논문 2005-42TC-1-4

다중경로 및 도플러 다이버시티를 위한 멀티캐리어 CDMA 시스템

(A Multicarrier CDMA System for Multipath and Doppler Diversity)

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요 약

다중반송파 변조방식의 주요한 문제점중의 하나는 도플러 천이에 의한 주파수 옵셋에 민감하다는 점이다. 주파수 옵셋은 다중반송파 변조된 신호의 주파수 중첩으로 인한 반송파간의 간섭을 야기시킨다. 그러나 채널변화에 따른 도플러 천이는 또 다른 다이버시티 이득을 제공할 수 있는 요소가 될 수 있다. 본 논문에서는 변형된 다중반송파 코드분할 다중접속(multicarrier CDMA) 시스템을 제안함으로써 다중경로 다이버시티외에 도플러 다이버시티를 이용할 수 있게 하였다. 이를 위하여 이동 무선채널을 독립적인 시간 및 주파수 페이딩 채널로 분해하고 시간 다이버시티를 이용하는 레이크 수신기를 주파수영역으로 확장하므로써 다중경로 및 도플러 다이버시티 이득을 동시에 얻을 수 있도록 하였다.

Abstract

One of the principal disadvantages of multicarrier modulation technique is the sensitivity to the frequency offset introduced by Doppler shift. This frequency offset introduces inter-carrier interference (ICI) among the multiplicity of carriers in the multicarrier modulated signal. However, Doppler spread induced by temporal channel variations can provide another means for diversity. In this paper, we propose a modified multicarrier code division multiple access (CDMA) system to exploit Doppler diversity as well as multipath diversity. The key work of our framework is a canonical time-frequency-based decomposition of the mobile wireless channel into series of independent fading channel. The decomposition naturally leads to a time-frequency generalization of the Rake receiver that exploits both multipath and Doppler diversity.

Keywords : Multicarrier CDMA, Diversity, Rake receiver, Doppler Diversity

Ⅰ. Introduction

One of the disadvantages of orthogonal frequency division multiplexing (OFDM) is sensitivity to frequency offset introduced by Doppler shift [1]. The frequency offset introduces inter-carrier interference among the multiplicity of carriers in the OFDM signal. Multiplecarriers are inherently closely spaced in frequency domain, and the tolerable frequency offset becomes a very small fraction of the channel bandwidth. Maintaining sufficient open loop frequency accuracy is difficult in links, such as satellite links with multiple frequency translations and mobile digital radio links withsignificant Doppler shift [2]. Multicarrier CDMA systems have been proposed to provide not only robustness against multipath fading, but also to achieve narrowband interference suppression[3]. Multicarrier CDMA systems use direct sequence (DS)-CDMA merely for multiplexing, and choose the signal waveforms using the OFDM principle[4].

In this paper, a modified multicarrier CDMA

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접수일자: 2004년8월9일, 수정완료일: 2004년12월16일

framework is proposed. The modified multicarrier CDMA scheme fully exploits the inherent channel diversity via joint time-frequency processing. The key idea behind our approach is joint multipath-Doppler diversity. The Doppler shift can be used to provide another means for frequency diversity, in conjunction with multipath diversity[5]. To exploit multipath and Doppler diversity, the signal should have orthogonality between adjacent subchannels as well as multipath signals. In this paper, we propose divided spreading sequence and data-code pattern to provide othogonality in time and frequency domain. The workhorse of our framework is a canonical time-frequency based decomposition of the mobile wireless channel into a series of independent fading channels. The decomposition naturally leads to a time-frequency generalization of the Rake receiver that exploits joint multipath-Doppler diversity. The modified 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 inter-ference, and achieves multipath and Doppler diversity by using specific data and code pattern.

This paper is organized as follows: Section II introduces the multicarrier CDMA system and describes data and code pattern. Section III presents time-frequency representation of channel model and signal model for the multicarrier CDMA system. Section IV presents Rake receiver for multipath and Doppler diversity. Simulation results are presented in Section V, and the conclusions are given in Section VI.

II. Transmitter of the multicarrier CDMA System

Table 1 describes some of symbol and notations used in this paper to help to understand system model and equations. Fig. 1 shows the divided PN sequence structure to spread S copied data streams. In this paper, we use m-sequence as a spreading PN sequence.

표 1. 본 논문에서 사용된 심볼 및 기호표
Table 1. Symbol and notations used in this paper.

symbol	
M	the number of S/P converted branches
S	the number of copied branches
N	the number of subcarriers (=M×S)
T_m	multipath delay spread
B_o	max. range of freq. offset
L	the number of resolvable path (for multipath)
V	the number of resolvable freq. offset
P	the number of rake receiver in freq. domain p : p-th rake receiver in freq. domain
λ	the number of rake receiver in time domain n: n-th rake receiver in time domain

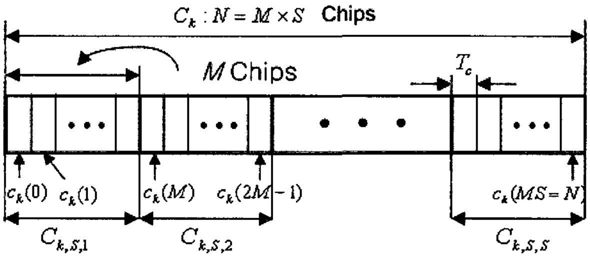

그림 1. 분할된 PN확산 시퀀스
Fig. 1. Divided PN spreading sequence.

The k-th user's PN sequence of length N is divided into S sub-PN sequences of length M (=N/S). As shown in Fig. 1, the k-th user's PN sequence of length N is

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

where 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 is divided into S sub-PN sequences and the i-th divided sub-PN sequence of length M is

$$C_{k,S,i} = \{ c_k((i-1)M), c_k((i-1)M+1), \cdots, c_k(iM-1) \}$$
$$i = 1, 2, \Lambda, S \tag{2}$$

The transmitter for user k of the proposed system is shown in Fig. 2 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

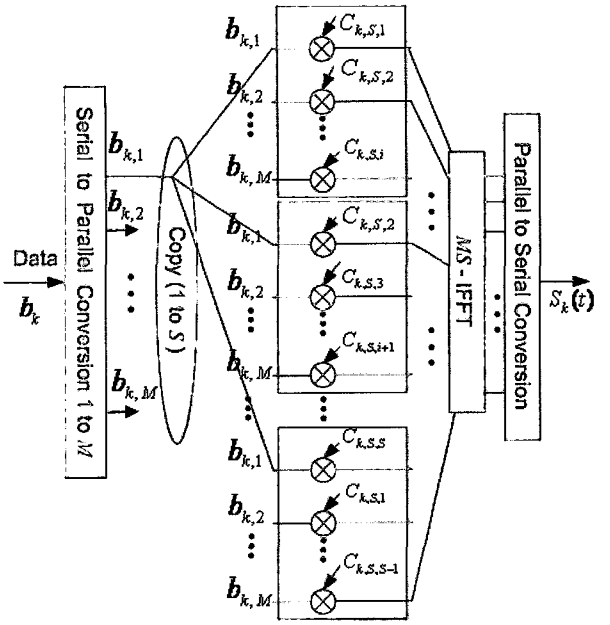

그림 2. 제안된 다중반송파 CDMA 시스템의 송신기 구조

Fig. 2. Transmitter scheme for modified multicarrier CDMA.

streams are spread by different divided PN sequences. The k-th user's 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 T_c 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[6] [8]. If S is equal to 1, the length of divided PN sequence is M, and this system can be considered as multicarrier DS-CDMA [9][10]. The $M \times S$ subcarriers are used for BPSK modulation of each stream.

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 transmitted signal of user k is given by

$$s_k(t) = \sum_{m=1}^{MS} \sqrt{2W} \cdot b_{k,d}(t) C_{k,S,i}(t) \cos(\omega_m t) \tag{3}$$

where d=1, 2,... ,M is the output branch index of the serial-to-parallel converter and the transmitted data bit $b_{k,d}(t)$ takes the values of 1 with equal probability. $C_{k,s,i}$ is the k-th user's i-th divided PN sequence. Also in (3), W is the transmitted power per subcarrier. 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 where length is N/S. The bit and chip waveforms are rectangular, an the orthogonal frequencies ω_m are related by

$$\omega_m = (m-1) 2\pi \frac{1}{T_c} \tag{4}$$

where m is the absolute subcarrier number in the system, m=1,2,...,$M \times S$. 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 to get orthogonality between subcarriers is $1/T_c$. To get particular spacing, we can use inverse fast Fourier transform (IFFT) [2].

Each divided PN sequence is transmitted by using different sub-carriers. As shown in Fig. 2, the $M \times S$ frequencies are assigned to the $M \times S$ streams such as, given a value of M, the frequency separation between any two successive identical-bit carriers is maximized, and divided PN sequences are assigned to the subcarriers to maximize the orthogonality between adjacent subcarriers. Also the Rake receiver can be adopted by using the property of divided PN sequences.

Ⅲ. Channel and Signal Model

Time-Frequency representations (TFR) is 2-dimensional signal representations in terms of both time and frequency, and are powerful tools for representing time-varying signal systems. As we will see, TFR is ideally suited for processing signals transmitted over the inherently time-varying wireless channel[5]. The concepts of time and frequency shift play a fundamental role in the theory of TFR and we will use them throughout this paper. We will denote time and frequency shifts by operators $\mathbf{T}_\tau$ and $\mathbf{F}_\theta$, respectively, defined as

$$(\mathbf{T}_\tau a)(t) \overset{def}{=} a(t-\tau), \quad (\mathbf{F}_\theta a)(t) \overset{def}{=} a(t)e^{j2\pi\theta t} \tag{5}$$

where the parameter τ denotes the value of the time-shift, and θ denotes the value of the frequency-shift introduced in the signal. The component of arbitrary signal $a(t)$,which have time delay τ and frequency shift θ, can be approximately calculated by short-time Fourier transform (STFT) which is defined for a signal a(t) as

$$\mathbf{STFT}_a(\theta,\tau;g) \overset{def}{=} \int a(t)g^*(t-\tau)e^{-j2\pi\theta t}dt \tag{6}$$

for a given window function $g(t)$. It is a projection of the signal onto a family of functions $\varphi_{(\theta,\tau)}$ that are time- and frequency-shifted versions of $g(t)$.

$$\mathbf{STFT}_a(\theta,\tau;g) \overset{def}{=} \langle a, \varphi_{(\theta,\tau)} \rangle \tag{7}$$

$$\varphi_{(\theta,\tau)}(t) \overset{def}{=} (\mathbf{F}_\theta \mathbf{T}_\tau g)(t) = g(t-\tau)e^{j2\pi\theta t} \tag{8}$$

where $\langle \cdot,\cdot \rangle$ denotes the inner product. **STFT** can also be interpreted as a time-frequency correlation function. We next develop the time-frequency-based channel and signal models. The complex baseband signal $r(t)$ at the receiver is given by

$$r(t) = y(t) + n(t) \tag{9}$$

where $n(t)$ is the complex AWGN with power spectral density N_0, and $y(t)$ is the channel-transformed version of the transmitted complex baseband signal $s(t)$

$$y(t) = \int_0^\infty h(t,\tau)s(t-\tau)d\tau \tag{10}$$

We are interested in a representation for the time-varying channel[11], described by the kernel $h(t,\tau)$, that maps $s(t)$ into y(t). It suffices to consider the unmodulated signal to characterize the effects of the channel. An equivalent representation of the channel which is central to our discussion is in terms of the spreading function defined as [11]

$$H(\theta,\tau) \overset{def}{=} \int h(t,\tau)e^{-j2\pi\theta t}dt \tag{11}$$

The corresponding representation of y(t) is

$$\begin{aligned} y(t) &= \iint H(\theta,\tau)(\mathbf{F}_\theta \mathbf{T}_\tau s)(t)d\theta d\tau \\ &= \iint H(\theta,\tau)s(t-\tau)e^{j2\pi\theta t}d\theta d\tau \end{aligned} \tag{12}$$

And thus θ corresponds to the frequency offset introduced by Doppler shifts, and τ corresponds to the multipath delay (time-shifts). The maximum range of the τ is called the multipah delay spread of the channel and is denoted T_m. Similarly, the maximum range of the values is denoted by B_0. In terms of these parameters, (12) becomes

$$\begin{aligned} y(t) &= \int_0^{T_m}\int_0^{B_0} H(\theta,\tau)(\mathbf{F}_\theta \mathbf{T}_\tau s)(t)d\theta d\tau \\ &= \int_0^{T_m}\int_0^{B_0} H(\theta,\tau)s(t-\tau)e^{j2\pi\theta t}d\theta d\tau \end{aligned} \tag{13}$$

Thus, T_m signifies the maximum multipath delay introduced by the channel, and B_0 corresponds to the maximum frequency offset produced by the channel. The spreading function $H(\theta,\tau)$ quantifies the time-frequency spreading introduced by the channel. Note from (12) that if we represent the channel by an operator **H**, it is composed of a linear combination of time- and frequency-shift operators

$$\mathbf{H} = \iint H(\theta,\tau)\mathbf{F}_\theta \mathbf{T}_\tau d\theta d\tau \tag{14}$$

It is well known that an arbitrary time-varying linear system admits such a representation in terms of time and frequency shifts [12], [13]. The time-variant channel impulse response $h(t,\tau)$ is best modeled as a stochastic process and a realistic model in many situations is the wide-sense stationary uncorrelated scatterer (WSSUS) model [11] in which the temporal variations in $h(t,\tau)$ are represented as a stationary Gaussian process, and the channel responses at different lags (different scatters) are uncorrelated (independent). Thus, the channel is characterized by second-order statistics, which are given by

$$\begin{aligned} &E\{H(\theta_1,\tau_1)\, H^*(\theta_2,\tau_2)\} \\ &= \psi(\theta_1,\tau_1)\delta(\theta_1-\theta_2)\delta(\tau_1-\tau_2) \end{aligned} \tag{15}$$

where

$$\psi(\theta,\tau) \overset{def}{=} E\{|\,H(\theta,\tau)\,|^2\} \tag{16}$$

and $\delta(t)$ denotes the Dirac delta function. The function $\psi(\theta,\tau) \geq 0$ is called the scattering function and denotes the power in the different multipath-delayed and Doppler-shifted signal components. It is particularly useful for describing some salient characteristics of the channel [11].

The following result describes the fundamental channel representation, obtained by a (θ,τ)-sampling of (13). If the multipath spread is greater than or equal to the chip period, $T_m \geq T_c$, and the frequency-offset is greater than or equal to the reciprocal to the waveform duration, $B_o \geq 1/T_c$, then the received signal $y(t)$ in (13) admits the finite-dimensional representation

$$y(t) \approx \sum_{l=1}^{L}\sum_{v=1}^{V} \hat{H}\left(\frac{V}{T_c}, lT_c\right) u_{v,l}(t) \tag{17}$$

Where $L = \lceil T_m / T_c \rceil$, $V = \lceil B_o T_c \rceil$, and $\hat{H}(\theta,\tau)$ is a band limited approximation of $H(\theta,\tau)$. The waveforms $u_{v,l}(t)$'s are defined as

$$u_{v,l}(t) \overset{def}{=} (\mathbf{F}_{\frac{p}{T_c}} \mathbf{T}_{lT_c} s)(t) = s(t - lT_c)e^{j\frac{2\pi vt}{T_c}} \tag{18}$$

In the case of proposed multicarrier CDMA system, transmitted signal $s(t)$ is described by (3). The orthogonality of the $u_{v,l}(t)$ implies that they can be processed as separate "channels", and the independence of the $\hat{H}(v/T_c, lT_c)$ implies that those channels can be processed independently to provide diversity [5]. The received signals has multipath-Doppler components with delay, lT_c, and Doppler shift ,v/T_c, and the received signals can be resolved into $V \times L$ independent multipath-Doppler components (diversity channels) by appropriate sampling of time-frequency plane.

Note that the orthogonality of the $u_{v,l}(t)$ is very important to determine the performance of multipath and Doppler diversity. In the proposed multicarrier CDMA system, data and code pattern is changed according to the number of serial-to-parallel converted branches M. It means that the orthogonality of the $u_{v,l}(t)$ is determined by the parameter M and S. The parameter M and S are the key parameters to determine the performance of multipath and Doppler diversity.

It is worth noting that there is virtually no loss of information in the approximate representation (17). The reason is that due to the time- and band-limited nature of the signaling waveform s(t), the receiver only "sees" a corresponding time- and band-limited version $\hat{H}(\theta,\tau)$ of the channel $H(\theta,\tau)$, which in turn justifies the sampling of the spreading function in (17). The proposed system uses divided PN spreading sequences and they has orthogonality in time and frequency domain by using the specific data and code pattern described in section II, and so the channel with multipath and freq. offset can be described as a finite linear combination of time-frequency shift operators (compare with (14)):

$$\hat{\mathbf{H}} \approx \sum_{l=1}^{L}\sum_{v=1}^{V} \hat{H}\left(\frac{V}{T_c}, lT_c\right) \mathbf{F}_{\frac{v}{T_c}} \mathbf{T}_{lT_c} \tag{19}$$

The above channel approximation depends on the time-bandwidth product of the spread-spectrum signal s(t).

Ⅳ. Rake Receiver for Multipath and Doppler Diversity

In this section, we describe the time-frequency Rake receiver that exploits time-frequency channel representation to achieve both multipath and Doppler diversity for the proposed multicarrier CDMA system.

Fig. 3 illustrates the receiver structure for multipath and Doppler diversity. To extract the independent multipath-frequency shift components, received signal r(t) is shifted in time and frequency by nT_c and p/T_c respectively. Time and frequency shifted signal $r_{p,n}(t)$ is used to get the independent

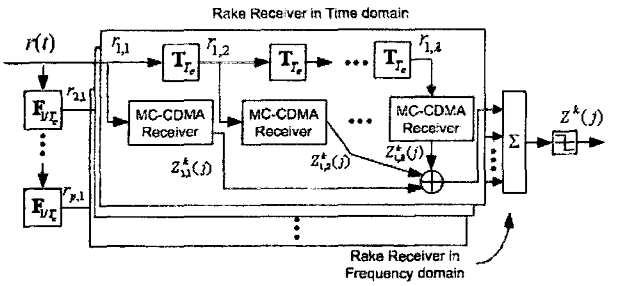

그림 3. 다중경로 및 도플러 다이버시티를 위한 레이크 수신기의 구현

Fig. 3. Implementation of Rake receiver for multipath and Doppler diversity.

detection values.

$$r_{p,n}(t) = \left(\mathbf{F}_{\frac{p}{T_C}} \mathbf{T}_{nT_C} r \right)(t) = r(t-nT_c)e^{\frac{j2\pi pt}{T_C}},$$

$$p = 1,2,\Lambda, P, \quad n = 1,2\Lambda, \lambda \tag{20}$$

The parameter P and are less than or equal to the V and L respectively. It is because that L is the maximum resolvable path in time domain and V is the maximum resolvable element in frequency domain.

Recalling the definition of the **STFT** in (6), we note that the matched filter outputs can be precisely computed via sampled **STFT**s . $Z^k_{p,n}(j)$ is the k-th user's detection value from the n-th path (nT_c) and p-th frequency shifted (p/T_c) component of the received signal. We can get $Z^k_{p,n}(j)$ from

$$\begin{aligned} Z^k_{p,n}(j) &= \sum_{i=1}^{S} \int_{(j-1)MT_c}^{jMT_c} r_{p,n}(t) \cdot g_{k,S,i}(t) \\ &= \sum_{i=1}^{S} \mathbf{STFT}_{g_{k,S,i}}\left(\frac{p}{T_c}, nT_c; r \right) \end{aligned} \tag{21}$$

$$g_{k,S,i}(t) = C_{k,S,i}(t)\cos(\omega_{i,j}t + \phi_{i,j}) \tag{22}$$

where $w_{i,j} = 2\pi(jM+i)/T_c$. Above STFT can be implemented by the block diagram in Fig. 4. Figure 4 shows the multicarrier CDMA receiver block. As shown in Fig. 4, the input received signal, rp,n is shifted in time and frequency domain and the received signal is divided into subchannels by using FFT block[2] and we can get the despreading value with correlator banks in Fig. 4. The outputs of multicarrier CDMA receivers are combined to get multipath and Doppler diversity as shown in Fig. 3. Using equal gain combining, the decision value is given as

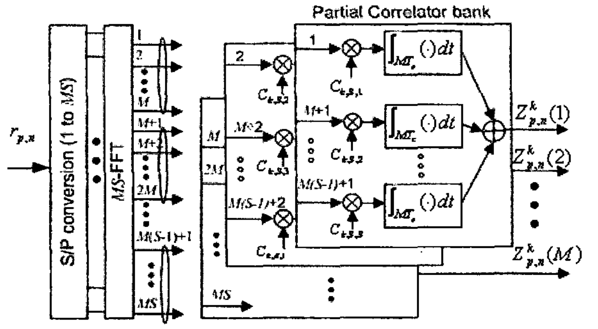

그림 4. 제안된 다중반송파 CDMA 의 수신기 블록

Fig. 4. Proposed multicarrier CDMA Receiver block in Receiver block.

$$Z^k(j) = \text{sgn}\left(\sum_{p=1}^{P} \sum_{n=1}^{\lambda} Z^k_{p,n}(j) \right) \tag{23}$$

Decision values, $Z^k(j)$,are serial-to-parallel converted to get the final detection data stream.

V. Simulation Results

We now present some simulation results regarding the performance of multipath-Doppler diversity techniques for the proposed multicarrier CDMA system. We assume a frequency selective Rayleigh fading channel, and we consider three kinds of channel delay profile: T_m/T_c=2, 3 and 4. We assume a perfect subcarrier synchronization and subcarrier state estimation. The m-sequences of length 64 are used to spread the transmitted data. We set the product of S and M as constant number (SXM = 64) and chip duration T_c is set constant, which means that the number of subcarriers is constant and the bandwidth of subcarriers are 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 multicarrier

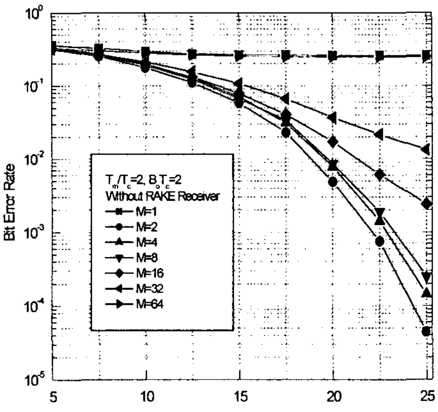

그림 5. 레이크수신기를 사용하지 않을 때의 다중반송파 CDMA의 BER성능: 지연확산 $T_m=2T_c$, $B_0T_c=2$.

Fig. 5. BER performance of the multicarrier CDMA without Rake Receiver: delay spread $T_m=2T_c$, $B_0T_c=2$.

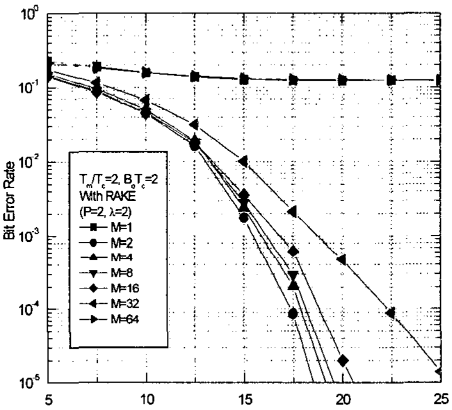

그림 6. 레이크 수신기를 갖는 다중반송파 CDMA의 BER성능비교 :지연확산 $T_m=2T_c$, $B_0T_c=2$.

Fig. 6. BER comparison of the multi-carrier CDMA with Rake receiver : delay spread $T_m=2T_c$, $B_0T_c=2$.

CDMA system. The key parameters for simulation are followed: the number of serial-to-parallel converted branches, $M=64/S$, the number of Rake receiver branches for multipath diversity, p, the ratio of delay spread to chip duration, $L=T_m/T_c$, the number of Rake receiver branches for Doppler diversity, p, and the ratio of frequency offset to subcarrier bandwidth, $V=B_0T_c$.

Fig.s 5 and 6 show the bit error rate (BER) performance of the proposed multicarrier CDMA scheme for $T_m/T_c=2$ and $B_0T_c=2$. Fig. 5 shows the system without Rake receiver and Fig. 6 shows the BER performance improvement by joint multipath -Doppler diversity. For M=2, 4, 8, 16 and 32, we can achieve 6~8dB diversity gain. It is much better performance than the case of non Rake receiver.

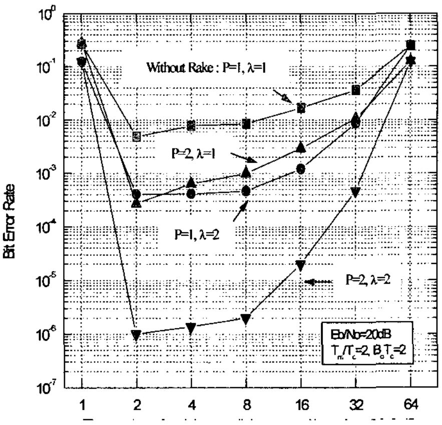

그림 7. 직병렬 변환, M, 에 따른 BER 성능 : 지연확산 $T_m=2T_c$, $B_0T_c=2$, , Eb/No=20dB.

Fig. 7. BER versus the number of serial-to -parallel converted branches M : delay spread $T_m=2T_c$, $B_0T_c=2$, , Eb/No=20dB

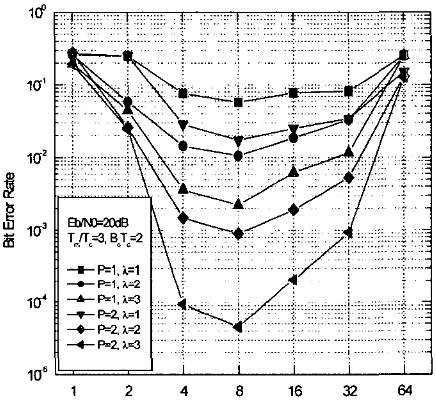

그림 8. 직병렬 변환, M, 에 따른 BER 성능 : 지연확산 $T_m=3T_c$, $B_0T_c=2$, Eb/No=20dB.

Fig. 8. BER versus the number of serial-to -parallel converted branches M : delay spread $T_m=3T_c$, $B_0T_c=2$, Eb/No=20dB.

Fig. 7 shows the BER performance for the varying size of the number of S/P converted branches, M. When Rake branches are used for only multipath diversity ($\lambda=2, P=1$), the performance is not much different from the case of using only frequency domain Rake branches($\lambda=1, P=2$). When both multipath and Doppler diversity are used ($\lambda=2, P=2$), the bit error rate becomes much lower than the others. For

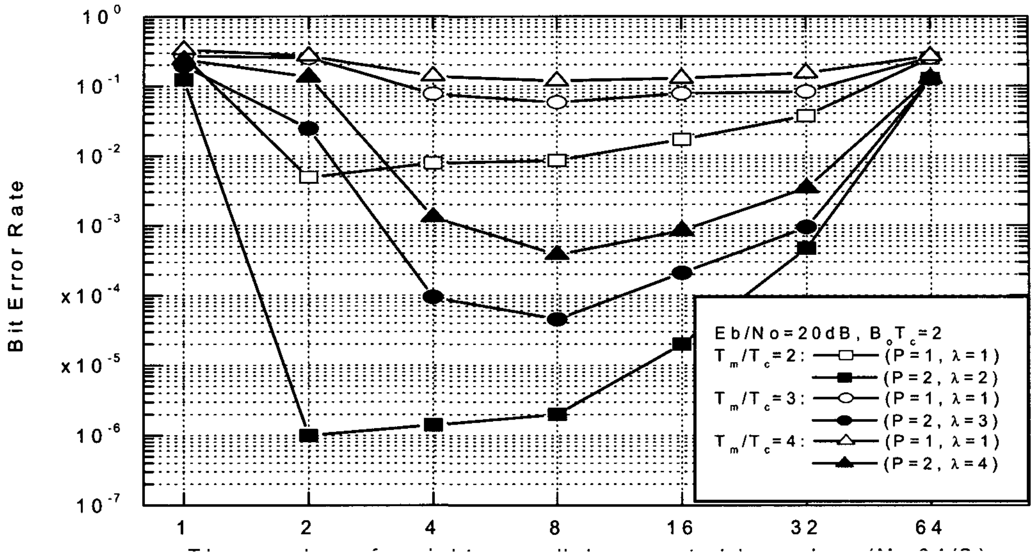

그림 9. 서로 다른 지연확산에 따른 제안된 다중반송파 CDMA의 BER성능
Fig. 9. BER performance of proposed multi-carrier CDMA with different delay spread.

M=1 and 64, BER performance is worse than the others. For M=1, the system does not have orthogonality in time domain, and inter symbol interference by multipath channel drops the system performance. For M=64, the system does not have orthogonality in frequency domain, and frequency offset becomes a severe interference to the system. Thus for M=1 and 64, the system performance improvement is not happen although time and frequency domain Rake receiver is used. Fig. 8 shows the BER performance for T_m/T_c=3 and B_0T_c=2. For M=8, the system achieve better BER performance than the others. For M=2, although Rake receiver is used for multipath and Doppler diversity, the BER performance is not much improved. It is because the system with M=2 has less orthogonality for multipath signal. As M increases, orthogonality for frequency shifted signal increase, whereas orthogonality for multipath signal decrease and as shown in Fig. 8 for T_m/T_c=3 and B_0T_c=2, the system with M=8 has better performance. Fig. 9 summarizes the BER performance under different channels with different delay spread. As delay spread becomes longer, bit error rate becomes higher due to inter symbol interference and the optimal number of serial-to-parallel branches increases due to high multipath diversity gain.

From the simulation results, we observe that system performance can be much improved using multipath-Doppler diversity technique. And we know that the effect of Rake receiver is different according to the number of serial-to-parallel converted branches (M) and channel delay spread and Doppler shift.

VI. Conclusion

In this paper, we propose a modified multicarrier CDMA transmission scheme and adopt Rake receiver to use multipath and Doppler shift. The multicarrier CDMA scheme fully exploits the inherent channel diversity via joint time-frequency processing. Divided spread code and proper data allocation provide orthogonality in time and frequency domain, which enable the system to achieve the joint multipath -Doppler diversity. Simulation results show that Doppler shift can be another information for diversity. The multicarrier CDMA system allows additional flexibility in the choice of system parameters such as the number of serial-to-parallel converted branches and copied branches. Upon varying system parameters, BER performance has been examined for the multicarrier CDMA system under frequency selective multipath fading channel. The simulation results show that the performance of the multicarrier CDMA system can be improved by using joint multipath-Doppler Rake receiver.

References

[1] Yuping Zhao, Sven-Gustav Haggman "Sensitivity to Doppler shift and carrier frequency errors in OFDM systems- the consequences and solutions," Proc. IEEE VTC'96, May 1996, pp.1564-1568.

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

[3] S. S. Hara, R. Prasad, "Overview of multicarrier CDMA," IEEE communication Magazine, December 1997, pp. 126-133.

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

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

[6] N. Yee, J-P. Linnartz and G. Ffettweis, "Multicarrier CDMA in indoor wireless radio networks," Proc. IEEE PIMRC'93, Yokohama, Japan, Sept. 1993, pp.109-113.

[7] K. Fazel and L. Papke, "On the performance of convolutionally-coded CDMA/ OFDM for mobile communications system," Proc. IEEE PIMRC'94, Yokohama, Japan, Sept. 1993, pp.468-472.

[8] A. Chouly, A. Brajal and S. Joudan, "Orthogonal multicarrier techniques applied to direct sequence spread spectrum CDMA systems," Proc. IEEE GLOBECOM'93, Houston, USA, Nov. 1993, pp. 1723-1728.

[9] V. M. DaSilva and E. S. Sousa, "Performance of orthogonal CDMA codes for quasi-synchronous communications systems," Proc. IEEE ICUPC'93, Ottawa, Canada, Oct. 1993, pp. 995-999.

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

[11] P. A. Bello, "Characterization of randomly time-variant linear channels," IEEE Trans. Comm. Syst., Vol. CS-11, pp.360-393, 1963.

[12] Ram G. Shenoy, Thomas W. Parks, "The Welyl correspondence and time-frequency analysis," IEEE trans. Signal Processing, Vol. 42, No. 2, February 1994, pp. 318-331.

[13] W. Kozek, "Time-frequency signal processing based on the Wigner-Welyl framework," IEEE trans. Signal Processing, Vol. 29, October 1992, pp. 77-92.

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