Performance of Cyclic Prefix Assisted Single Carrier CDMA Uplink System with MIMO Multiplexing

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Abstract

In this paper, we describe a novel type of cyclic prefix assisted single carrier CDMA system with Frequency Domain Equalization (FDE) and MIMO Multiplexing. The proposed method is referred to as MIMO SC/FDE CDMA. Multipath Interference can be mitigated by inserting cyclic prefix at the transmitter. Furthermore, we use different scrambling codes to separate different transmit antennas. At the receiver, Frequency Domain Equalization was employed with an iterative soft interference cancellation method. Simulation results show that the proposed MIMO SC/FDE CDMA system can achieve high performance while still keeping low complexity.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an effective scheme to combat the frequency selectivity of the multipath channel. It prevents inter symbol interference (ISI) by inserting a cyclic prefix (CP) between adjacent OFDM symbols. The OFDM signal can be transmitted and received using fast Fourier transform without increasing the transmitter and receiver complexities. However, OFDM based MC-CDMA system suffers from two main problems. First, MC-CDMA is very sensitive to frequency offset and RF phase noise. Second, the peak-to-average ratio (PAR) of the transmitted signal power is very large. This inefficiency is especially a problem in the uplink where the transmitter is a battery driven terminal.

Recently, cyclic prefix assisted single-carrier transmission with frequency domain equalization (SC/FDE) has been proposed as an alternative to OFDM [1]. A number of authors have compared the performance between SC/FDE and OFDM [2-5]. Studies in [2], [3] show that SC/FDE can allow a more power efficient transmitter, which is very important for mobile terminals. Meanwhile, the complexity and performance of SC/FDE are similar to those of OFDM [1]. Simulation results in [4],[5] show that when combined with CDMA, SC/FDE CDMA can achieve better performance than MC-CDMA and DS-CDMA in the downlink system.

So far, few authors have discussed the SC/FDE in CDMA uplink system, especially in a MIMO case. In this paper we combine SC/FDE and MIMO multiplexing for CDMA uplink transmission. Section 2 introduces the proposed MIMO SC/FDE CDMA system model. The receiver structure is presented and discussed in Section 3. Computer simulation results and conclusions of the proposed system are given in Section 4 and Section 5 respectively.

2 System Model

Figure 1 illustrates the baseband transmitter structure of the proposed MIMO SC/FDE CDMA system. We consider the uplink transmission in a single cell CDMA system with U active users and each user has N transmit antennas. At the transmitter, a binary data sequence is transformed into data-modulated symbol sequence and then serial-to-parallel (S/P) converted into N parallel symbol sequence. These data symbols are then spread and scrambled. Note that the spreading codes are user specific while the scrambling codes are antenna

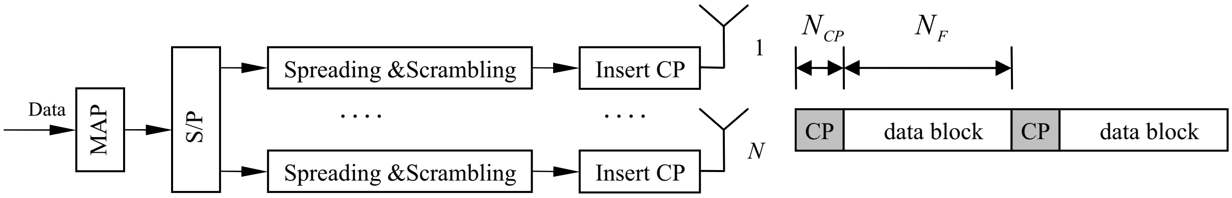

Fig.1 MIMO SC/FDE CDMA Transmitter and Transmit Block

specific. The scrambled sequence is grouped into data blocks, and a cyclic prefix of N_{CP} chips is added at the beginning of each block to form a transmit block. This process is similar to OFDM system and can be illustrated in the following formula:

$$\mathbf{P}_u(b,k)=\begin{cases}\mathbf{X}_u(b,N_F-N_{CP}+k) & 0\le k\le N_{CP}-1\\ \mathbf{X}_u(b,k-N_{CP}) & N_{CP}\le k\le N_L-1\end{cases} \quad (1)$$

where $\mathbf{X}_u(b,i)$ is an N-dimensional data vector, which denotes the i^{th} scrambled chip of b^{th} data block of the u^{th} user. N_F denotes the length of each data block and $N_L=N_{CP}+N_F$ is the length of each transmit block. We assume there is B transmitted blocks in each frame, and the final k^{th} transmitted vector of the u^{th} user can be express as:

$$\mathbf{S}_u(k)=\mathbf{P}_u(\lfloor k/N_L\rfloor, k \bmod N_L) \quad 0\le k\le BN_L-1 \quad (2)$$

where $\lfloor x\rfloor$ denotes the largest integer that is not bigger than x.

The base station with M receive antennas will receive the data stream from each user asynchronously. The k^{th} received signal vector is represented as:

$$\mathbf{R}(k)=\sum_{u=1}^{U}\mathbf{R}_u(k-\tau_u)+\boldsymbol{\eta}(k) \quad (3)$$

where $\mathbf{R}_u(k)$ and τ_u are the M-dimensional received signal vector and time delay for the u^{th} user respectively, and $\boldsymbol{\eta}(k)$ is the AWGN noise vector. $\mathbf{R}_u(k)$ is expressed as follows:

$$\mathbf{R}_u(k)=\sum_{l=1}^{L_u}\mathbf{h}_u(l)\mathbf{S}_u(k-l)$$
$$\mathbf{h}_u(l)=\begin{bmatrix} h_u^{1,1}(l) & \cdots & h_u^{1,M}(l)\\ \vdots & \ddots & \vdots\\ h_u^{N,1}(l) & \cdots & h_u^{N,M}(l)\end{bmatrix} \quad (4)$$

where $h_u^{i,j}(l)$ is the l^{th} multipath component from the i^{th} transmitted antenna to the j^{th} received antenna.

At the receiver, after removal of Cyclic Prefix from each block, N_F-point FFT is applied to obtain the N_F frequency components. The received signal vector for the i^{th} frequency component of the b^{th} data block of the u^{th} user can be expressed as follows:

$$\begin{aligned}\mathbf{F}_u(b,i)&=\mathbf{H}_u(i)\mathbf{D}_u(b,i)+\sum_{v=1,v\ne u}^{U}\mathbf{T}_{v,u}(b,i)\\ &\quad+\boldsymbol{\Psi}_u(b,i) \qquad i=0,1,\ldots,N_F-1\end{aligned} \quad (5)$$

where

$$\mathbf{H}_u(i)=\sum_{l=1}^{L_u}\mathbf{h}_u(l)\exp(-j2\pi\tau_l^u\frac{i}{N_F}) \quad (6)$$

$$\mathbf{D}_u(b,i)=\sum_{k=0}^{N_F-1}\mathbf{X}_u(b,k)\exp(-j2\pi k\frac{i}{N_F})$$

$$\mathbf{T}_{v,u}(b,i)=\sum_{k=0}^{N_F-1}\mathbf{R}_v(bN_L+N_{CP}+\tau_u-\tau_v+k)\exp(-j2\pi k\frac{i}{N_F})$$

$$\boldsymbol{\Psi}_u(b,i)=\sum_{k=0}^{N_F-1}\boldsymbol{\eta}(bN_L+N_{CP}+\tau_u+k)\exp(-j2\pi k\frac{i}{N_F})$$

The second and third items of equation (5) represent the Multi Access Interference (MAI) and noise interference in frequency domain respectively. After that, two-dimensional linear frequency domain equalization can be employed as follows:

$$\mathbf{Y}_u^0(b,i)=\mathbf{W}_u^0(i)\mathbf{F}_u(b,i) \quad (7)$$

The equalization and diversity combination matrix $\mathbf{W}_u^0(i)$ can be chosen according to the estimated channel parameters $\hat{\mathbf{H}}_u(i)$ and different criterions:

$$\mathbf{W}_u^0(i)=\begin{cases}\hat{\mathbf{H}}_u^{\mathrm{H}}(i) & \text{MRC}\\ \hat{\mathbf{H}}_u^{\mathrm{H}}(i)(\sum_{v=1}^{U}\hat{\mathbf{H}}_v(i)\hat{\mathbf{H}}_v^{\mathrm{H}}(i)+\frac{N_0}{E_c}\mathbf{I}_M)^{-1} & \text{MMSE}\end{cases} \quad (8)$$

Then the equalized frequency domain signal $\mathbf{Y}_u^0(b,i)$ $i=0,1,\ldots,N_F-1$ is converted to time-domain signal $\hat{\mathbf{X}}_u^0(b,k)$ $k=0,1,\ldots,N_F-1$ with an IFFT operation, and the transmitted data symbol is obtained after descrambling and dispreading.

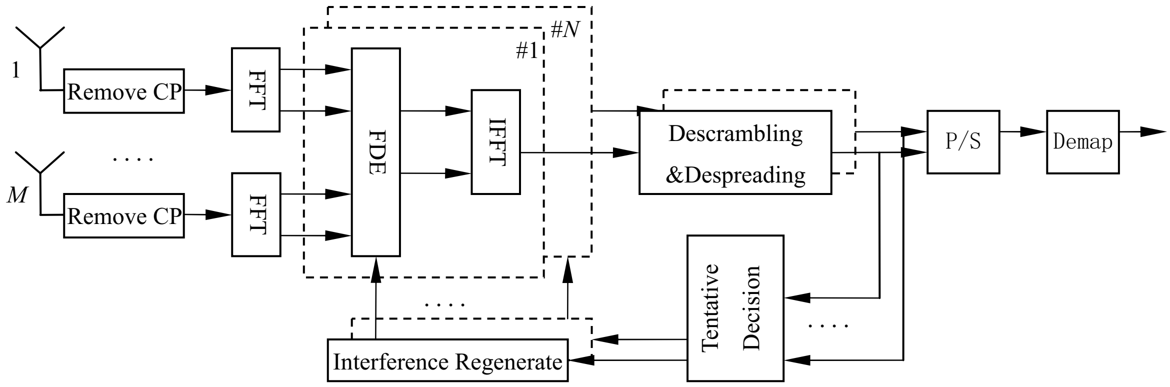

Fig.2 MIMO SC/FDE CDMA Receiver

3 Frequency Domain Multistage Interference Cancellation

In the uplink transmission, the MIMO SC/FDE CDMA system is asynchronous between users and it will suffer from the MAI that can degrade the system performance considerably. A multistage interference cancellation method can significantly improve the performance and capacity of the system which is illustrated in figure 2.

Without loss of generality, we denote $\hat{\mathbf{d}}_v^{(m-1)}$ $v=1,2,\ldots,U$ as the estimated data symbol of the v^{th} user in the $(m\text{-}1)^{\text{th}}$ iteration. The tentative decision in the m^{th} iteration is performed as follows:

$$\hat{\mathbf{d}}_v^{m-1}(n)=\frac{1}{\sqrt{2}}\{\Lambda[\beta\,\mathrm{Re}(\hat{\mathbf{d}}_v^{(m-1)}(n))]+j\Lambda[\beta\,\mathrm{Im}(\hat{\mathbf{d}}_v^{(m-1)}(n))]\}$$
$$\Lambda(x)=[1-\exp(-x)]/[1+\exp(-x)] \tag{9}$$

where β is the control factor of the tentative decision. The tentative decision data is then spread and scrambled using the corresponding codes and a replica of the received signal is reconstructed with the estimated channel parameters and FFT operation. After subtracting the reconstructed signal from the received signal, the residual frequency domain signal associated with the n^{th} transmit antenna of the u^{th} user can be represented as:

$$\begin{aligned}\widehat{\mathbf{F}}_{u,n}^{m}(b,i)&=\mathbf{F}_u(b,i)-\gamma\sum_{v=1,v\neq u}^{U}\hat{\mathbf{T}}_{v,u}^{m-1}(b,i)\\&\quad-\gamma\hat{\mathbf{H}}_{u,n}^{''}(i)\hat{\mathbf{D}}_u^{m-1}(b,i)\end{aligned} \tag{10}$$

The second item of equation (10) represents the regenerated interference from the other users and the third item represents the regenerated interference from the u^{th} user's other transmit antennas. γ is the interference cancellation weight, $\hat{\mathbf{T}}_{v,u}^{m-1}(b,i)$ is the reconstructed frequency domain signal for the v^{th} user, and $\hat{\mathbf{D}}_u^{m-1}(b,i)$ is the estimated transmitted symbol value in frequency domain which is obtained in the $(m\text{-}1)^{\text{th}}$ iteration. $\hat{\mathbf{H}}_{u,n}^{''}(i)$ is equal to $\hat{\mathbf{H}}_u(i)$ except that all elements in the n^{th} column are zeros.

After interference cancellation, joint frequency domain equalization and receive antenna diversity combination is performed simultaneously to obtain the signal component $\mathbf{Y}_{u,n}^{m}(b,i)$ associated with the n^{th} transmit antenna of the u^{th} user:

$$\mathbf{Y}_{u,n}^{m}(b,i)=\mathbf{W}_{u,n}^{m}(i)\widehat{\mathbf{F}}_{u,n}^{m}(i) \tag{11}$$

$\mathbf{W}_{u,n}^{m}(i)$ is 1-by-M equalization vector at the m^{th} iteration given by:

$$\mathbf{W}_{u,n}^{m}(i)=\begin{cases}\hat{\mathbf{H}}_{u,n}^{\mathrm{H}}(i) & \text{MRC}\\ \hat{\mathbf{H}}_{u,n}^{\mathrm{H}}(i)(\hat{\mathbf{H}}_{u,n}(i)\hat{\mathbf{H}}_{u,n}^{\mathrm{H}}(i)+\frac{N_0}{E_c}\mathbf{I}_M)^{-1} & \text{MMSE}\end{cases} \tag{12}$$

where $\hat{\mathbf{H}}_{u,n}(i)$ is the n^{th} column vector of $\hat{\mathbf{H}}_u(i)$. After IFFT operation, descrambling and despreading, the new estimated value at the m^{th} iteration can be obtained.

4 Simulation Results

In this section, the results of the computer simulations determining the bit error rate (BER) performance of the MIMO SC/FDE CDMA system are presented. We consider an asynchronous uplink system without any channel coding. Each transmitted frame consists of 16 data blocks. The channel model is assumed to be a multipath slow fading Rayleigh channel and the channels between different transmit and receive antennas are assumed to be independent. The maximum timing delay between users is 10 chips. Ideal channel estimation and power control are assumed. More details of simulation parameters are given in Table 1:

Table1: Simulation parameters

Modulation	QPSK
Spreading codes	OVSF codes with processing gain 32
Scrambling codes	Long Gold sequence
Multipath channel	L=8 , and each path has the same average power
FFT points	N_F =256
Cyclic Prefix	N_{CP} =16
Equalization	MRC method
Weight control	$\beta = 10, \quad \gamma = 0.8$

Figure 3 and figure 4 shows the BER performance of an 8-user MIMO SC/FDE CDMA system under different iterations. As a benchmark, the single-user BER is provided in both figures for comparison. In Fig.3 (N,M)=(1,2) while in Fig.4 (N, M)=(2,2). It can be seen from both figures that as the number of iterations increases, the BER performance improves. No additional improvement is obtained by increasing the number of iterations from 3 to 4. It is sufficient to use 3 iterations to achieve a BER performance close to the single user BER bound.

Fig.5 presents BER performance of the proposed system with different transmit and receive antennas. Obviously, the BER performance improves as the number of receive antennas increase. For instance, a (2,2) system can achieve the same BER performance as that of a (1,1) system without iteration (iteration=0) while the total capacity of the previous system is approximately two of the latter one due to transmit multiplexing. Further more, after 3 iterations, the (2,2) system outperforms the (1,1) system significantly as shown in the figure.

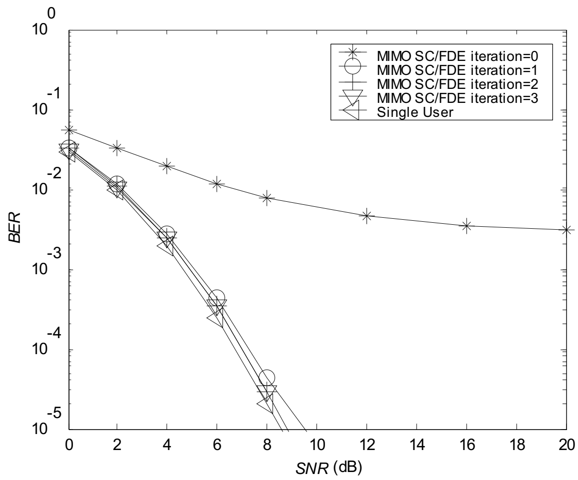

Fig.3 BER performance of different iterations of MIMO SC/FDE CDMA uplink system, Number of users =8, (N,M)=(1,2), Processing Gain =32

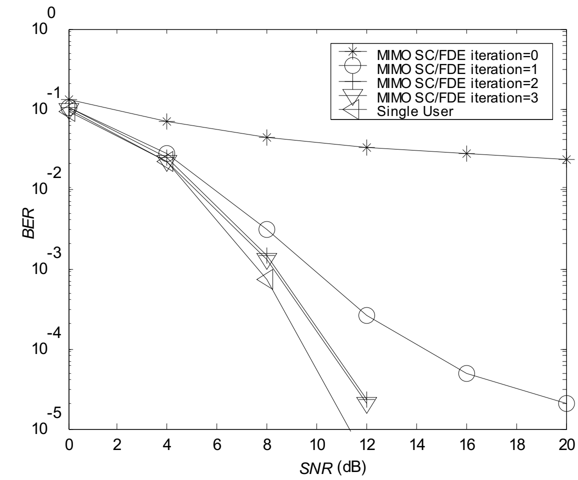

Fig.4 BER performance of different iterations of MIMO SC/FDE CDMA uplink system, Number of users =8, (N,M)=(2,2), Processing Gain =32

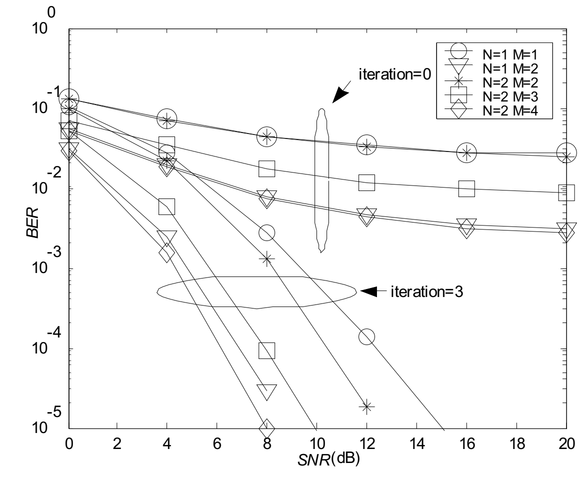

Fig.5 BER comparison with different antennas and number of iterations, Number of users =8

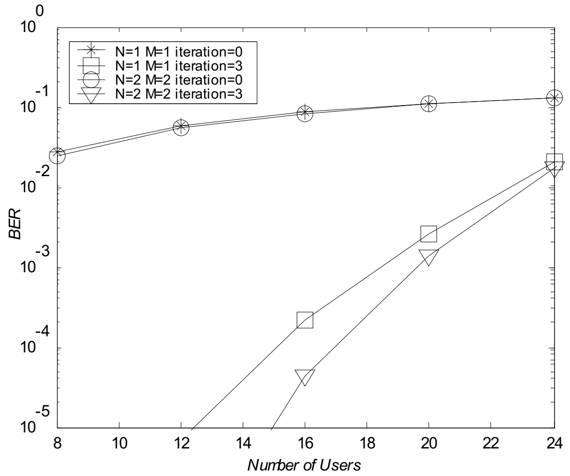

Fig.6 BER performance of the proposed system against number of users with SNR=20dB

Fig.6 shows the BER performance as a function of the number of users (*U*) with *SNR*=20dB. It demonstrates that with multistage interference cancellation, the proposed MIMO SC/FDE CDMA can give a BER of about 0.001 for a 20-user system. The (2,2) system with 3 iterations still outperforms the (1,1) system in a multi-user system..

5 Conclusions

In this paper, we proposed a cyclic prefix assisted single-carrier transmission method combined with transmit multiplexing and multistage interference cancellation for the CDMA uplink system. The achievable BER performance of MIMO SC/FDE CDMA system was evaluated through computer simulation. The results show that the proposed system can achieve high performance in a heavily loaded system with 3-stage interference cancellation. This indicates that MIMO SC/FDE CDMA is a promising candidate for high-speed uplink transmission due to its simple transmitter and receiver structure and better PAR properties.

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