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Adaptive Subchannel Allocation for MC-CDMA System

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***Abstract*—**Multicarrier code-division multiple-access is one of the effective techniques to gain its multiple access capability, robustness against fading, and to mitigate the ISI. In this paper, we propose an improved mulcarrier CDMA system with adaptive subchannel allocation. We analyzed the performance of our proposed system in frequency selective fading environment with narrowband interference existing and compared it with that of parallel transmission over many subchannels (namely, conventional MC-CDMA scheme) and DS-CDMA system. Simulation results show that adaptive subchannel allocation scheme，when used in conventional multicarrier CDMA system, the performance will be greatly improved.

***Keywords*—**MC-CDMA, Rayleigh fading, Narrowband interference, Channel estimation.

I. INTRODUCTION

INTENSE interest has been focused on multicarrier modulation techniques, which can provide bandwidth efficiency and interference rejection capability in high date rate transmission systems. Also, mulcarrier techniques can combat intersymbol interference (ISI); a major problem in wideband wireless transmission over multipath fading channels. Code Division Multiple Access (CDMA) is the mainstream multiple access scheme for IMT-2000. It's obvious that mulcarrier CDMA system is one of promising technologies for high rate data transmission in mobile communication applications [1]-[9]. The conventional MC CDMA is to transmit identical narrowband direct-sequence (DS) waveform in parallel over a number of subchannels uniformly. While in this paper, we propose an adaptive subchannel allocation scheme for MC-CDMA system in which each user's waveform is transmitted over the use's best-conditioned subchannel rather than over all the subchannels. This paper is organized as follows: In Section Ⅱ, we will give the system model. The scheme of adaptive subchannel allocation is studied in Section Ⅲ. Then we investigate the performance of the MC CDMA system with adaptive subchannel allocation in Section Ⅳ. Simulation results are provided in Section Ⅴ. Finally, conclusions are drown in Section Ⅵ.

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II. SYSTEM MODEL

We consider a proposed MC CDMA system with *K* users. Differently from conventional MC CDMA system, in the proposed scheme, a best-conditioned subchannel is first chosen for each user, and a narrowband DS waveform is transmitted through the chosen subchannel instead of all the subchannels. Then the transmitted signal is given by

$$s(t)=\sqrt{2ME_c}\sum_{k=1}^{K}\sum_{l=-\infty}^{\infty}d_l^{(k)}c^{(k)}(t-lT)\cos\omega_{j_k}t \quad (1)$$

Where

$$c^{(k)}(t)=\sum_{n=0}^{N-1}c_n^k\,p(t-nT_c)$$

In (1), $d_h^{(k)}$ is the binary symbol bit of the *k*th user, $c_n^{(k)}$ is the signature sequence of the kth user, *T=NMTc* is the symbol duration with *MTc* the chip duration for MC system, and Ec is the energy per chip. M is the number of subcarriers, j_k indicates the best transmission subchannel (which will be determined in next section), and p(*t-nMTc*) is a rectangular pulse with duration *MTc*.

We assume that the channel is frequency selective Rayleigh fading, but the subchannels is frequency nonselective and independent of each other: this can be achieved by selecting M properly as in [10]. Then the complex lowpass impulse response of the subchannels can be modeled as

$$h_{k,m}(t)=\alpha_{k,m}e^{j\phi_{k,m}}\delta(t) \quad (2)$$

where $\alpha_{k,m}$ is the fading amplitude, $\phi_{k,m}$ is the random phase of the subchannel. The amplitude $\{\alpha_{k,m}, m=1,2,\cdots M\}$ are independent and identically distributed (i.i.d.) Rayleigh fading random variables and $\{\phi_{k,m}, m=1,2,\cdots M\}$ are uniform i.i.d. random variables over $[0,2\pi)$.

The received signal at the *k*th mobile is given by

$$r(t)=\sqrt{2ME_c}\sum_{k=1}^{K}\sum_{l=-\infty}^{\infty}d_l^{(k)}c^{(k)}(t-lT)\alpha_{k,j_k}\cos\left(\omega_{j_k}t+\phi_{k,j_k}\right)+n_W(t)+n_J(t) \quad (3)$$

where $n_W(t)$ is the additive white Gaussian noise with a double-side spectral density of $N_0/2$, and $n_J(t)$ is partial band interference with spectral density of $S_{n_J}(f)$.The pdf of the partial band interference , $S_{n_J}(f)$ is defined as

$$S_{n_J}(f)=\begin{cases}\frac{N_J}{2}, & f_J-\frac{W_J}{2}\le|f|\le f_J+\frac{W_J}{2}\\ 0, & elsewhere\end{cases} \tag{4}$$

III. The Scheme of Determinning the Best-Conditioned Subchannel

First we denote by $\alpha_{k,m}$ the magnitude of the channel gain (assuming the coherent reception) of the mth subcarrier as seen by the *k*th user, which can be obtained by pilot signal. Furthermore, we denote by $f_k(c)$ the required power (in energy per symbol) in a subcarrier for reliable reception of c information bits/symbol when the channel gain is equal to unity. Note that the function $f_k(c)$ depends on k, and this allows different users to have different quality-of-service (QoS). In order to maintain the required QoS at the receiver, the transmitted power, allocated to the mth subcarrier by the kth user must equal

$$p_{k,m}=\frac{f_k(c_k)}{\alpha_{k,m}^2} \tag{5}$$

where $f_k(c)$ is a convex and increasing function with $f_k(c)=0$.

Our goal is find the best-conditioned subchannel for each user for given QoS requirements specified through $f_k()$, $k=1,\ldots K$. and narrowband interference existing. Obviously, the subchannel that has the minimal transmitted power will be the best-conditioned subchannel for that user. So the scheme is executed as follows:

①For the kth user, the base station estimates the fading amplitudes of all subchannels with the pilot signal, namely, $\{\alpha_{k,m}, m=1,2,\cdots M\}$.

② Calculate the transmitted power without narrowband interference for all the subchannels $P_{k,m}^{(1)}$ using (5).

③ Calculate narrowband interference for all the subchannels $P_{k,m}^{(2)}$, which is given by

$$P_{k,m}^{(2)}=S_{n_J}(f)\cdot W_{J,m} \tag{6}$$

where $W_{J,m}$ is the bandwidth of narrowband interference for the mth subchannel

④ Calculate the transmitted power with narrowband interference existing for all the subchannels $P_{k,m}$

$$P_{k,m}=P_{k,m}^{(1)}+P_{k,m}^{(2)} \tag{7}$$

⑤Select the subchannel that needs the minimum transmitted power denoted by j_k The index j_k indicates the best-conditioned subchannel for the kth user.

With the index information, each user's DS waveform is transmitted over its own best subchannel other than all the subchannels used in conventional MC CDMA system.

IV. Performance Analysis

The output of the low-pass filter for the subchannel j_k is expressed by

$$y_{j_k}(t)=\sqrt{ME_c}\,\alpha_{k,j_k}\sum_{i\in U_{j_k}}\sum_{l=-\infty}^{\infty}d_l^{(i)}\sum_{n=0}^{N-1}c_n^{(i)}\cdot h(t-(lN+n)MT_c)+\tilde{n}_W(t)+\tilde{n}_J(t) \tag{8}$$

where $h(t)=F^{-1}|p(f)|^2$, $\tilde{n}_W(t)$ is the filtered AWGN, $\tilde{n}_J(t)$ is the filtered narrowband interference, and U_{j_k} is the set of users who share the subchannel j_k.

The output signal of the correlator for the *l*th data bit can be written as

$$Y_{j_k}=S_{Y_{j_k}}+I_{Y_{j_k}}+J_{Y_{j_k}}+N_{Y_{j_k}} \tag{9}$$

where

$$\begin{aligned}S_{Y_{j_k}}&=\sqrt{ME_c}\,\alpha_{k,j_k}\sum_{n'=0}^{N-1}\sum_{n=0}^{N-1}d_l^{(k)}c_{n'}^{(k)}c_n^{(k)}h\left[(n'-n)MT_c\right]\\&=N\sqrt{ME_c}\,\alpha_{k,j_k}d_l^{(k)}\end{aligned} \tag{10}$$

In (9), $S_{Y_{j_k,l}}(t)$ is the desired signal, $I_{Y_{j_k,l}}(t)$ is the interference from other users, $J_{Y_{j_k,l}}(t)$ is the narrowband interference and $N_{Y_{j_k,l}}(t)$ is the filtered AWGN. Let $N_{I_{j_k}}$, $N_{J_{j_k}}$ and $N_{W_{j_k}}$ denote the interference power from other users, narrowband interference and noise power respectively. Furthermore, we can get

$$\begin{aligned}N_{I_{j_k}}&=Var\left[I_{Y_{j_k}}\right]\\&=NR_{I_{j_k}}(0)+2\sum_{l=0}^{N-1}R_{I_{j_k}}(lMT_c)\sum_{n'=l}^{N-1}c_{n'}^{(k)}c_{n'-l}^{(k)}\end{aligned} \tag{11}$$

$$\begin{aligned}N_{J_{j_k}}&=Var\left[J_{Y_{j_k}}\right]\\&=NR_{J_{j_k}}(0)+2\sum_{l=0}^{N-1}R_{J_{j_k}}(lMT_c)\sum_{n'=l}^{N-1}c_{n'}^{(k)}c_{n'-l}^{(k)}\end{aligned} \tag{12}$$

$$\begin{aligned}N_{W_{j_k}}&=Var\left[N_{Y_{j_k}}\right]\\&=\sum_{n'=0}^{N-1}\sum_{n=0}^{N-1}c_{n'}^{(k)}c_n^{(k)}R_{N_{j_k}}\left[(n'-n)MT_c\right]\\&=NR_{N_{j_k}}(0)=N\cdot\frac{N_0}{2}\end{aligned} \tag{13}$$

where $R_{I_{j_k}}(\tau)$, $R_{J_{j_k}}(\tau)$ and $R_{N_{j_k}}(\tau)$ are the autocorrelation functions of $I_{y_{j_k,l}}(t)$, $J_{y_{j_k,l}}(t)$ and $N_{y_{j_k,l}}(t)$ respectively.

From ref.[11], we can deduce the spectral density of $I_{y_{jk,l}}(t)$, which is given by

$$S_{I_{j_k}}(f) = \frac{(\bar{n}_{j_k} - 1)E_c}{2T_c} \cdot |p(f)|^4 \qquad (14)$$

where $\bar{n}_{j_k}$ is the size of set U_{j_k}, that is, $\bar{n}_{j_k}$ is the mean number of users allocated to the subchannel j_k at the same time, and $p(f)$ is a raise-cosine filter. Then the autocorrelation functions $R_{I_{j_k}}(0)$ can be written as

$$R_{I_{j_k}}(0) = \int_{-\infty}^{\infty} S_{I_{j_k}}(f)df = \frac{(\bar{n}_{j_k} - 1) \cdot ME_c}{2}\left(1 - \frac{\alpha}{4}\right) \qquad 15)$$

where α is a roll-off factor of raise-cosine

V. Simulation Results

In this section, the performance of the proposed scheme is investigated along with that of the conventional MRC MC-CDMA system and DS-CDMA.

In the following results, we keep the total available bandwidth the same for three systems and set *NM*=512. Then the processing gain for each subchannel signal is *N*=128,and 64 when the number of subchannels is *M*=4 and 8, respectively. For DS-CDMA system, the processing gain is 512. The number of users *K*=50 and roll-off factor of raise-cosine filter α =0.5. We define the ratio of narrowband interference power to signal power, *JSR* by

$$JSR = 10\lg\left(\frac{N_J \cdot W_J}{E_b / T}\right) = 10\lg\left(\frac{N_J}{M \cdot E_c}\right) \qquad (16)$$

The BER performances for different number of subchannels and different JSR are shown in Fig.1、Fig. 2. From the figures, we can see that: (1) The proposed system outperforms the conventional MRC MC CDMA system and DS system obviously as *JSR* increases,:the reason being that we eliminate the bad-conditioned subchannels and allocate all the signal energy to the good-conditioned subchannel. (2) With the number of subchannels increasing, the SNR gain of the proposed system over the conventional MC-CDMA system increases.

VI. Conclusions

In this paper, we propose an improved MC-CDMA system with adaptive subchannel allocation in which each user's wave-form is transmitted over the use's best-conditioned subchannel rather than over all the subchannels. We analyzed the performance characteristics of the proposed system in frequency selective fading environment with narrowband interference existing The result shows that the proposed system outperforms the conventional MRC MC-CDMA system obviously as *JSR* increases.

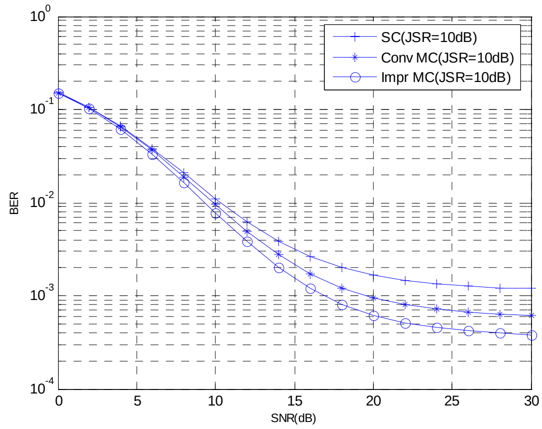

Fig.1 (a). BER versus SNR (when *M*=8, *JSR*=10dB)

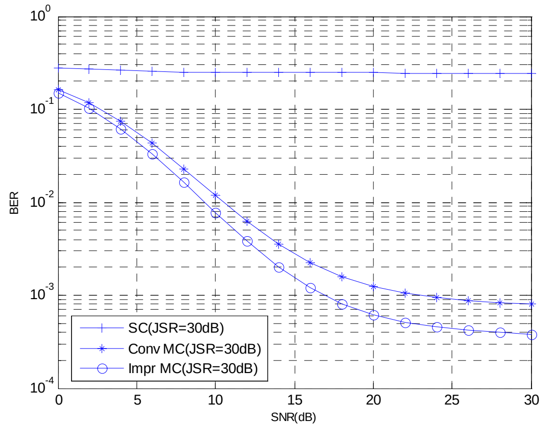

Fig.1 (b). BER versus SNR (when *M*=8, *JSR*=30dB)

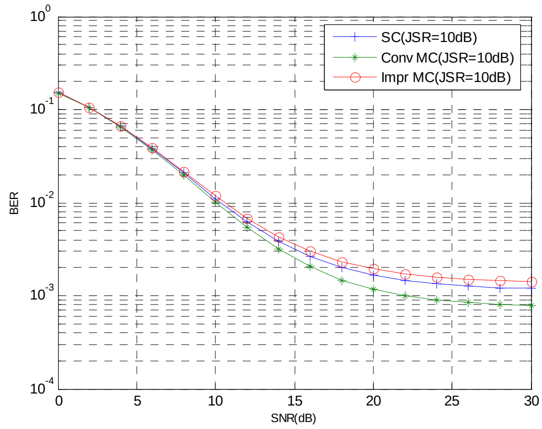

Fig.2 (a). BER versus SNR (when *M*=4, *JSR*=10dB)

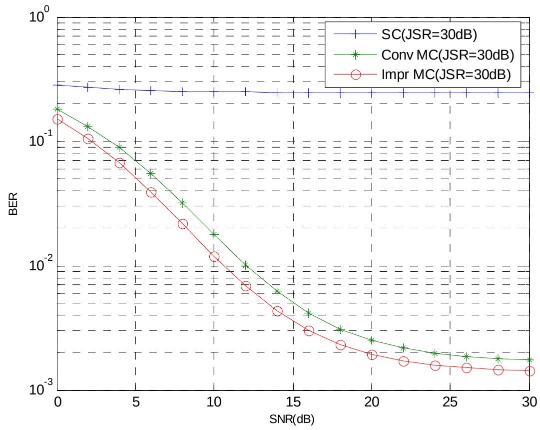

Fig.2 (b). BER versus SNR (when *M*=4, *JSR*=30dB)

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