Successive Interference Cancellation for the Uplink of MC-CDMA Systems with Multiple Receive Antennas

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Abstract

Successive interference cancellation(SIC) for the uplink of MC-CDMA mobile communications systems is an effective method to improve performance. We propose a successive interference cancellation(SIC) technique for the uplink of MC-CDMA mobile systems with multiple receive antennas. The destination uses optimum combining(OC) to combine the signals from an OFDM Demodulator with multiple receiving antennas, and applies SIC processing to the combined signals. Achieved interference cancellation order is depends on the signal to interference-plus-noise ratio (SINR) at the output of the optimum combiner. Monte-Carlo simulations are employed to verify the proposed technique.

Key words : MC-CDMA, SIC, OC, Rayleigh Fading, AWGN.

Ⅰ. Introduction

Multi-carrier code division multiple access(MC-CDMA) is considered as a promising candidate for the 4th-generation mobile communications systems, where users can ubiquitously access the network with very high data rates and enjoy a large range of services such as voice, data communications and video communications any time. This system takes full advantage of both OFDM and CDMA technologies, which offer features such as strong survivability over frequency selective fading, large network capacity, high bandwidth efficiency and low implementation complexity, etc. The performance of an MC-CDMA system-similar to a direct sequence CDMA(DS-CDMA) system-is limited by the presence of multiple access interference(MAI). Many MAI cancellation techniques for a single-antenna receiver were proposed[2], such as decorrelation, parallel interference cancellation, successive interference cancellation, etc.

Receive antenna arrays can be used to suppress co-channel interference(CCI) and improve the performance of wireless communications systems over fading channels by combining and weighting the received signals appropriately[3]. Optimum combining is a well known technique in space diversity reception that combines and weights the received signals to maximize the signal to interference-plus-noise ratio(SINR) at the output of the combiner[4].

An MC-CDMA mobile communications system with a multiple receive antenna base station(BS) is a feasible idea because it can take advantages of both the high order of spatial diversity and high interference-survivable nature of MC-CDMA technology. In this paper, we propose a detection technique for the' receiver of the BS of such a system. This technique combines of OC and SIC where undesirable users that cause high SINRs at the output of the optimum combiner are suppressed one by one, and the total received signal for the remaining users are updated every cancellation until the desired users are reached. Different from SIC in [2] that uses the absolute value of a decision variable as a reliable measure of the interference cancellation order, our SIC utilizes SINR. Moreover, s single-antenna receiver is examined in [2] while this paper investigates a multi-antenna version.

The rest of the paper is organized as follow: Section II presents the system model and the proposed detection technique in details. Section Ⅲ presents the results of Monte-Carlo simulations of this proposed detection technique intended to verify its validity and to compares its performance with those of the existing techniques. Finally, conclusions appear in section Ⅳ.

Ⅱ. A Combination of Optimum Combining and Successive Interference Cancellation

We consider the uplink of an MC-CDMA mobile communications system with K active users. Each mobile user is equipped with single transmit antenna while their BS has M receive antennas. This case is very practical because deploying multiple antennas at the BS is feasible while doing so for each user`s handset is not, due

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to its cost and size limitations, etc.

2-1 MC-CDMA Transmitter

A block diagram of base-band signal processing block diagram of an MC-CDMA transmitter for user k is shown in Fig. 1. A binary phase shift keying-modulated symbol x_k(i.e., x_k takes on values +1 and -1) is copied N times before being spreaded by user k's spreading code consisting of N chips $c_{k1}, c_{k2}, \cdots, c_{kN}$. Then N resultant symbols $x_k c_{ks}, s \in \{1, \cdots, N\}$ on the parallel branches are modulated by an OFDM modulator with N sub-carriers. Note that for simplicity without loss of generality, Fig. 1 plots only useful signal processing blocks but neglects unrelated blocks, for example, pilot insertion.

The equivalent low-pass transmitted signals can be written as follows:

$$s_k(t) = \sum_{s=1}^{N} \sqrt{\frac{E_{Sk}}{NT}}\, x_k c_{ks} e^{j2\pi \frac{s}{T_s} t}, \quad 0 \le t \le T \tag{1}$$

where E_{Sk} is the average MC-CDMA symbol energy of user k, T_S is the symbol duration, T is the total MC-CDMA symbol duration and $T - T_S = T_{CP}$ is a cyclic prefix duration that is inserted between two consecutive MC-CDMA symbols to eliminate inter-symbol interference(ISI) that caused by channel delay spread.

2-2 Fading Channel Model

We consider a multi-path fading channel with coherence bandwidth smaller than the total bandwidth of the MC-CDMA system, thus, it can be considered as frequency selective fading. We also assume that the fading of channels is likely stationary and its temporal variation is small compared with the MC-CDMA symbol duration, i.e, it is approximately constant during the individual symbol duration T.

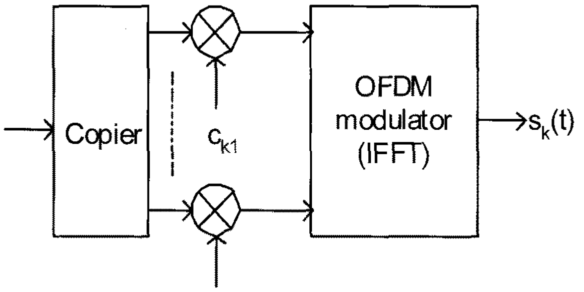

Fig. 1. Base-band block diagram of a MC-CDMA transmitter for user k(IFFT denotes inverse fast Fourier transform).

The complex equivalent low-pass time-variant impulse response of the channel between the transmit antenna of user k and the receive antenna m of the base station can be written as

$$h_{km}(t) = \sum_{l=1}^{L_{km}} \alpha_{kml} \delta(t - \tau_{kml}) \tag{2}$$

where L_{km} is the number of resolvable paths, τ_{kml} is the delay time of the l-th path, α_{kml} is an independent complex Gaussian random variable tap weight, $\delta(.)$ is a Dirac delta function; $k \in \{1, \cdots, K\}$ and $m \in \{1, \cdots, M\}$. We denote

$$\sum_{l=1}^{L_{km}} E[|\alpha_{kml}|^2] = \zeta_{km}$$

We also assume that the channels between any pair of transmit and receive antennas are statistically independent.

2-3 Proposed MC-CDMA Receiver

The base-band block diagram of an MC-CDMA receiver with M receiving antennas is shown in Fig. 2. After OFDM demodulation, the output sample at sub-carrier s on antenna m can be given by

$$r_{ms} = \sum_{k-1}^{K} H_{kms} \underbrace{\sqrt{\frac{E_{sk}}{N}\left(1 - \frac{T_{CP}}{T}\right)}}_{\sqrt{E_{sk}}} x_k c_{ks} + n_{ms}, \quad 1 \le s \le N \tag{3}$$

where

$$H_{kms} = \sum_{l=1}^{L_{km}} \alpha_{kml} e^{-j2\pi s \tau_{kml}/T}$$

is the attenuation coefficient of the channel between the transmit antenna of user k and the receive antenna m of the base-station at sub-carrier s, and n_{ms} is an inde-

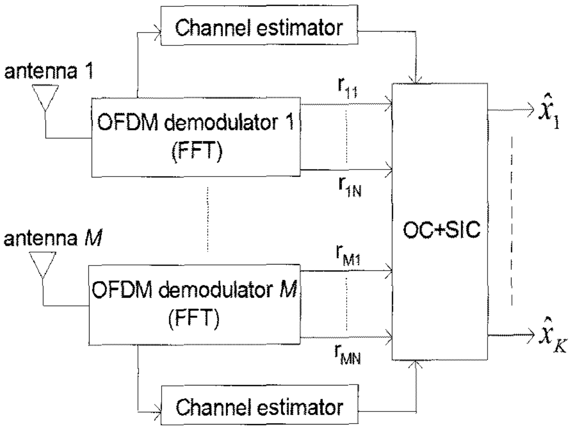

Fig. 2. Base-band block diagram of a MC-CDMA receiver with multiple receive antennas using a combination of OC and SIC.

pendent zero-mean complex Gaussian noise sample1). We assume that the random variables n_{ms} have identical independent distribution with variance N_0 at sub-carrier *s* on the receive antenna *m*, and the ratio T_{CP}/T represents the percentage of energy loss due to cyclic prefix insertion.

We write all the output samples of *M* OFDM demodulators in the compact form as follows.

$$\underbrace{\begin{bmatrix} r_{11} \\ \vdots \\ r_{1N} \\ \vdots \\ r_{M1} \\ \vdots \\ r_{MN} \end{bmatrix}}_{r} = \underbrace{\begin{bmatrix} \sqrt{\widetilde{E}_{S1}}\, H_{111}c_{11} & \cdots & \sqrt{\widetilde{E}_{SK}}\, H_{K11}c_{K1} \\ \vdots & \cdots & \vdots \\ \sqrt{\widetilde{E}_{S1}}\, H_{11N}c_{1N} & \cdots & \sqrt{\widetilde{E}_{SK}}\, H_{K1N}c_{KN} \\ \vdots & \cdots & \vdots \\ \sqrt{\widetilde{E}_{S1}}\, H_{1M1}c_{11} & \cdots & \sqrt{\widetilde{E}_{SK}}\, H_{KM1}c_{K1} \\ \vdots & \cdots & \vdots \\ \sqrt{\widetilde{E}_{S1}}\, H_{1MN}c_{1N} & \cdots & \sqrt{\widetilde{E}_{SK}}\, H_{KMN}c_{KN} \end{bmatrix}}_{D} \begin{bmatrix} x_1 \\ \vdots \\ x_k \end{bmatrix} + \underbrace{\begin{bmatrix} n_{11} \\ \vdots \\ n_{1N} \\ \vdots \\ n_{M1} \\ \vdots \\ n_{MN} \end{bmatrix}}_{n} \tag{4}$$

Then the vector *r* is input to a block that consists of an optimum combiner and a successive interference cancellator to detect all original symbols. The interference cancellation order of SIC is based on SINR at the output of the optimum combiner. According to [4], SINR *k* of user *k* is given by

$$\gamma_k = D(:,k)^H R_k^{-1} D(:,k) \tag{5}$$

where *D*(:,*k*) denotes the *k*-th column of the matrix $D, (.)^{-1}$ is the matrix inverse operator, $(.)^H$ is the Hermitian operator and R_k is the covariance matrix of the received interference-plus-noise for user *k* given by [4]

$$R_k = D(\neq k)D(\neq k)^H + N_0 I_{MN} \tag{6}$$

with $D(\neq k)$ is a matrix obtained from *D* by eliminating the *k*-th column and I_u is the $u \times u$ identity matrix.

SIC for detecting the data of the user *d* uses the following algorithm:

Step 1: Calculate the SINR (using (5)) of all remaining users.

Step 2: Choose an user with the highest SINR(say the user *h*). Then recover the data of this user according to the principle of the optimum combining[4].

$$\widehat{x}_k = sign(Re(w^H r)) \tag{7}$$

where *sign*(.) is signum function, *Re*(.) is the real part and the weight vector *w* is given by

$$w = R_h^{-1} D(:,h) \tag{8}$$

If *h*=*d*, the algorithm stops. Otherwise, it proceeds with step 3.

Step 3: Subtracting the signal component of the user *h* from the received signal *r*

$$r \leftarrow r - D(:,h)\widehat{x}_h \tag{9}$$

to reduces the size of matrix *D*

$$D \leftarrow D(\neq h) \tag{10}$$

and return to step 1.

Note that if only optimum combining is used to recover the original data[4], the detected symbol of user *k* is given by

$$\widehat{x}_k = sign(Re(w^H r)) \tag{11}$$

with

$$w = R_k^{-1} D(:,k),\ R_k = D(\neq k)D(\neq k)^H + N_0 I_{MN} \tag{12}$$

The combining of OC and SIC signal processing is described in Fig. 3 as follows.

Ⅲ. Simulation Results

In this section, we do Monte-Carlo simulations to compare the BER performances of four detection techniques: 1) minimum mean square error (MMSE)[2, pp. 211-217], 2) MMSE with SIC(MMSE+SIC)[2, pp. 211-

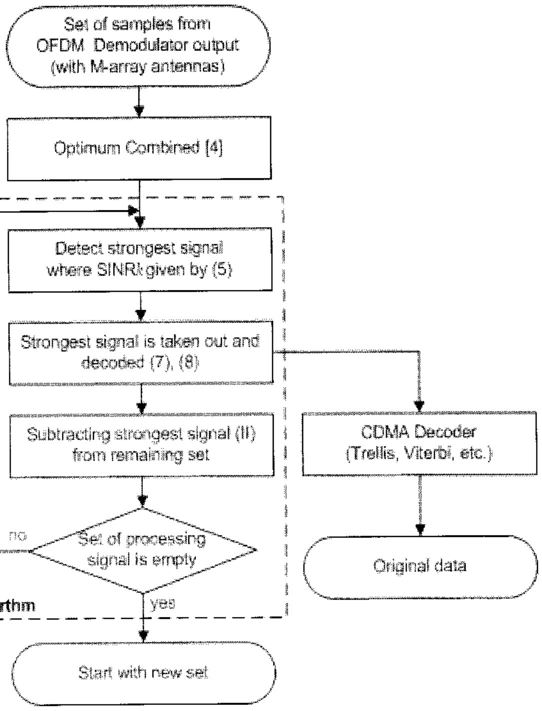

Fig. 3. OC and SIC process.

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1) We assume that the random variables n_{ms} have identical independent distribution.

217], 3) OC[4], and 4) our proposal of OC with SIC (OC+SIC). Note that MMSE and MMSE+SIC are only presented for a single-antenna receiver(M=1) in [2]. The complex baseband-equivalent model is used for simulations. For the sake of illustration, we choose the following simulation parameters: the number of sub-carriers is N=8, spreading codes are chosen from an $N \times N$ Walsh-Hadamard matrix and all users have same symbol energy, i.e. $E_{S1} = \cdots = E_{SK} = E_S$.

We also assume that all channels between any pair of transmit and receive antennas experience an identical power delay profile and $\zeta_{km}=1$ for every k and m. The considering channel under consideration is a two-path slow-varying channel with equal powers are allocated among the paths; the delays are $\tau_{km1}=0$, $\tau_{km2}=0.1\ T$. In order to suppress ISI completely, T_{CP} must be larger than the maximum channel delay spread τ_{km2}. Therefore, we adopt $T_{CP}=0.15\ T$. Because of slow fading, accurate channel estimation is possible in the base station[5]. Thus, we will assume perfect channel-state information at the base station.

Fig. 4 displays BER of user 1 via E_S/N_0 for K=4 and $M \in \{1,2,3\}$. This shows that our proposal is significantly better than MMSE and MMSE+SIC detectors over the whole range of E_S/N_0. Additionally, OC+SIC outperforms OC for any values of M and the improvement of OC+SIC's performance over OC alone is more obviously when E_S/N_0 is increased. Specifically, OC+SIC can provide a gain of greater than 0.7 dB over OC alone at the target BER of less than 10^{-3} with the value M=3. In terms of computing and implementing complexities, it is obvious that both OC and OC+SIC suffer from same complication. However, the delay caused by OC+SIC is proportional to the number of active users.

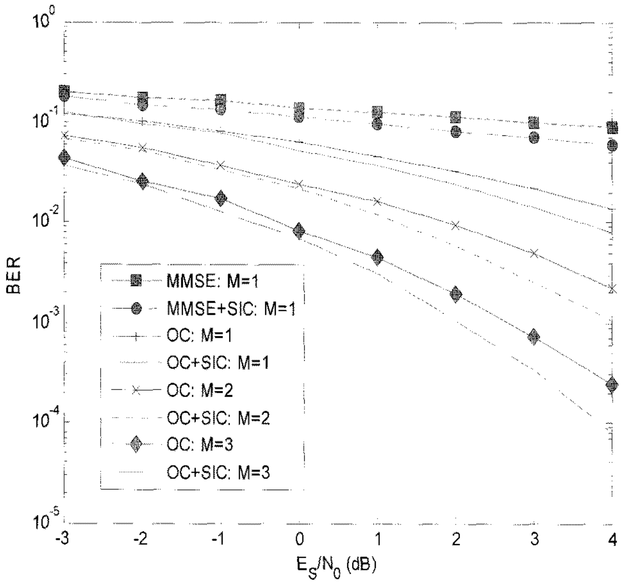

Fig. 4. BER performance of the user 1 via E_S/N_0.

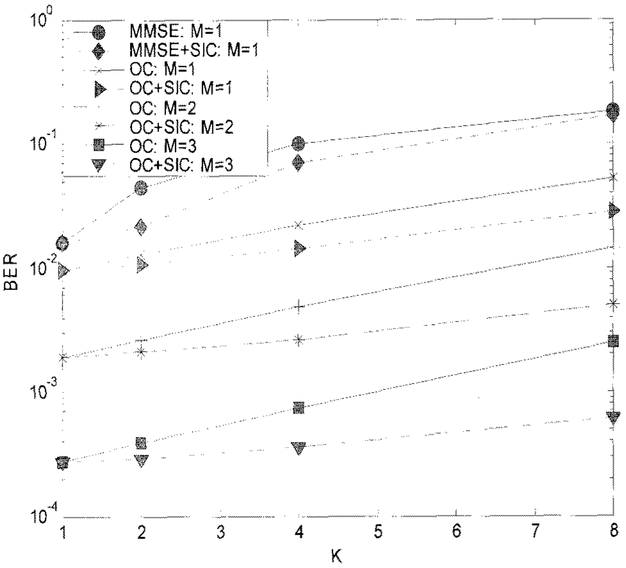

Fig. 5. BER performance of the user 1 via K.

Fig. 5 illustrates the BER performance of the detectors versus the number of active users at $E_S/N_0=3$ dB. This shows that OC+SIC provides the best performance. In addition, its performance is almost unchanged with K, especially for large number of receive antennas while the performance of other detectors is considerably degraded when K increases. This comes from the fact that a combination of OC and SIC takes the advantage of the fact that OC that suppresses MAI through the receive antenna array and SIC that suppresses MAI by considering the interference from other users as useful information for detection.

Ⅳ. Conclusion

In this paper, we presented the successive interference cancellation for the uplink of MC-CDMA mobile communications systems with a receive antenna array that uses optimum combining. Since successive interference cancellation has been proposed for single received antennas in the literature, this paper shows that SIC also provides a significant improvement in terms of system performance with multiple receiving antennas. Additionally, this combination can considerably reduces the negative effect of multiple access interference on system performance.

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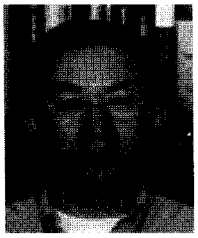

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