A modified Parallel Interference Canceller in MC-CDMA uplink systems

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Abstract

In the MC-CDMA uplink system, the user signal experiences different fading, suffering from a large amount of interference from other users. For reliable data detection, the use of multi user detector (MUD) with high complexity has been considered in the MC-CDMA uplink system. In this paper, we propose a modified parallel interference cancellation scheme (MPIC) that can provide the performance better than conventional MUD, while requiring affordable complexity.

1. Introduction

Multi-carrier code division multiple access (MC-CDMA) is a promising multiple access scheme for the 4th generation mobile radio, since it combines the advantages of orthogonal frequency division multiplexing (OFDM) and code division multiple access (CDMA) system [1,2]. In MC-CDMA system, each signal is spreaded over several sub-carriers in the frequency domain to exploit the frequency diversity of multi-path fading channel. Since each user signal experiences different multi-path fading characteristics in the MC-CDMA uplink, the orthogonality between the spreading codes of each user is destroyed. Thus, the receiver suffers from so-called multiple access interference (MAI). Several schemes have been proposed to mitigate the MAI problem. The minimum mean square error (MMSE) multi user detector (MUD) is the optimum linear receiver that takes into accounts both the MAI and addictive white Gaussian noise (AWGN) [3]. However, its performance is not good compared to single user performance, while requiring large implementation complexity. The maximum likelihood (ML) detector is the optimum detector, but its complexity is exponentially increased as the number of multiple access users increases [4]. The use of pre-equalization has been considered, where the user signal is pre-distorted at the transmitter so as to be orthogonal at the receiver [5]. Thus, it simplifies the despreading process in the receiver. However, it requires the channel state information (CSI) at the transmitter. The CSI can be delivered from the remote site through feedback, significantly reducing the spectral efficiency. The CSI can be obtained using the reciprocal property of the uplink and downlink channel in time division duplex system. However, in mobile environment, the variation of channel characteristics makes it difficult to predict the CSI and may cause significant performance degradation.

The use of parallel interference cancellation (PIC) was proposed to cancel out the interference from other users using pre-decoded data [6,7]. Since this process is usually performed in an iterative manner, the performance of tentative decision is important to reduce the error-propagation problem. In the MC-CDMA uplink system, the use of a simple combining method such as one-tap MMSE combining or maximal ratio combining (MRC) for tentative decision does not provide good performance due to unreliable tentative decision at the initial stage [2]. The error rate of tentative decision at the initial stage can be reduced using an MMSE MUD [8]. However, it requires large implementation complexity.

In this paper, we propose a modified PIC (MPIC) scheme that uses a simple MRC scheme at each stage. To reduce the probability of error in tentative decision, we introduce an additional error correction module after the tentative decision in each stage. This error correction can

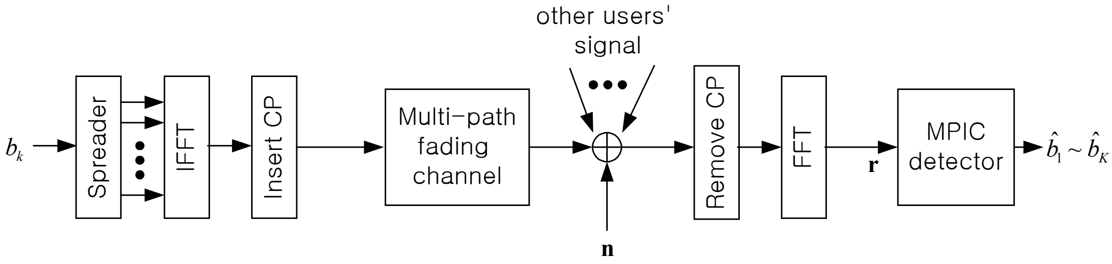


Fig. 1. System model for MC-CDMA with MPIC detector

provide significant performance improvement, yielding a performance close to that of single user.

This paper is organized as follows. Section 2 describes the system model. Section 3 presents the proposed MPIC detection structure. The performance of the proposed scheme is verified by computer simulation in Section 4. Finally, we conclude in Section 5.

2. System model

For ease of description, we consider the reverse link in a single cell configuration. We assume that the CSI is known to the receiver. K mobile users transmit the signal over N sub-carriers using the spreading code $(\mathbf{c}_1, \mathbf{c}_2, \cdots, \mathbf{c}_K)$ in the frequency domain. The signal is converted into a time domain signal using inverse fast Fourier transform (IFFT). A cyclic prefix is added to avoid the inter-symbol interference (ISI) and inter-carrier interference (ICI). In the receiver, the cyclic prefix is removed and then the signal is converted into a frequency domain signal by FFT. Assuming that the length of the cyclic prefix is larger than the maximum delay spread of the channel, the received signal vector after FFT can be represented as

$$\mathbf{r} = \sum_{k=1}^{K} b_k \mathbf{c}_k \cdot \mathbf{h}_k + \mathbf{n} = \sum_{k=1}^{K} b_k \mathbf{u}_k + \mathbf{n} \qquad (1)$$

where b_k, $\mathbf{c}_k$ and $\mathbf{h}_k$ are respectively the transmitted bit, frequency domain spreading code vector and frequency domain channel coefficient vector for user k, and

$$\mathbf{u}_k = \mathbf{c}_k \cdot \mathbf{h}_k = [c_k^1 h_k^1 \cdots c_k^N h_k^N]^T = [u_k^1 \cdots u_k^N]^T \qquad (2)$$

Here, the superscript T denotes the transpose operation.

3. Proposed PIC structure

The received signal $\mathbf{r}$ is input to the MRC combiner. The data bit for user k is tentatively decoded as

$$\tilde{b}_k^1 = sgn\left(\mathbf{u}_k{}^H \mathbf{r}\right) \qquad (3)$$

where the superscript H denotes the matrix conjugate and transpose operation, and $\operatorname{sgn}(x)$ is the sign function; $\operatorname{sgn}(x) = 1$ if $x \geq 0$, -1, otherwise. Using these tentative decision bits, noiseless signal $\tilde{\mathbf{r}}_1$ for the first stage is generated.

$$\tilde{\mathbf{r}}_1 = \sum_{k=1}^{K} \tilde{b}_k^1 \mathbf{u}_k \qquad (4)$$

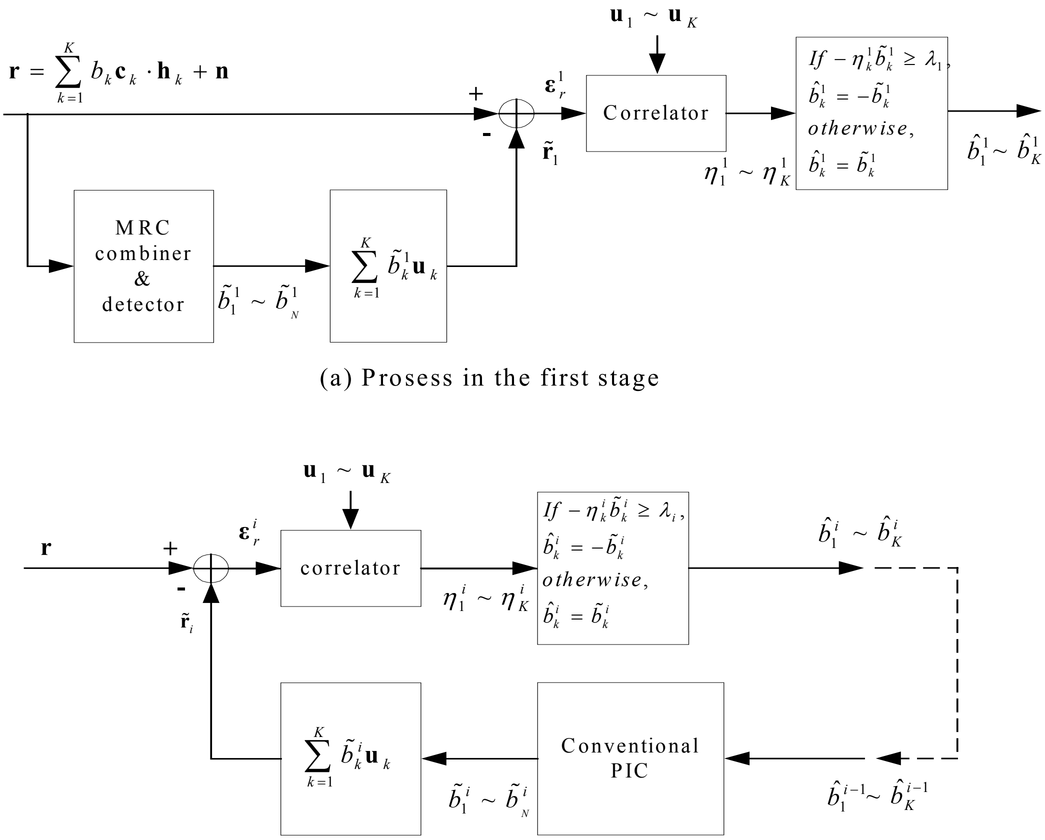
If the tentatively decoded data bits are correct, the residual signal $\boldsymbol{\varepsilon}_r^1 (= \mathbf{r} - \tilde{\mathbf{r}}_1)$ contains only the noise term. The residual signal $\boldsymbol{\varepsilon}_r^1$ is correlated with $\mathbf{u}_1, \cdots, \mathbf{u}_K$ to generate the decision variables for error correction in the first stage.

$$\eta_k^1 = \mathbf{u}_k{}^H (\mathbf{r} - \tilde{\mathbf{r}}_1) = \sum_{j=1}^{K} (b_j - \tilde{b}_j^1) \mathbf{u}_k{}^H \mathbf{u}_j + \mathbf{u}_k{}^H \mathbf{n} \qquad (5)$$

To correct the erroneous tentative decoding, we consider the following term.

$$T_k^1 \triangleq -\eta_k^1 \tilde{b}_k^1 = -\tilde{b}_k^1 (b_k - \tilde{b}_k^1) \mathbf{u}_k{}^H \mathbf{u}_k - \tilde{b}_k^1 \left(\sum_{j=1, j \neq k}^{K} (b_j - \tilde{b}_j^1) \mathbf{u}_k{}^H \mathbf{u}_j + \mathbf{u}_k{}^H \mathbf{n} \right) \qquad (6)$$

Assuming that $\mathbf{u}_k{}^H \mathbf{u}_k = \sum_{l=1}^{N} \left| h_k^l \right|^2 = 1$, the first term of T_k^1 is 2 or 0. Since $\mathbf{u}_k{}^H \mathbf{u}_j$ given $k \neq j$ is the sum of multiple independent random variables and $\mathbf{n}$ is Gaussian random



(a) Prosess in the first stage

(b) Process in the *i-th* stage

Fig. 2. MPIC detector structure

variable, the second term can be approximated as Gaussian random variable given $b_j - \tilde{b}_j^1$. The mean of T_k^1 given $b_k - \tilde{b}_k^1$ can be written as

$$\begin{aligned} &E\left[T_k^1 \mid (b_k - \tilde{b}_k^1)\right] \\ &= E\left[-\tilde{b}_k^1 (b_k - \tilde{b}_k^1)\mathbf{u}_k{}^H \mathbf{u}_k \mid (b_k - \tilde{b}_k^1)\right] \\ &+E\left[-\tilde{b}_k^1\left(\sum_{j=1, j\neq k}^{K} (b_j - \tilde{b}_j^1)\mathbf{u}_k{}^H \mathbf{u}_j + \mathbf{u}_k{}^H \mathbf{n}\right) \mid (b_k - \tilde{b}_k^1)\right] \\ &= \begin{cases} 2 + \alpha_w^1 & if \;\; \tilde{b}_k^1 \neq \hat{b}_k^1 \\ 0 + \alpha_r^1 & if \;\; \tilde{b}_k^1 = \hat{b}_k^1 \end{cases} \end{aligned} \tag{7}$$

Where α_w^1 and α_r^1 is the mean of second term in T_k^1 given wrong and right tentative decoding, respectively. If T_k^1 is less than a predetermined threshold value λ_1, we decide that the tentatively decoding was wrong and correct the tentative decoded data bit as

$$\hat{b}_k^1 = \begin{cases} \tilde{b}_k^1, & if \;\; -\eta_k^1 \tilde{b}_k^1 < \lambda_1 \\ -\tilde{b}_k^1, & ohterwise \end{cases} \tag{8}$$

Since T_k^1 depends on the statistics of previous tentative decision, it is not easy to determine the optimum value of λ in an analytic manner. As will be discussed later, it may be practical to determine λ using computer simulation.

In the next stage, the tentatively decoded data bits $\hat{b}_1^1, \cdots, \hat{b}_K^1$ are used for conventional PIC operation. The interference free signal is generated as

$$\mathbf{r} - \sum_{j=1, j\neq k}^{K} \hat{b}_k^1 \mathbf{u}_k \tag{9}$$

Using the MRC, the user data is tentatively decoded in the second stage as

$$\tilde{b}_k^2 = sgn\left\{\left(\mathbf{r} - \sum_{j=1, j\neq k}^{K} \hat{b}_k^1 \mathbf{u}_k\right)\mathbf{u}_k{}^H\right\} \tag{10}$$

As in the first stage, $\eta_1^2, \cdots, \eta_K^2$ is obtained using $\tilde{b}_1^2, \cdots, \tilde{b}_K^2$. Using $\eta_1^2, \cdots, \eta_K^2$ and pre-defined second stage threshold value λ_2, the tentatively decoded data bits in second stage are corrected to $\hat{b}_1^2, \cdots, \hat{b}_K^2$ as like in the first stage.

In this manner, the decoding process continues until the decoding performance satisfies the desired one.

4. Numerical Results

To verify the performance of the proposed PIC scheme, we consider an MC-CDMA system with N=64 and K=48, where Walsh Hadamard code is used as the spreading code in the frequency domain. We assume that the receiver has perfect knowledge on the CSI.

Fig.3 depicts the bit error rate (BER) performance of MC-CDMA with the use of the proposed MPIC, where the iteration-l means the number of iterations to get the final data bits. It can be shown that the use of the proposed PIC can provide the receiver performance close to that of a single user as the number of iterations increases. In practice, it may be enough to use the proposed scheme with 3 iterations to get admissable performance.

For performance comparison, Fig. 4 depicts the BER performance of other detection schemes. It can be seen that the use of conventional PIC results in floored BER performance unlike the use of the proposed PIC. This is mainly due to that incorrectly decoded data at each stage in the presence of the MAI can cause the effect of increased interference in the next stage decoding process. Since the proposed MPIC scheme can correct erroneously decoded data bits, it can outperform the conventional PIC scheme. It can also be seen that other convention detection schemes cannot provide the BER performance as much as the proposed PIC scheme.

In the proposed bit inversion operation, threshold value plays a very important role. Fig. 5 depicts the BER performance of the proposed MPIC for different value of λ. It can be seen that the optimum threshold value increases as the number of iterations increases. However, it may be practical to use a fixed threshold value of $\lambda = 1.5$ for all stages.

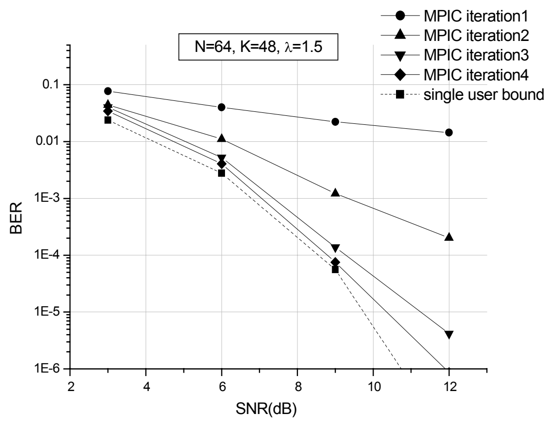


Fig. 3. BER performance of MPIC with different iteration

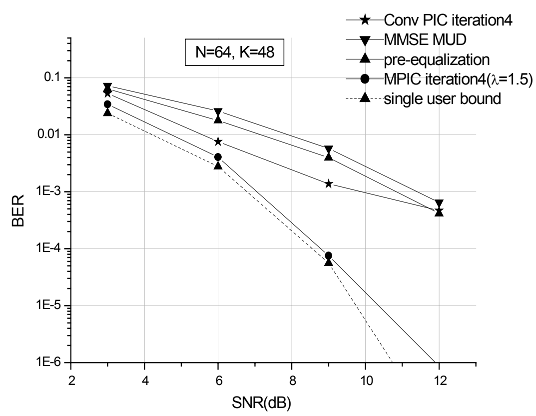


Fig. 4. Performance of conventional detection schemes

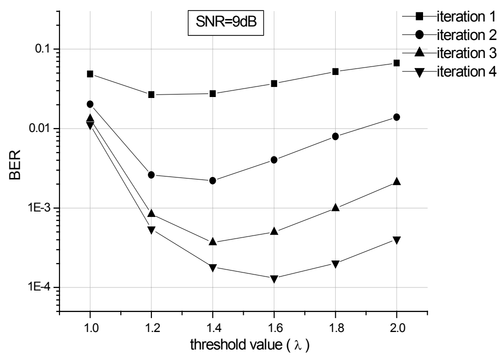


Fig. 5. BER performance with different threshold value

5. Conclusion

In this paper, we have proposed a modified PIC scheme for an MC-CDMA receiver in the uplink. The proposed MPIC scheme employs a data bit connection module to provide the data bits with reduced decision error to the next PIC processor. The proposed MPIC scheme outperforms the conventional PIC schemes with a small additional implementation complexity. Simulation results show that the use of the proposed MPIC scheme can provide the receiver performance close to that of a single user.

6. References

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