Uplink Interference Rejection Combining for WCDMA Using Multiple Antennas

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Abstract. A major limitation to the capacity of WCDMA is multiple access interference (MAI) produced by the other co-channel users. In this paper, a simplified rake receiver with interference rejection combining (IRC) is investigated. The signal transmitted on the control channel is used for channel estimation and weight calculation. Compared to the maximum ratio combining (MRC), IRC can get better MAI rejection. It is a simplified algorithm to be implemented.

Keywords: WCDMA, MAI, IRC, MRC.

1 Introduction

With the development of the 3rd generation wireless communication, WCDMA is coming into the commercial phase in Europe, North America and Asia [1]. It has become the most widely accepted standard of the 3rd wireless communication in the world. However, the interferences including intersymbol interference (ISI) and multiple access interference (MAI) are the key limiting challenges to overcome in the cellular systems of the 3rd generation [2].

The Interference Rejection Combining (IRC) has been proven to mitigate both multipath fading and co-channel interference. The IRC principle has been successful for co-channel and adjacent channel interference (MAI) suppression in 2G and 3G systems [3]. In [4], the relative performance of IRC is studied. The wiener filter with IRC combining in down-link is discussed in [5]. [6] proposed a spatio-temporal rake receiver but the calculation of the covariance matrix of interference and noise is complicated. In [7], the signal received by the antenna (before despreading) is used to calculate the covariance.

Space diversity can significantly improve the performance of wireless communication [8]. In this paper, we propose a more simplified method to calculate the covariance matrix employing multiple antennas. The signal transmitted on the control channel is used to estimate the channel impulse response and reconstruct the desired signal. Expressions for the correlation of interference and noise for a WCDMA uplink with receive diversity are presented in the paper.

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2 Data Model

In the WCDMA, the uplink transmission is performed using two types of codes namely scrambling and channelization codes, while scrambling codes are used for device identification, channelization codes are used for channel separation [9]. The uplink spreading is depicted in Fig. 1. There is only one DPDCH (dedicated physical data channel). The I branch is the DPDCH, the Q branch is the DPCCH (dedicated physical control channel). The transmitted signal is modeled as [6].

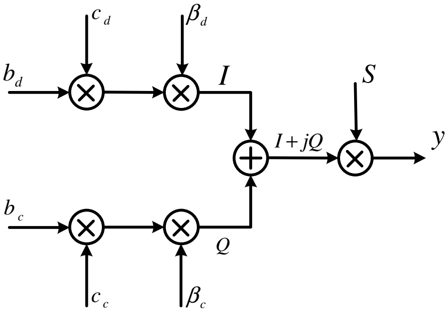

Fig. 1. The spreading of DPDCH and DPCCH

$$y(t)=\beta_d\sqrt{2E_c}\sum_i b_d[i]a_{d,i}(t-iN_dT_c)+j\beta_c\sqrt{2E_c}\sum_i b_c[i]a_{c,i}(t-iN_cT_c)\,. \tag{1}$$

Where $b_d\in\{-1,+1\}$ is the sequence of bits transmitted on the data channel (DPDCH) and $b_c\in\{-1,+1\}$ is the sequence of bits transmitted on the control channel (DPCCH). The spreading factors for the data channel and the control channel are denoted N_d and N_c. The transmitted energy per chip is related to E_c and the gain factors, β_d and β_c, are used to adjust the power ratio of the data channel and the control channel. T_c is the chip duration. The spreading waveforms are modeled as

$$a_{d,i}(t)=\sum_{n=0}^{N_d-1}c_{d,i}[n]p_s(t-nT_c)\,, \tag{2}$$

$$a_{c,i}(t)=\sum_{n=0}^{N_c-1}c_{c,i}[n]p_s(t-nT_c)\,. \tag{3}$$

Where $p_s(t)$ is pulse shape, it is assumed that the pulse is normalized so that $\int|p_s(t)|^2dt=1$. The spreading sequences are modeled as

$$c_{d,i}[n]=c_d[n]S[iN_d+n]\,, \tag{4}$$

$$c_{c,i}[n] = c_c[n]S[iN_c + n]. \tag{5}$$

Where $c_d[i] \in \{-1,+1\}$ and $c_c[i] \in \{-1,+1\}$ are the channelization codes for the data and control channels. $S[i]$ is scrambling code.

The signal $r(t)$ received by the K antennas can be expressed as

$$r(t) = \sum_{l=0}^{L-1} h_l y(t-\tau_l) + \sum_{m=1}^{M}\sum_{l=0}^{L-1} h_{m,l} y_m(t-\tau_{m,l}) + n(t). \tag{6}$$

The k th element of the $K\times 1$ vector $r(t)$ holds the signal of the k th antenna. L is the resolvable multi-path. h_l is the complex valued coefficient of the l th ray with delay τ_l. M is the number of the interference. $y_m(t)$ is the signal of the m th interference which is modeled as

$$y_m(t) = \beta_d\sqrt{2E_I}\sum_i b_d[i]a_{d,i}(t-iN_dT_c) + j\beta_c\sqrt{2E_I}\sum_i b_c[i]a_{c,i}(t-iN_cT_c). \tag{7}$$

Where E_I is the energy per chip of the interfering signal.

3 Combining Weights

The received signal of each antenna is descrambled and despreaded, we can get the signal of the control and data channel separately. The rake receiver combines the data channel signals from all antennas and all fingers. We assume that the number of the fingers is L. The output of the l th finger on the k th antenna is simply expressed as

$$r_{k,l}(t) = h_{k,l}(\tau_l)y(t-\tau_l) + u_{k,l}(t). \tag{8}$$

where $u_{k,l}(t)$ models the overall noise (noise and interference).

For applying the interference rejection combining, we need to calculate the covariance of the interference and noise i.e., $R_{uu} = E\left[uu^H\right]$, $u = \left[u_{1,1},\cdots u_{k,1}, u_{1,2}\cdots, u_{k,2},\cdots, u_{k,l}\right]^T$, $E[\cdot]$ denotes expected value, H denotes conjugate transpose, $(\cdot)^T$ denotes transpose of a matrix.

In this paper, the signal of the control channel is used to estimate the channel impulse response $\hat{h}_{k,l}$ as follows:

$$\hat{h}_{k,l} = \frac{1}{N_c}\sum_{i=1}^{N_c} p^*(i)\tilde{p}_{k,l}(i). \tag{9}$$

Where $*$ denotes the complex conjugate. $p(i)$ is the pilot symbol. $\tilde{p}_{k,l}(i)$ means the pilot symbols in the received signals on the k th antenna of the l th finger, which is descrambled and despread by the scrambling code and the channelization code for the control channel.

The estimated channel impulse response is used to reconstruct the desired signal, which is subtracted from the received signal of the data channel. The correlation between fingers of different antennas is expressed as

$$R_{ks,lj} = \frac{1}{P \cdot N_d} \sum_{i=0}^{PN_d - 1} \left(r_{kl}(i) - \hat{h}_{kl} p(i) \right) \left(r_{sj}(i) - \hat{h}_{sj} p(i) \right)^* \quad k, s = 1, \cdots, K \quad l, j = 1, \cdots, L . \tag{10}$$

where P means the number of symbols in one slot on the data channel.

The covariance is obtained as follows:

$$R_{uu} = \left\{ R_{ks,lj} \right\} \quad k, s = 1, \cdots, K \quad l, j = 1, \cdots, L . \tag{11}$$

The optimum weights can be expressed as

$$\omega_{IRC}^{H} = \hat{h}^{H} R_{uu}^{-1} . \tag{12}$$

where $\hat{h} = \left[\hat{h}_{1,1}, \cdots, \hat{h}_{K,1}, \hat{h}_{1,2}, \cdots, \hat{h}_{K,2}, \cdots, \hat{h}_{K,L} \right]^T$.

We compare the IRC receiver with the MRC receiver, which weighting vector can be expressed as

$$\omega_{MRC}^{H} = \hat{h}^{H} . \tag{13}$$

4 Simulation Results

To verify the the ability of the IRC receiver to reject the MAI, the IRC receiver using multiple antennas is simulated. The channel coding is not considered. During this simulation, we followed the WCDMA standard. Related simulation parameters can be seen in TABLE I. The channelization code is OVSF (orthogonal variable spreading factor). For simplicity, there are 2 antennas and one-ray Rayleigh distributed channel, the maximum Doppler frequency is 40 Hz. $\beta_c = \beta_d = 1$.

Table 1. WCDMA Simulation Parameter

Item	Parameter
Spreading Code	OVSF
Scrambling Code	Gold code
Modulation	BPSK
Chip Rate (Mcps)	3.84
Spreading Factor of Data Channel	64
Spreading Factor of Control Channel	256

Fig. 2 shows the BER characteristics of both the IRC receiver and MRC receiver with $E_c = E_I$. As can be seen, when there is one interfering user, at the typical BER value of 10^{-3}, IRC gives about 4dB better performance than MRC. When the number of interfering users increases, the difference between IRC and MRC becomes small.

Fig. 3 illustrates the BER as a function of Ec/N0 with different SIR (signal to interference ratio). SIR is defined as $SIR = E_c / ME_I$. In the simulation, there is one interfering user. Fig. 3 demonstrates that the IRC receiver has an excellent performance for combating the effect of MAI. At the BER value of 10^{-2}, SIR=-3dB, the IRC gives about 1 dB better performance than MRC. When SIR=-6dB, the IRC gives about 12dB better performance than MRC.

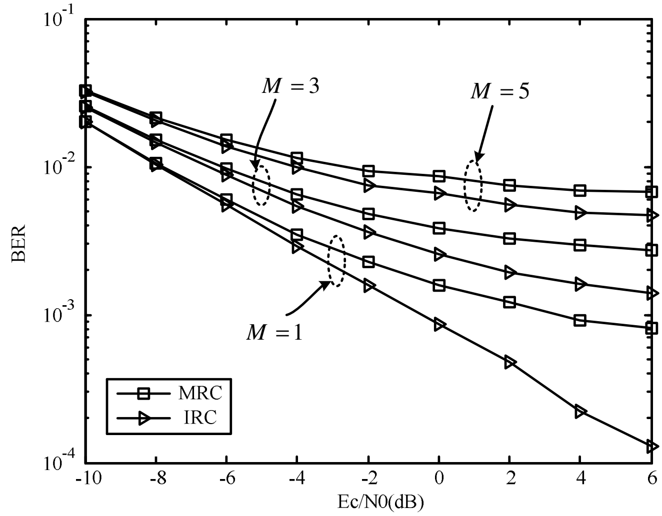

Fig. 2. The BER performance Vs Ec/N0. M : the number of interfering users

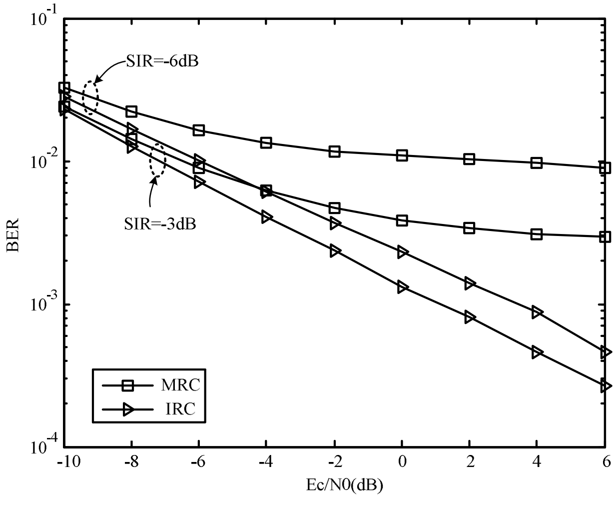

Fig. 3. The BER performance Vs Ec/N0. $SIR = E_c / ME_I$

5 Conclusions

In this paper, the BER performance of IRC receiver and MRC receiver in uplink is evaluated. The signal transmitted on the control channel is used to estimate the channel response and calculate the covariance of the interference and noise. From the simulation results we have seen that the BER performance of IRC receiver is better than that of the MRC receiver. When the MAI power is equal to the desired user, the difference between the IRC and MRC becomes small when the number of interfering users increases. In the case of the MAI signal is stronger than the desired signal, the IRC receiver has an excellent performance for combating the effect of MAI. At the BER value of 10^{-2}, the power of MAI signal is three times stronger than the desired signal, the IRC gives about 12 dB better performance than MRC. For further study, we will investigate the performance of the IRC receiver in frequency domain.

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