논문 02-27-6B-2 한국통신학회논문지 '02-6 Vol.27 No.6B

시간 주파수 다이버시티를 위한 분할된 확산코드를 이용한 멀티캐리어 CDMA 시스템

정회원 박 형 근*, 주 양 익**, 김 용 석**, 차 균 현**

A Multicarrier CDMA System Using Divided Spreading Sequence for Time and Frequency Diversity

Hyung-Kun Park*, Yang-Ick Joo**, Yongsuk Kim** and Kyun Hyon Tchah** *Regular Members*

ABSTRACT

This paper proposes a new multicarrier code division multiple access (CDMA) system. The proposed multicarrier CDMA system provides the advantages that the transmission bandwidth is more efficiently utilized by using divided spreading sequence, time and frequency diversity is achieved in frequency selective multipath fading channel, and inter-carrier interference (ICI) can be minimized by using specific data and code pattern. In this system, transmitted data bits are serial-to-parallel converted to some parallel branches. On each branch each bit is direct-sequence spread-spectrum modulated by divided spreading sequences and transmitted using orthogonal carriers. The receiver provides a Rake for each carrier, and the outputs of Rakes are combined to get time and frequency diversity. This multicarrier CDMA system allows additional flexibility in the choice of system parameters. Upon varying system parameters, bit error rate (BER) performance is examined for the proposed multicarrier CDMA system. Simulation results show that the proposed multicarrier CDMA scheme can achieve better performance than the other types of conventional multicarrier CDMA systems.

***key words:** multicarrier CDMA, diversity, OFDM, Rake receiver,*

I. 서 론

A multicarrier Modulation (MCM) has been proposed for high data rate application to reduce the effect of inter-symbol interference (ISI) and adapt to channel conditions. Multicarrier CDMA [1] uses direct sequence (DS)-CDMA merely for multiplexing, and choose the signal waveforms using the orthogonal frequency division multiplexing (OFDM) principle [2]. Signals to different users are added linearly onto a multiplex of multicarrier CDMA signals. The advantages of multicarrier modulation and CDMA technique motivated many researchers to investigate the suitability of the combination of multicarrier modulation with CDMA, known as multicarrier CDMA for cellular systems. This combination as a multiple access scheme will allow one to take advantages of both schemes: higher flexibility, higher spectral efficiency, simpler detection techniques, narrow band interference rejection capability, etc.

In fact, multicarrier CDMA systems have already been proposed, and these proposed techniques can be categorized mainly into two groups [1]. One, namely, multicarrier (MC)-CDMA spreads the original data stream using a given spreading code, and then modulates a different subcarrier with each chip (in a sense, the spreading operation in the frequency domain)

---

* (주) 현대시스콤 시스템 그룹 (hkpark@hysyscomm.com)

논문번호: 020031-0123, 접수일자: 2002년 1월 23일

** 고려대학교 전자공학과 차세대 이동통신 연구실

[3]-[5], and the other, called multicarrier DS-CDMA spreads the serial-to-parallel (S/P) converted data stream (the spreading operation in the time domain) [6], [7], similar to a normal DS-CDMA scheme. In the MC-CDMA system [3]-[5], each carrier is subject to nonselective fading, and frequency diversity can be achieved. Unless the chip duration is longer than the channel delay spread, this system suffers from severe inter symbol interference. On the other hand, the multicarrier DS-CDMA [6], [7] system is robust to multipath fading and requires a lower chip rate since the entire bandwidth of the system is divided into equi-width frequency bands, but this system cannot achieve frequency diversity since subcarriers have different data. One of the principal disadvantages of multicarrier modulation technique is the sensitivity to the frequency offset in the mobile channel. This channel offset introduces inter-carrier interference among the multiplicity of carriers in the multicarrier modulated signal [8].

In this paper, we propose the following modifications to the conventional multicarrier CDMA schemes. At the transmitted side, the initial data stream is serial-to-parallel converted into lower rate data streams. Each stream is copied into several parallel streams. These streams are assigned to different subcarriers to get the frequency diversity in the frequency selective fading channel. Divided PN sequence is used for efficient transmission bandwidth. The receiver provides a Rake for each carrier, and the outputs of Rakes are combined to get time diversity. The proposed multicarrier CDMA system is shown to provide the following advantages: the proposed multicarrier CDMA lowers the chip rate of spreading sequence by using divided pseudo-noise (PN) spreading sequence, minimizes inter-carrier interference by using specific data and code pattern, and achieves frequency and time diversity. The performance of the proposed system is shown to outperform the conventional multicarrier CDMA systems under the multipath and frequency offset channel environment.

This paper is organized as follows: Section 2 introduces the proposed multicarrier CDMA system, and describes data and code pattern. Section 3 presents channel models. Section 4 shows the receiver scheme for the modified multicarrier CDMA system. Simulation results are presented and discussed in Section 5, and the conclusions are given in Section 6.

Ⅱ. Proposed Multicarrier CDMA System

2.1 Transmitter Scheme

The transmitter for user k of the proposed system is shown in Fig. 1. At the transmitting side, the bit stream with bit duration T_b is serial-to-parallel converted into M parallel streams. The symbol duration on each stream is $T = MT_b$. Each stream feeds S parallel streams such that the same data stream exists on the S branches. These S parallel streams are spread by different divided PN sequences. The k-th users PN sequence with length N is divided into S sub-PN sequences with length N/S. In this paper, we make the total number of subcarriers fixed at N for any selection of M and S ($M \times S = N$), and the total transmit bandwidth is constant regardless of M and S, which means chip duration Tc is constant. If M is equal to 1, the length of divided PN sequence is S, and this system can be considered as MC-CDMA [3]-[5]. If S is equal to 1, the length of divided PN sequence is M, and this system can be considered as multicarrier DS-CDMA [6], [7]. The $M \times S$ subcarriers are used for BPSK modulation of each stream.

In order to obtain a compact signal in frequency, it would be desirable to space the subcarriers as closely together as possible. The closest possible spacing between subcarriers is $1/T_c$. With this particular spacing, the structure of the signal is exactly that of OFDM system. Assuming K users, all employing the proposed multicarrier CDMA system with equal selection of M and S, and the same power for all carriers, the

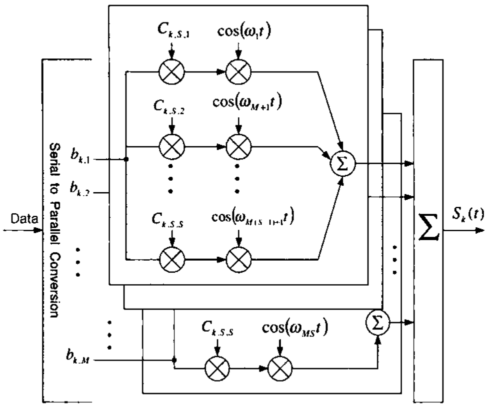


Fig. 1 Transmitter scheme for modified multicarrier CDMA

transmitted signal of user k is given by

$$s_k(t)=\sum_{m=1}^{MS}\sqrt{2P}\cdot b_{k,p}(t)C_{k,S,i}(t)\cos(\omega_m t) \tag{1}$$

where p=1, 2, · , M is the output branch index of the serial-to-parallel converter, and $p=1+[(m-1)\bmod M]$ such that $b_{k,p}(t)$ is the data bit stream on the identical data bit branches fed from the p-th branch as shown in Fig. 1. $C_{k,S,i}$ is the k-th users i-th divided PN sequence. The transmitted data bit $b_{k,p}(t)$ takes the values of ±1 with equal probability. Also in (1), P is the transmitted power per subcarrier. The bit and chip waveforms are rectangular, and the orthogonal frequencies ω_m are related by

$$\omega_m=\omega_1+(m-1)\cdot 2\pi\cdot\frac{F}{T_c}$$

$$\text{where } m=1,2,3,\ldots,MS \text{ and } \omega_1=2\pi f_c \tag{2}$$

where m is the absolute subcarrier number in the system. The subcarriers are spaced apart from its neighboring subcarriers by F/T_b where F is an integer number.

Observing the model of the transmitter in Fig. 1, the implementation of a proposed multicarrier CDMA transmitter appears prohibitive with the bank of oscillators, one for each of the subcarriers. However, it should be noted for the case of $F=1$, as mentioned above, the multicarrier CDMA shares the same signal structure as OFDM. The analysis of OFDM has shown that the discrete-time version of the OFDM transmitter is simply a discrete Fourier transform (DFT). Thus, the transmitter model for multicarrier CDMA may simply be replaced by an FFT operation for $F=1$ which is the minimum frequency spacing between adjacent subcarriers [3].

2.2 Data and Code Pattern

Fig. 2 shows the divided PN sequence structure to spread S copied data streams. In this paper, we use m-sequence as a spreading PN sequence. The k-th users PN sequence of length N is divided into S sub-PN sequences of length M (=N/S). As shown in Fig. 2, the k-th users PN sequence of length N is

$$C_k=\{c_k(0),c_k(1),\cdots,c_k(N-1)\} \tag{3}$$

where $c_k(i)$ is the k-th user's and the i-th chip element of spreading PN sequence C_k . The elements of C_k take value of ±1, and C_k is divided into S sub-PN sequences

$$C_k=\{C_{k,S,1},C_{k,S,2},\cdots,C_{k,S,S}\} \tag{4}$$

i-th divided sub-PN sequence of length M is

$$C_{k,S,i}=\{c_k((i-1)M),c_k((i-1)M+1),\cdots,c_k(iM-1)\} \tag{5}$$

The spreading gain of each subcarrier is N/S, where N is the length of the spreading PN sequence, but the total processing gain can be considered as N because S copied data are spread by S different divided PN sequences of which length is N/S.

Each divided PN sequence is transmitted by using different sub-carriers. The MS frequencies are assigned to the MS streams such as, given a value of M, the frequency separation between any two successive identical-bit carriers is maximized,

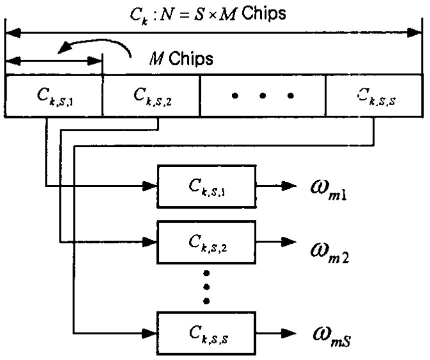


Fig. 2 Divided PN spreading sequence

and divided PN sequences are assigned to the subcarriers to maximize the orthogonality between adjacent subcarriers which have the different data bits. Also the Rake receiver can be adopted by using the property of divided PN sequences. The divided PN sequences are assigned by (6) which is the case of *MS* = 64.

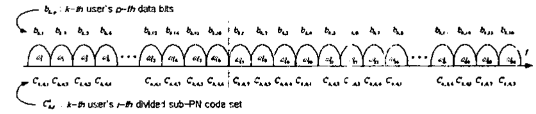
$$i = \begin{cases} 1 + \left\{ ((m-1)\bmod M)\bmod S + \left\lfloor \frac{m-1}{M} \right\rfloor \cdot \alpha \right\} \bmod S & (M \geq S) \\ 1 + \left\{ ((m-1)\bmod M)\bmod S + \left\lfloor \frac{m-1}{M} \right\rfloor \cdot \alpha + \left\lfloor \frac{m-1}{32} \right\rfloor \cdot \left\lfloor \frac{\log_2 S - 1}{4} \right\rfloor \right\} \bmod S & (M < S) \end{cases} \quad (6)$$

$$\alpha = 0 \quad (S = 0), \quad \alpha = 1 \quad (2 \leq S \leq 16), \quad \alpha = 2 \quad (32 \leq S \leq 64)$$

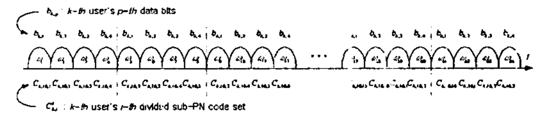
where i indicates the i-th sub-PN sequence among S divided PN sequences. This i-th sub-PN sequence is assigned to the m-th subcarrier. The data bits are assigned sequentially $b_{k,1}, b_{k,2}, \cdots, b_{k,M}$ to the MS subcarriers. Fig. 3 shows the example of data and pilot pattern for M=16, S=4 and M=4, S=16. The data and code pattern is determined to maximize the distance of identical data bits in frequency domain and achieve the orthogonality between adjacent subcarriers. To maximize the frequency diversity gain, the separation between identical data branches should be maximized. From the data and code pattern in (6), we can achieve the orthogonality between adjacent subchannels. For example, in Fig. 3 (a), the correlation between data $b_{k,1}$ and $b_{k,2}$ is

$$R_{k_1,k_2}(S=4) = b_{k,1} b_{k,2} \int^{\frac{T}{4}} \left(C_{k,4,1} C_{k,4,2} + C_{k,4,2} C_{k,4,3} + C_{k,4,3} C_{k,4,4} + C_{k,4,4} C_{k,4,1} \right) dt$$
$$= b_{k,1} b_{k,2} \int^{T} C_k(t) C_k(t - 16T_c) dt \approx 0$$

As shown in (7), we can get orthogonality between adjacent channels by using specific code and data pattern. This orthogonality can minimize the inter channel interference. But in the case of *M*=64 (*S*=1), we cannot get orthogonality between adjacent subcarriers because the same spreading PN sequences are carried on different subcarriers.



(a) example of code and data pattern: *M*≥*S*
(*M=16, S=4, N=MS=64*)



(b) example of code and data pattern: *M* < *S*
(*M=4, S=16, N=MS=64*)

Fig. 3 Spectrum of the transmitted signal

III. Channel Model

In this paper, the multipath fading channel model is defined as a discrete type of multipaths. The Rake in this system can resolve a fixed number of Rayleigh faded paths with *delay* > T_c. Even though the multipaths cannot be synchronous, we conveniently assume that we utilize the tapped delay line model [9], [10]. The complex low-pass impulse response of the channel for carrier *m* of user *k* is given by

$$h_{k,m}(t) = \sum_{l=1}^{L} g_{k,m,l} \delta(t - t_{k,l}) \Phi_m(t) \quad (8)$$

$$\Phi_m(t) = \exp(j 2\pi f_m t) \quad (9)$$

where L is the number of resolvable paths, $g_{k,m,l} = \beta_{k,m,l} e^{j\gamma_{k,m,l}}$ is a complex Gaussian random variable with zero mean and variance σ_l^2. $\beta_{k,m,l}$ is the Rayleigh random variables, and $\gamma_{k,m,l}$ is the uniformly distributed random phase. Since we consider only uniform multipath power profiles, σ_l^2 is equal to $1/L$ and the channel auto-covariance function is found to be $\sum_{l=1}^{L}\sigma_l^2\delta(t-t_{k,l})$ and the unit energy constraint on the fading process covariance function implies, $\sum_{l=1}^{L}\sigma_l^2=1$. $\Phi_m(t)$ is the frequency offset component of the channel. For the discrete channel, we assume $f_m=v/T_c$ (v = 0, 1, 2 ... V) with equal probability [11]. Thus we can rewrite the impulse channel response $h_{k,m}(t)$ as

$$h_{k,m}(t)=\sum_{v}^{V}\sum_{l=1}^{L}g_{k,m,l}\delta(t-t_{k,l})\exp\left(j2\pi\frac{v}{T_c}t\right) \tag{10}$$

Since the channel model is assumed to be synchronous, the delay of the l-th path of the k-th user is $t_{k,l}=(l-1)T_c$. The path gains $\{g_{k,m,l}\}$ are assumed to be independent for different users and different paths, but $\{g_{k,m,l}\}$ are correlated for different subcarriers of the same user and path. The amount of correlation depends on the frequency separation with respect to the coherence bandwidth of the channel. $T_{\rm rms}$, the correlation between the different subchannel signals is given by [12]

$$R_h(i-j)=E\left[h_{k,i}h_{k,j}^*\right]=\frac{1}{1+2\pi j\Delta_{f_{i,j}}T_{\rm rms}} \tag{11}$$

where $\Delta_{f_{i,j}}$ is frequency interval between *i*-th and *j*-th subchannels, defined by

$$\Delta_{f_{i,j}}T_{\rm rms}=|i-j|\frac{T_{\rm rms}}{T_c} \tag{12}$$

Formally the coherence bandwidth is the bandwidth for which the autocovariance of the signal amplitudes at two extreme frequencies reduces from 1 to 0.5 [12].

Ⅳ. Receiver Model

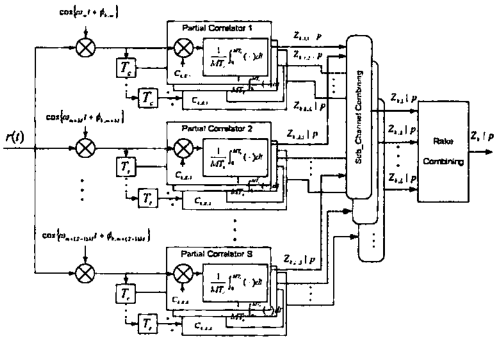


Fig. 4 Receiver scheme for modified multicarrier CDMA system

The receiver structure for k-th user of the proposed multicarrier CDMA system is shown in Fig. 4. In Fig. 4, the output $Z_k\,|\,p$ is the p-th output among the M serial-to-parallel converted data. In the receiver, there are MS matched filters for each multipath signal with one matched filter for each subcarrier. To extract the desired signal component, partial correlations, $Z_{k,i,l}\,|\,p$, are calculated by using divided PN sequences. In Fig. 4, $Z_{k,i,l}\,|\,p$ is the partial correlation output of the *k*-th users *i*-th copied data for the *l*-th multipath component where *i* = 1, 2, ..., S and *l* =1, 2, ..., L. The outputs of S partial correlator detectors are combined in subchannel combining block to get frequency diversity, and we get the l-th multipath component $Z_{k,l}\,|\,p$. Even if outputs of matched filters are partial correlation values, we can get the full correlation value of the spreading sequence by summing those partial correlation values. We also consider the case that the detector of each carrier employs a Rake receiver. Outputs of Rake receiver branches are also combined into $Z_k\,|\,p$ in a Rake combining block to get time diversity gain. The outputs of Rake combining blocks, $Z_k\,|\,1, Z_k\,|\,2,\ldots, Z_k\,|\,M$, are parallel to serial converted to get the desired signal sequence.

In the proposed system, the values *M* and *S* are two of the most important design parameters to determine the bit error performance as well as diversity gains. Therefore, it is critical to pursue the system optimization in terms of these system parameters in accordance with the given data rate. The receiver of user *k* employs *MS* matched filter detectors; each tuned and synchronized to one of the carriers. The received signal takes the form

$$r(t)=\sqrt{2P}\sum_{k=1}^{K}\sum_{v=1}^{V}\sum_{m=1}^{MS}\sum_{l=1}^{L}\beta_{k,m,l}b_{k,p}(t-t_{k,l}-\tau_k)C_{k,S,i}(t-t_{k,l}-\tau_k)$$
$$\times\cos\left((\omega_m+\Delta\omega_v)t+\phi_{k,m,l}\right)+n(t) \tag{13}$$

where $n(t)$ $N_0/2$,

$\phi_{k,m,l}=(\gamma_{k,m,l}-\omega_m t_{k,l}-\omega_m\tau_k)\bmod 2\pi$

$\Delta\omega_v=2\pi(v-1)/VT_c\cdot t$ τ_k, $\{\tau_k\}$ are i.i.d. uniformly distributed random variables with the values in [0, *T*]. For simplicity of performance analysis, we assume *V*=2. The output of *k*-th users matched filter of carrier *q* and *l*-th path is given by and the set which is the frequency offset by mobile channel. The propagation delay for user k is and is AWGN with zero mean and two-sided power spectral density

$$Z_{k,i,l}\mid p=\int_{t_{1,l}}^{t_{1,l}+MT_c}r(t)C_{k,S,i}(t-t_{1,l})\cos(\omega_q t+\phi_{1,q,l})dt \tag{14}$$

where q MT_c $T=S\cdot M\cdot T_c$. $S\times L$ matched filters are added (post detection equal gain combining is accomplished) For the bit transmitted on group p, p=1, 2, ·, M, the decision statistics of the because is the absolute carrier number within group p. The relation between i and carrier number m=q is described in Section 2. 2. The integration interval T/S is equal to

$$Z_k\mid p=\sum_{l=1}^{L}\sum_{i=1}^{S}Z_{k,i,l}\mid p \tag{15}$$

where *L* is the number of Rake branches. We use Equal Gain Combining (EGC) to reduce the effect of the fading and interference while not enhancing the effect of the noise on the decision of what data symbol was transmitted.

V. Simulation Results

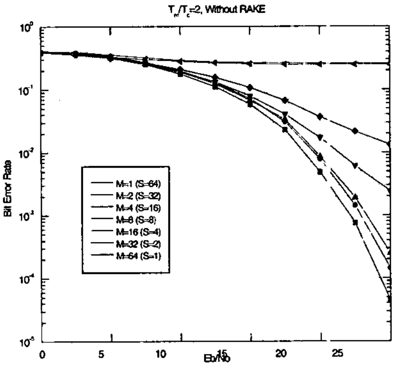


Fig. 5 BER performance of multicarrier CDMA with different M: delay spread $T_m=2T_c$ and without Rake receiver (λ =1)

We now present some simulation results regarding the performance of the proposed multicarrier CDMA, and we investigate the influence of different design parameters on the performance of the proposed system. In this simulation, we assume a frequency selective Rayleigh fading channel, and we consider three kinds of channel delay profiles: *Tm/Tc*=2, 3 and 4. We assume a perfect subcarrier synchronization and subcarrier state estimation. Maximal length sequences of length 64 are used to spread the transmitted data. We set the product of *S* and *M* as constant number (*S* ×*M* = 64) and chip duration T_c is set constant, which means that the number of subcarriers is constant and the bandwidth of subcarriers is identical regardless of *S* and *M*. The number of serial-to-parallel converted bits can be *M* = 1, 2, 4, 8, 16, 32 and 64 in which *S* = 64, 32, 16, 8, 4, 2 and 1 respectively. We investigate the influence of different design parameters on the performance of the proposed multicarrier CDMA system. Simulation results compare the performance of three kinds of different parameters: the number of serial-to-parallel converted branches (*M*=64/*S*), the number of Rake receiver branches (λ), and the ratio of delay spread to chip duration ($L = T_m / T_c$) which is the number of resolvable paths.

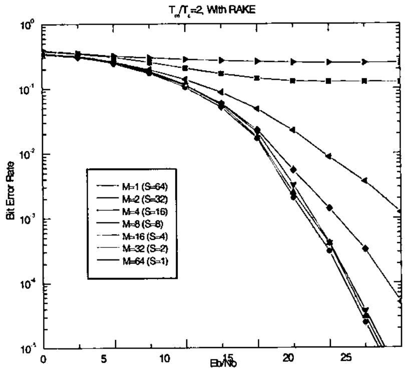


Fig. 6 BER performance of multicarrier CDMA with different M: delay spread $T_m = 2T_c$ and using Rake receiver (λ =2)

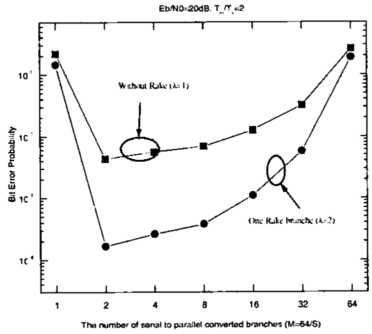


Fig. 7 BER versus the number of serial-to-parallel converted branches M: delay spread $T_m = 2T_c$, Eb/N0 = 20dB

Figs. 5 ~ 7 show the BER performance of proposed multicarrier CDMA scheme in the case of T_m / T_c=2. Fig. 5 shows the BER performance according to the varying size of the number of S/P converted branches, M, while the Rake receiver is not used. Fig. 6 is the same case as Fig. 5, but the Rake receiver is used. Fig. 7 shows the effect of the Rake receiver at E_b/N_0=20dB. As shown in Fig. 5 and 6, for M = 2 (S = 32), the system achieves better BER performance than the others. Also the BER performance improvement can be obtained by using the Rake receiver. Especially for M=2, 4, 8, about 3~5dB diversity gain is obtained by the Rake receiver. For M=1 and 64, BER performance is almost unchanged whether the Rake receiver is used or not. Figs. 8~10 show the BER performance for T_m / T_c=3. It can be seen from Fig. 8 that for M=8, the system achieves better BER performance than the others, but for M=2, the system achieves the worst BER performance. This result is quite different from the case of T_m / T_c=2. Figs. 9 and 10 show the effect of time diversity using the Rake receiver. For M=2, the performance improvement due to the Rake receiver is very small compared to Fig. 7. The reason for this result is that for M=2 and T_m / T_c=2, delay spread is not longer than the data duration, but for M=2 and T_m / T_c=3, delay spread becomes longer than data duration. If the delay spread is longer than data duration, severe inter-symbol-interference occurs by multipath fading channel. Fig. 11 shows the BER performance in the case of T_m / T_c=4. For M=4, 8 and 16, the system achieves better BER performance than the others and the performance improvement by the Rake receiver is higher than the others. This results are similar to the case of T_m / T_c=3. Fig. 11 demonstrates that the proposed multicarrier CDMA system can achieve better BER performance as the number of the Rake branches increase, but for M = 1,2 and 64, this system achieves either compatible or slightly better performance.

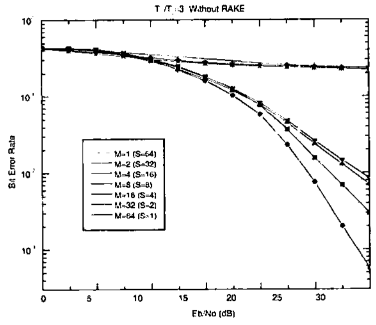


Fig. 8 BER performance of multicarrier CDMA with different M: delay spread $T_m = 3T_c$ and without Rake receiver (λ =1)

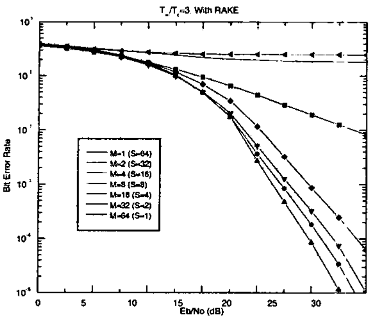


Fig. 9 BER performance of multicarrier CDMA with different M: delay spread $T_m = 3T_c$ and using Rake receiver (λ =3)

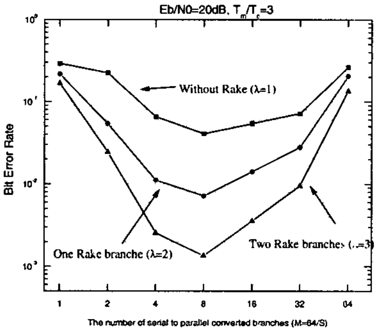


Fig. 10 BER versus the number of serial-to-parallel converted branches M: delay spread $T_m = 3T_c$, Eb/N0 = 20dB

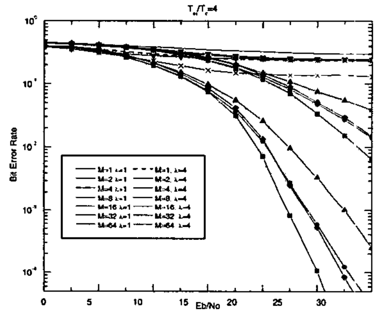


Fig. 11 BER performance of multicarrier CDMA with different M: delay spread $T_m = 4T_c$

For M=1 (S=64), the system is considered as a MC-CDMA scheme. MC-CDMA system has not orthogonality in time domain because signals are spread in frequency domain. It induces severe inter symbol interference by multipath fading channel. For M=64 (S=1), the system is considered MC-DS-CDMA scheme. In that case, Each subcarriers have the same PN sequence and the system suffers from severe inter carrier interference. From the simulation results, we observe that the system performance mainly depends on the S/P number, M, and the delay spread of channel. The proposed scheme is robust to inter-symbol interference and inter-channel interference by choosing proper M and S parameters, and outperforms the conventional schemes such as M=1 and M=64.

Ⅵ. Conclusions

In this paper, we propose a modified multicarrier CDMA transmission scheme, and simulation results are presented to investigate the performance of the modified multicarrier CDMA system. This multicarrier CDMA scheme fully exploits the inherent channel diversity. The spreading sequence is divided into S branches and these sequences are transmitted by each different subcarrier. These S subchannels undergo a different fading and noise condition and consequently we can achieve frequency diversity. Using the sum of partial correlation in the receiver, a Rake receiver can be utilized to achieve time diversity. And we can get the orthogonality between adjacent channels by using specific data and code allocation, which reduces the inter carrier interference effect. The proposed scheme is robust to inter-symbol interference and inter-channel interference by choosing proper M and S parameters, and outperforms the conventional schemes such as M=1 (MC-CDMA scheme) and M=64 (MC-DS-CDMA scheme). The modified multicarrier CDMA system allows additional flexibility in the choice of system parameters, and the performance of the proposed multicarrier CDMA system improves as the number of Rake branches increase.

References

[1] S. S. Hara, R. Prasad, "Overview of multicarrier

CDMA," *IEEE communication Magazine*, pp. 126-133, December 1997.

[2] L. J. Cimini, "Analysis and simulation of A digital Mobile channel using orthogonal frequency division multiplexing," *IEEE Trans. Comm.*, Vol. 34, No. 7, pp. 665-675, July 1985.

[3] N. Yee, J-P. Linnartz and G. Ffettweis, "Multicarrier CDMA in indoor wireless radio networks," *Proc. IEEE PIMRC93*, pp.109-113, Yokohama, Japan, Sept. 1993.

[4] K. Fazel and L. Papke, "On the performance of convolutionally-coded CDMA/ OFDM for mobile communications system," *Proc. IEEE PIMRC94*, pp.468-472, Yokohama, Japan, Sept. 1993.

[5] A. Chouly, A. Brajal and S. Joudan, "Orthogonal multicarrier techniques applied to direct sequence spread spectrum CDMA systems," *Proc. IEEE GLOBECOM93*, pp. 1723-1728, Houston, USA, Nov. 1993.

[6] V. M. DaSilva and E. S. Sousa, "Performance of orthogonal CDMA codes for quasi-synchronous communications systems," *Proc. IEEE ICUPC93*, pp. 995-999, Ottawa, Canada, Oct. 1993.

[7] L. Vandendorpe, "Multitone direct sequence CDMA system in an indoor wireless environment," *Proc. IEEE First Symposium of Communications and Vehicular Technology*, pp.4.1-1 4.1-8, the Benelux, Delft, The Netherlands Oct. 1993.

[8] Richard van Nee and Ramjee Prasad, *OFDM for Wireless Multimedia Communications*, Artech House Publishers, 2000.

[9] G. L. Stuber and C. Kchao, "analysis of a multiple cell direct sequence CDMA cellular mobile radio system," *IEEE J. Select. Areas Commun.*, Vol. 10, No. 4, pp. 669-6769, May 1992.

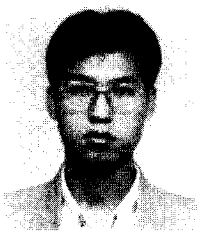
[10] H. Ochsner, "Direct sequence spread spectrum receiver for communication on frequency selective fading channels," *IEEE J. Select. Areas Commun.*, Vol. SAC-5, No. 2, pp. 188-193, February 1987.

[11] Akbar M. Sayeed, Behnaam Aazhang, "Joint multipath-Doppler diversity in mobile wireless communications," *IEEE trans. Commun.*, Vol. 47, No. 1, pp. 123-132, January 1999.

[12] J. P. Linnartz, at al., *Wireless Communication: The interactive Multi-Media CD-ROM*, Edition 1999, Baltzer Science Publishers, Netherlands, 1999.

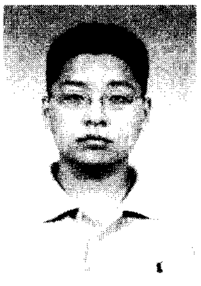
[13] E. Sourour and M. Nakagawa, "Performance of orthogonal multicarrier CDMA in a multipath fading channel," *IEEE trans. Commun.*, Vol.44, No.3, pp. 356-367, March 1996.

박 형 근(Hyung-Kun Park) 정회원



1995년 2월 : 고려대학교 전자공학과 학사
1997년 2월 : 고려대학교 전자공학과 석사
2000년 8월 : 고려대학교 전자공학과 박사
2000년 9월~2001년 8월: University of Colorado at Colorado Springs, Postdoc.
2001년 9월~현재 : (주)현대시스콤 시스템그룹 선임 연구원
<주관심 분야> IMT-2000, 무선자원관리, Spread Spectrum, OFDM

주 양 익(Yang-Ick Joo) 정회원



1998년 2월 : 고려대학교 전자공학과 학사
2000년 8월 : 고려대학교 전자공학과 석사
2000년 9월~현재 : 고려대학교 전자공학과 박사과정
<주관심 분야> Spread Spectrum, OFDM, 블루투스, 무선 ad hoc 네트워크

김 용 석(Yongsuk Kim) 정회원

1989년 2월 : 고려대학교 전자공학과 학사
1995년 2월 : 경기대학교 멀티미디어 통신공학 석사
1998년 9월~현재 : 고려대학교 전자공학과 박사과정
1989년 3월~현재 : (주) 삼성전자
<주관심 분야> 멀티미디어 CDMA 시스템, 블루투스, 무선 PAN/LAN, 무선 ad hoc 네트워크

차 균 현(Kyun Hyon Tchah) 정회원

1965년 2월 : 서울대학교 전기공학과 학사
1967년 6월 : 미국 일리노이 공과대학 석사
1976년 6월 : 서울대학교 전자공학과 박사
1977년 3월~현재 : 고려대학교 전자공학과 교수
1998년 1월~1998년 12월 : 한국통신학회 회장
2000년 5월~현재 : IEE Fellow
2001년 1월~현재 : IEEE Seoul Section Chair
<주관심 분야> 통신 이론, 블루투스, WPAN/WLAN, 차세대 이동통신 시스템