

# Adaptive Subchannel Allocation for MC-CDMA System

Cuiran Li, Jianli Xie, and Chengshu Li

**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 data 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.

Manuscript received July 12, 2005. This work was supported by Nation Science Foundations of China under Grant 60372093 and Research Foundations of Northern JiaoTong University under Grand 2003RC051.

Cuiran Li is with the Department of Electrical Engineering, Northern JiaoTong University, Beijing, China (phone: 86-10-58022888-201; fax: 86-10-58022066; mail: xie\_jianli@grandi.cn xjl5942@sina.com).

Jianli Xie is with the Embedded Software Division, Grand Digital Information LTD., Beijing, China (e-mail: xie\_jianli@grandi.cn).

Chengshu Li is with the Department of Electrical Engineering, Northern JiaoTong University, Beijing, China (e-mail: csli@center.njtu.edu.cn).

Simulation results are provided in Section V. Finally, conclusions are drawn in Section VI.

## 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  $k$ th user,  $T=NMT_c$  is the symbol duration with  $MT_c$  the chip duration for MC system, and  $E_c$  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  $p(t-nMT_c)$  is a rectangular pulse with duration  $MT_c$ .

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  $\{\alpha_{k,m}, m = 1, 2, \dots, M\}$  are independent and identically distributed (i.i.d.) Rayleigh fading random variables and  $\{\phi_{k,m}, m = 1, 2, \dots, M\}$  are uniform i.i.d. random variables over  $[0, 2\pi)$ .

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

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

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

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

### 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  $m$ th 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  $m$ th subcarrier by the  $k$ th user must equal

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

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  $f_k()$ ,  $k=1, \dots, K$ . 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:

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

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

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

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

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

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

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

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

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

$$Y_{j_k} = S_{Y_{j_k}} + I_{Y_{j_k}} + J_{Y_{j_k}} + N_{Y_{j_k}} \quad (9)$$

where

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

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

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

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

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

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

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

where  $\bar{n}_{jk}$  is the size of set  $U_{jk}$ , that is,  $\bar{n}_{jk}$  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  $R_{I_{jk}}(0)$  can be written as

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

where  $\alpha$  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  $\alpha=0.5$ . We define the ratio of narrowband interference power to signal power,  $JSR$  by

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

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-

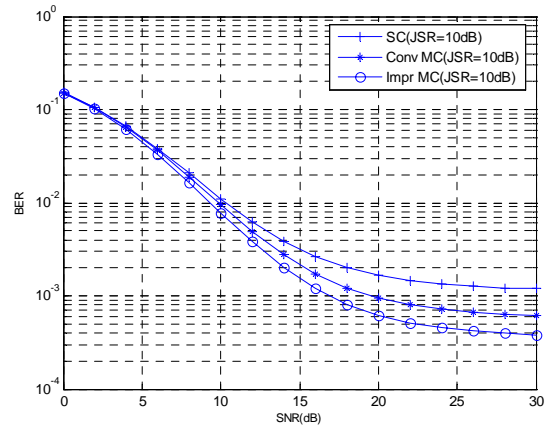


Fig.1 (a). BER versus SNR (when  $M=8$ ,  $JSR=10\text{dB}$ )

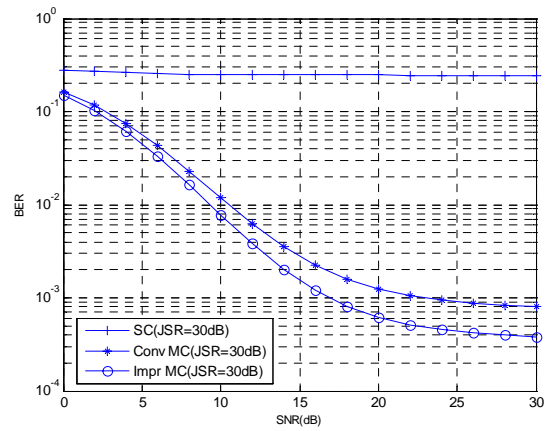


Fig.1 (b). BER versus SNR (when  $M=8$ ,  $JSR=30\text{dB}$ )

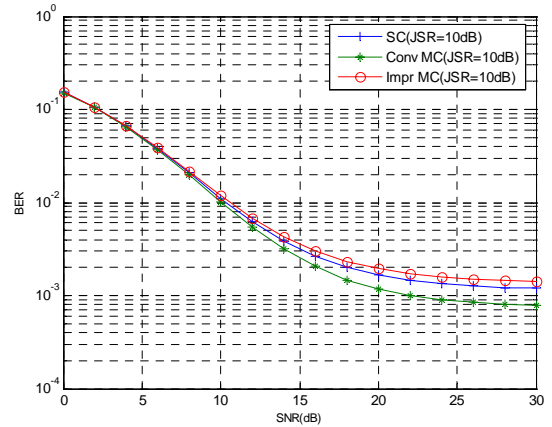


Fig.2 (a). BER versus SNR (when  $M=4$ ,  $JSR=10\text{dB}$ )

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.

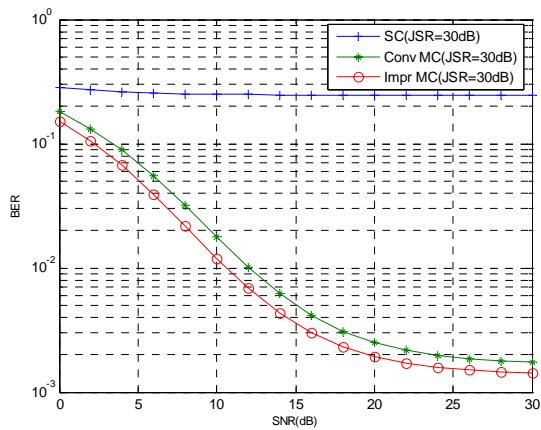


Fig.2 (b). BER versus SNR (when  $M=4$ ,  $JSR=30dB$ )

REFERENCES

- [1] S. Qinghua, M. Latva-Aho, "Accurate bit-error rate evaluation for synchronous MC-CDMA over Nakagami-m-fading channels using moment generating functions", IEEE Trans. on Wireless Commun., Volume 4, pp. 422-433, March 2005
- [2] S.Chatterjee, W.A.C Fernando and M.K. Wasantha," Adaptive modulation based MC-CDMA systems for 4G wireless consumer applications" IEEE Trans. on Consumer Electronics, Volume 49, pp: 995-1003, Nov. 2003
- [3] H.Xiaoyu, C.H. Yong, "On the performance and capacity of an asynchronous space-time block-coded MC-CDMA system in the presence of carrier frequency offset" IEEE Trans.on VTC, Volume 53, pp.1327-1340, Sept. 2004
- [4] W. Xianbin, P. Ho and Y. Wu, "Robust channel estimation and ISI cancellation for OFDM systems with suppressed features", IEEE Journal on Selected Areas in Communications, Volume 23, pp. 963-972, May 2005
- [5] B. Hombs, J.S. Lehnert, "Multiple-access interference suppression for MC-CDMA by frequency-domain oversampling", IEEE Trans. on Commun, Volume 53, pp. 677-686, April 2005
- [6] S.A Zekavat, C.R Nassar and S. Shattil, "Merging multicarrier CDMA and oscillating-beam smart antenna arrays: exploiting directionality, transmit diversity, and frequency diversity", IEEE Trans. on Commun, Volume 52, pp. 110-119, Jan. 2004
- [7] L. Junqiang, K .B. Letaief, and C Zhigang, "Space-time turbo multiuser detection for coded MC-CDMA", IEEE Trans. on Wireless Commun, Volume 4, pp. 538-549, Mar. 2005
- [8] K. Kyunbyoung, K. Taeyoung, C. Sooyong and H. Daesik. "Semianalytical approach of asynchronous MC-CDMA systems with a cyclic prefix", IEEE Commun Letters, Volume 9, pp.142-144, Feb. 2005
- [9] S.Kondo and L.B.Milstein, "Performance of multicarrier DS CDMA system", IEEE Trans. Commn., vol. 44, pp.238-246, Feb.1996
- [10] Cuiran Li. Researches in Key Technologies for Wireless Communication Systems Using MC-CDMA. Doctoral Dissertation in Northern Jiaotong University, P.R.China. Mar. 2003
- [11] A. Papoulis. Probability, Random Variables, and Stochastic Processes. 3<sup>rd</sup> ed, Singapore: McGraw Hill, 1991