u,i}$ is the decision output of stage 1 for user $u$ for the $i^{th}$ spreading code, and $\text{MAI}$ is the multi-access interference. The reliability is introduced shortly below.