수정된 ZCD 부호를 사용하는 Pre-Rake TDD-CDMA 시스템

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A Pre-Rake TDD-CDMA System Using Modified ZCD Code

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요 약

주파수선택성 패이딩 채널 상황에서 Pre-Rake 다이버시티 기술은 이동단말에게 충분한 다이버시티 효과를 제공하며 이동단말의 수신기가 단순한 구조가 되도록 도와준다. 하지만, 기존의 Pre-Rake 시스템은 주파수선택성 페이딩 환경에서 Rake 시스템보다 두 배에 가까운 멀티패스에 의해 영향을 받기 때문에 다중유저 간섭을 Rake 시스템보다 훨씬 더 심각하게 받게 된다. 결국 이와 같은 간섭은 사용자가 증가할수록 성능이 열화하게 되는 원인이 된다. 따라서 이러한 문제점을 해결하기 위해 본 논문에서는 ZCD (Zero Correlation Code) 확산코드를 이용한 Pre-Rake TDD-CDMA 시스템을 제안한다. 또한 GI (Guard interval)를 포함하는 수정된 ZCD 코드들을 제시하고 다양한 채널환경에서 컴퓨터 시뮬레이션을 수행하고 그 성능을 평가한다.

Key Words : ZCD code, TDD, Pre-Rake, CDMA, Multiple Access Interference, Multipath Fading

ABSTRACT

In a frequency selective fading channel, Pre-Rake diversity technique provides simple receiver structure and sufficient diversity effect for mobile terminals. However, conventional Pre-Rake systems are more severely affected than Rake systems with regard to multiple access interference since the number of multipaths received at the mobile unit is nearly twice that of the Rake systems. In order to overcome the problem, a Pre-Rake TDD-CDMA system using zero correlation duration (ZCD) spreading code is proposed. Modified ZCD codes including guard interval (GI) is also proposed and the performance is evaluated by computer simulation under the condition of various channel environment.

Ⅰ. Introduction

In TDD-CDMA (Time Division Duplex-Code Division Multiple Access) systems, Pre-Rake Diversity can be utilized at the base station (BS) to reduce the complexity of the mobile unit by using the reciprocity of the duplex channel [1]. In Pre-Rake systems, the path diversity effect is achieved with a simple receiver employing just one Rake finger at the mobile unit [1], [2].

Recently, Pre-Rake diversity has been applied to Ultra-WideBand (UWB) systems in [7] and many other works on Pre-Rake UWB system have been shown in [8]-[13]. Furthermore, the pre-rake combined by antenna-arrays were experimentally studied in [13] and the channel reciprocity was verified by experimental measurements.

However, the Pre-Rake combiner creates a larger number of paths towards the mobile unit so that more severe multiple access interference (MAI) and multipath interference (MPI) occur at the mobile unit receiver. In [1], it is found that the interference increases and the BER performance degrades as the number of paths and the number of users increases.

In the case of L-path environment, the Pre-Rake transmits L path signals created by the Pre-Rake combiner to the mobile unit. The transmitted Pre-Rake signals are convolved by channel impulse response and $2L-1$ paths are then received at the mobile unit. In the CDMA system using the Rake combiner, L path signals are received at the mobile unit so that the number of paths

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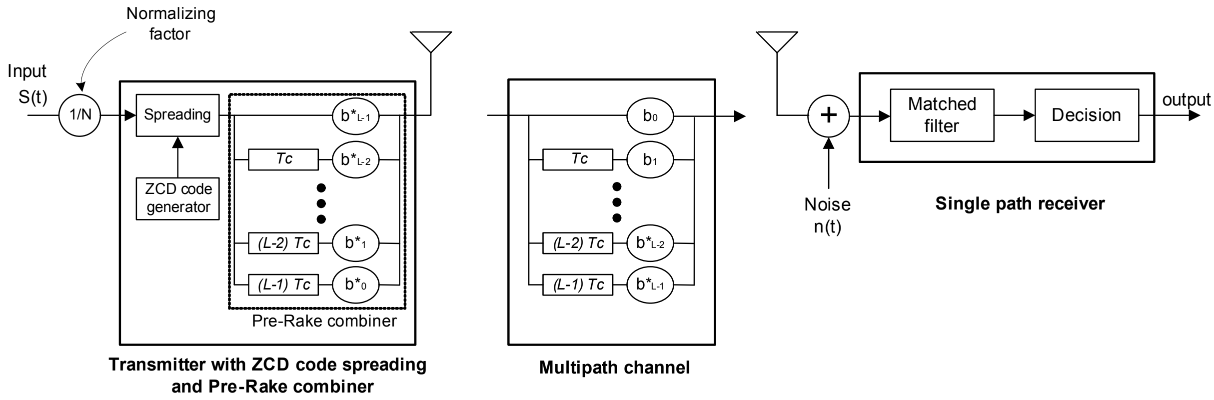

Fig 1. Proposed Pre-Rake TDD-CDMA transmitter and receiver structure

received in the Pre-Rake system becomes nearly twice that of the Rake system. Therefore, the Pre-Rake systems are affected by the interference caused by an increased number of paths, and so the resulting BER performance becomes worse than that of the Rake system. To avoid this interference, efficient interference mitigation techniques such as multiuser detection (MUD) schemes should be adopted at the mobile receiver. However, it is not desirable to use such a complicated MUD technique in the Pre-Rake systems. In order to solve this problem, we propose a Pre-Rake TDD-CDMA system with zero correlation duration (ZCD) codes.

This paper is organized as follows. In section Ⅱ, the structure of the proposed system and Pre-Rake combining process using ZCD code is described. The system performance is analyzed in section Ⅲ and computer simulation results are shown in section Ⅳ. Finally, conclusion is given in section Ⅴ.

Ⅱ. System Model

1. Pre-Rake TDD-CDMA with ZCD Code

To resolve the above problem, a Pre-Rake TDD-CDMA based on a continuously orthogonal spreading code is proposed. In Fig. 1, the transmitter and receiver structure is shown for the proposed Pre-Rake TDD-CDMA systems with zero correlation duration (ZCD) spreading code [3],[4] where ZCD is utilized as a continuously orthogonal spreading code. The modulated Input signals are normalized to keep the transmit power constant and spread with the ZCD code. BPSK is assumed for the modulation, but various modulation schemes can be used as a modulation method. As for the continuously orthogonal spreading code, different types of codes shown in [3]-[6] can be utilized for spreading. In this paper, ZCD code is employed, where there are two types of ZCD codes such as the binary ZCD code [3] and the ternary ZCD code [4]. These two codes can be used for the proposed system as a spreading code. After the spreading process, the spread signal is fed to the Pre-Rake combiner and then finally transmitted to the mobile unit.

2. Two-path Case

In Fig. 2, the concept of the Pre-Rake combining process for the proposed system is depicted together with the received signals for the case of 2-path environment. In the base station (BS), the input signal is combined by a Pre-Rake combiner, and then the combined signal with 2 paths is transmitted to the intended mobile unit. At the mobile unit, the channel output with 3 paths is received after passing through the multipath channel. The mobile unit tunes a matched filter (MF) to t_2-path signal which corresponds to the $(L-1)$th path among the channel output and detects the transmitted signal. On the other hand, guard interval (GI) τ is needed for the proposed system to maintain the orthogonality between the spreading codes. The GI should be added at the head and the back of the spread signal, and the relation of $\tau \geq (L-1)T_c$ should be satisfied to avoid the interferences. From the above process, modified ZCD code with 2 GI is generated.

As shown in Fig. 2, the channel output which consists of a t_1-path signal, two t_2-path signals, and a t_3-path signal is received at the mobile unit. Among them the t_2-path signals are tuned and detected by the MF. If the orthogonal code such as Walsh-Hadamard code is used for spreading, the orthogonality is not maintained any

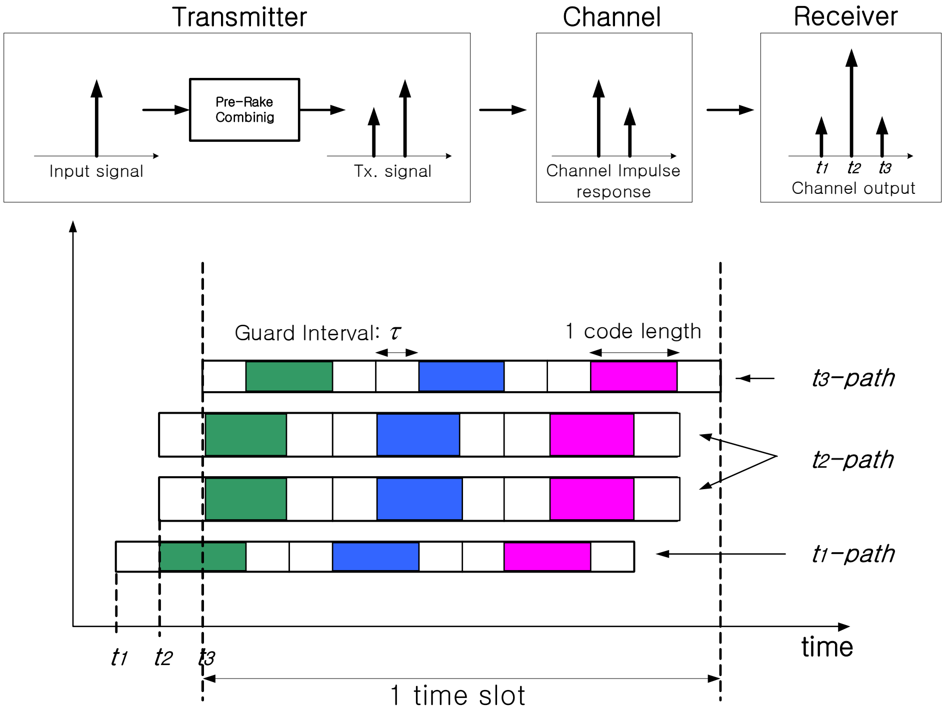

Fig 2. Concept of Pre-Rake combining process and the received signal exemplification for the proposed system

longer due to the increased multipath interferences. In the proposed system, sufficient GI is added for the spread signal and ZCD code is used for spreading so that the MF gives out a desired signal without generating any interference signals. Due to the characteristic of ZCD code that the zero correlation duration exists before and behind t_2, all the channel output signals which are the convolution result of Pre-Rake combined signals and channel impulse responses are included in the zero correlation duration. Therefore, the proposed system is not affected by either MAI or MPI, and achieves the path diversity effect leading to the interference-free communication system even after the number of paths increases due to the Pre-Rake combining process.

Ⅲ. System Performance

1. Channel Model

The complex low-pass impulse response of the channel for user k is given by

$$h_k(t) = \sum_{l=0}^{L-1} \beta_{k,l} \exp(jr_{k,l})\delta(t - l T_c) \quad (1)$$

where L is the number of channel paths, the path gain $\beta_{k,l}$ are independent identically distributed (i.i.d.) Rayleigh random variables (r. v.'s) for all k and l, the angles $jr_{k,l}$ are i.i.d. uniformly distributed in $[0, 2\pi)$, and T_c is the spreading code chip duration. In a TDD system under slow fading conditions we assume that $h_k(t)$ does not change during two successive up and down link time slots.

2. Pre-Rake TDD-CDMA

Without channel estimation error, the downlink transmitted signal for user k with BPSK modulation can be represented by

$$s_k(t) = \sqrt{\frac{2P}{U_k}} \sum_{l=0}^{L-1} \beta_{k,L-l-1} b_k[t - l T_c] \cdot a_k[t - l T_c] \exp[jw(t - l T_c) - j\gamma_{k,L-l-1}] \quad (2)$$

where P is the transmitted power, ω is the carrier frequency, $b_k(t)$ is the differentially encodes data stream for user k consisting of a train of i.i.d. data bits with duration T which take the value of ± 1 with equal probability. The current bit is denoted by b_k^0 while next or previous bits are denoted by adding or subtracting the superscripts by 1. $a_k(t)$ is the ZCD spreading code of user k with chip duration T_c and code length $N = T/T_c$.

In the proposed system, it is assumed that the number of multipaths, L does not exceed $L_{ZCD}=\frac{ZCD+1}{2}$. The ZCD is defined by $ZCD=2\Delta-1$ where Δ is a chip-shift increment [3].

The normalizing factor U_k that keeps the instantaneous transmitted power constant is given by

$$U_k=\sum_{n=0}^{L-1}\beta_{k,n}^2 \tag{3}$$

Assuming a CDMA system with K users, the received signal at user1 in downlink is given by

$$r_1(t)=\mathrm{Re}\sum_{k=1}^{K}\sum_{j=0}^{L-1}s_k(t-jTc)\beta_{1,j}\exp(j\gamma_{1,j})+n(t) \tag{4}$$

where $n(t)$ is the zero mean AWGN with two sided power spectral density $\frac{N_0}{2}$. From Eq.(4), we can see that channel output includes $2L-1$ paths with a strong peak when $j+l=L-1$ and just one MF is needed to synchronize to this path.

The output of user1 MF is given by

$$\begin{aligned}Z=&\int_{(L-1)T_c}^{(L-1)T_c+T}r_1(t)a_1[t-(L-1)T_c]\\&\cdot\cos[wt-wT_c(L-1)]dt\\=&D+S+A+\eta\end{aligned} \tag{5}$$

where S is the self interference due to multipath, A is the multiple access interference, and η is a zero mean Gaussian r.v with variance $\frac{N_0T}{4}$. D is the desired part for the current bit given by the $k=1$ part of $r_1(t)$ and $j+l=L-1$ in Eq.(5).

After some manipulation, D is given by

$$D=\sqrt{\frac{P}{2}}b_1^0T\sqrt{U_1} \tag{6}$$

3. Self interference

This interference exists in a single user system and is caused by the multipath. From Eq.(2) and Eq.(4), S is found by putting $k=1$ and $j+l\neq L-1$. S can be written by

$$\begin{aligned}S=&\sqrt{\frac{P}{2U_1}}\sum_{j=0}^{L-1}\sum_{m=0,\neq j}^{L-1}\beta_{1,j}\beta_{1,m}\\&\cdot\cos[wT_c(j-m)+\gamma_{1m}-\gamma_{1,j}]\\&\cdot\int_0^T b_1[t-(j-m)T_c]a_1[t-(j-m)T_c]a_1(t)dt\end{aligned} \tag{7}$$

where

$$\begin{aligned}&\int_0^T b_k[t-(j-m)T_c]a_k[t-(j-m)T_c]a_1(t)dt\\&=\begin{cases}T_c[b_k^{-1}C_{k,1}(N-m+j)+b_k^0C_{k,1}(j-m)],(j-m)\geq 0\\T_c[b_k^0C_{k,1}(j-m)+b_k^{+1}C_{k,1}(N-m+j)],(j-m)<0\end{cases}\end{aligned} \tag{8}$$

In Eq.(8), $C_{k,1}$ is the discrete aperiodic cross-correlation function. Denoting $C_{1,1}(j-m)$ by $C_1(j-m)$ and utilizing $C_1(j-m)=C_1(m-j)$, we can get

$$\begin{aligned}S=&T_c\sqrt{\frac{P}{2U_1}}\sum_{j=0}^{L-2}\sum_{m=j+1}^{L-1}\beta_{1,j}\beta_{1,m}\\&\cdot\cos[wT_c(j-m)+\gamma_{1,m}-\gamma_{1,j}]\\&\cdot[b_1^{-1}C_1(N-m+j)+b_1^{+1}C_1(N-m+j)+2b_1^0C_1(m-j)]\end{aligned} \tag{9}$$

Taking the second moment of Eq.(9) we can get

$$\begin{aligned}E[S^2|\beta_{1,l}]=&\frac{PT^2_c}{2U_1}\sum_{j=1}^{L-2}\sum_{m=j+1}^{L-1}\beta_{1,j}^2\beta_{1,m}^2\\&\cdot E[C_1^2(N-m+j)+2C_1^2(m-j)]\end{aligned} \tag{10}$$

4. Multiple Access interference

The multiple access interference A is due to other users is found by the $k>1$ part of $r_1(t)$ in Eq.(4). The interference is given by

$$\begin{aligned}A=&\frac{\sqrt{P}}{2}\sum_{k=2}^{K}\sum_{j=0}^{L-1}\sum_{m=0}^{L-1}\beta_{1,j}\frac{\beta_{,k,m}}{\sqrt{U_k}}\cos[\omega T_c(j-m)+\gamma_{k,m}-\gamma_{1,j}]\\&\cdot\int_0^T b_k[t-(j-m)T_c]a_k[t-(j-m)T_c]a_1(t)dt\end{aligned} \tag{11}$$

For orthogonal codes, Eq.(11) can be written as

$$\begin{aligned}A=&\sqrt{\frac{P}{2}}\sum_{k=2}^{K}\sum_{j=0}^{L-2}\sum_{m=j+1}^{L-1}\frac{T_c}{\sqrt{U_k}}\\&\cdot\{\beta_{1,j}\beta_{k,m}\cos[wT_c(j-m)+\gamma_{k,m}-\gamma_{1,j}]\\&\cdot[b_k^0C_{k,1}(j-m)+b_k^{+1}C_{k,1}(N+j-m)]\\&+\beta_{1,m}\beta_{k,j}\cos[wT_c(m-j)+\gamma_{k,j}-\gamma_{1,m}]\\&\cdot[b_k^{-1}C_{k,1}(m-j-N)+b_k^0C_{k,1}(m-j)]\}\end{aligned} \tag{12}$$

The second moment of Eq.(12) is given by

$$E[A^2|\beta_{1,l}] = \frac{PT_c^2 Q}{4}\sum_{k=2}^{K} \cdot \left\{\sum_{j=0}^{L-2}\sum_{m=j+1}^{L-1}\beta_{1,j}^2[C_{k,1}^2(j-m)+C_{k,1}^2(N+j-m)] + \sum_{j=0}^{L-2}\sum_{m=j+1}^{L-1}\beta_{1,m}^2[C_{k,1}^2(m-j-N)+C_{k,1}^2(m-j)]\right\} \tag{13}$$

where Q is given for all k by

$$Q = Q_{k,j} = E\left[\frac{\beta_{k,j}^2}{U_k}\right] = \frac{1}{L}, \quad j=0,1,2,\cdots,L-1 \tag{14}$$

5. SINR

In the conventional Pre-Rake TDD-CDMA system, MAI and MPI exist in the received signal. The variance of the interference components are given by Eq.(10) and Eq.(13) where the expected values for the correlation functions are given by Eq.(15), which determines the performance of the Pre-Rake CDMA system.

$$\begin{aligned} &E\left[C_i^2(m)\right] = N-|m|, \quad \text{for } m \neq 0 \\ &E\left[C_{k,i}^2(m)\right] = N-|m| \\ &E\left[C_{k,i}(m)C_{k,i}(n)\right] = 0, \quad \text{for } m\neq n,\ k\neq i \end{aligned} \tag{15}$$

On the other hand in the proposed system, ZCD code with 2 GI is utilized for spreading code so that the expected value of Eq.(15), can be written as follows,

$$\begin{aligned} &E\left[C_i^2(m)\right] = 0, \quad \text{for } m \neq 0 \\ &E\left[C_{k,i}^2(m)\right] = 0 \\ &E\left[C_{k,i}(m)C_{k,i}(n)\right] = 0, \quad \text{for } m\neq n,\ k\neq i \end{aligned} \tag{16}$$

In the proposed system, it is assumed that $L \le L_{ZCD}$ so that the channel output with $2L-1$ paths does not exceed ZCD. This results in zero correlation among different multipath CDMA signals. Applying Eq.(16) to Eq.(10) and Eq.(13), the interferences (MPI and MAI) of the proposed system becomes zero and the signal to interference and noise ratio (SINR) Y can be given by

$$Y = \left[\frac{L}{\overline{r_b}U_1}\right]^{-1} \tag{17}$$

where $\overline{r_b}$ is the average received signal to noise ratio. Y can be obtained by $Y = \frac{D^2}{2\,Var(Z)}$ where $Var(Z)$ is the variance of the Gaussian r.v. Z in Eq.(5). Therefore, the probability of error conditioned on $\{\beta_{1,m}\ ,\ m=0,1,2,\cdots, L-1\}$ is given by

$$P(e\,|\beta_{1,m}) = \frac{1}{2}\mathrm{erfc}(\sqrt{Y}) \tag{18}$$

Ⅳ. Simulation Results

Computer simulations have been carried out to evaluate the proposed system performance by using C program. Simulation parameters are shown in Table 1. TDD is utilized as a duplex method and 1 time slot has 0.667ms long. In this paper, the binary ZCD code with 32 chips (spreading factor=32) whose family size is 6 and zero correlation duration is 5 [3], is employed.

Table 1. Simulation Parameters

Wirelss Access Scheme	TDD-CDMA
Time slot length	0.667ms
Spreading code	ZCD binary code ZCD ternary code (Spreading Factor=32),
Transmit chip rate	3.84 Mcps
Transmit data rate	120 kbps
Uplink channel estimation	Perfect
No. of paths	3, 4 Rayleigh fading (1 chip delay, equal path gain)
Modulation	BPSK
Max. Doppler frequency	32Hz
Channel coding/decoding	Uncoded

Fig. 3 shows the BER performance of the proposed Pre-Rake CDMA with binary ZCD codes under the condition of 3 paths. We also performed computer simulation for the proposed system with ternary ZCD code with 32 chips whose family size is 8 and zero correlate duration is 5. The simulation result is depicted in Figure 4.

In contrast with the conventional Pre-Rake system, the BER performance of the proposed system does not degrade for any number of users ($\le$ 6) and is almost same as with the MRC (Maximal Ratio Combining) diversity combining. This implies that the proposed system is not subject to the MAI and MPI, i.e., interference-free, due to the inherent continuous orthogonal property of the ZCD spreading code employed.

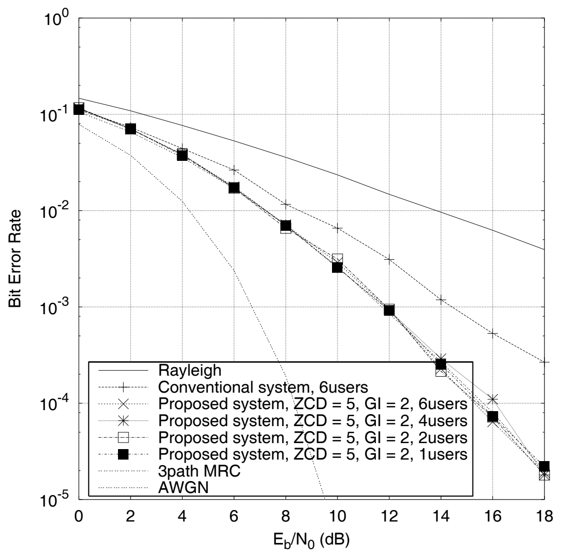

Fig 3. BER performance of the proposed system with binary ZCD code for 3-path environment

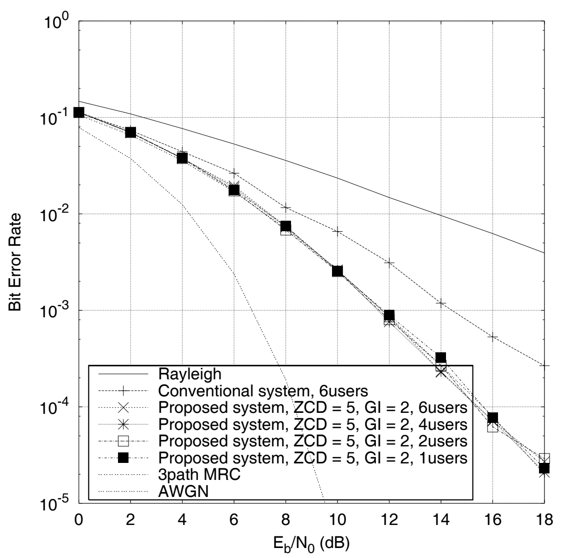

Fig 4. BER performance of the proposed system with ternary ZCD code for 3-path environment

Even though the interferences can be removed perfectly by inserting the sufficient GI, the increased GI deteriorates the efficiency of frequency use. Therefore, we consider three ZCD codes (original ZCD code, modified ZCD code with 1 GI, and modified ZCD code with 2 GI) shown in figure 5. As being expected the correlation is no longer zero for the original ZCD code and the modified ZCD code with 1 GI since the ZCD codes are corrupted by adjacent codes containing different data bit.

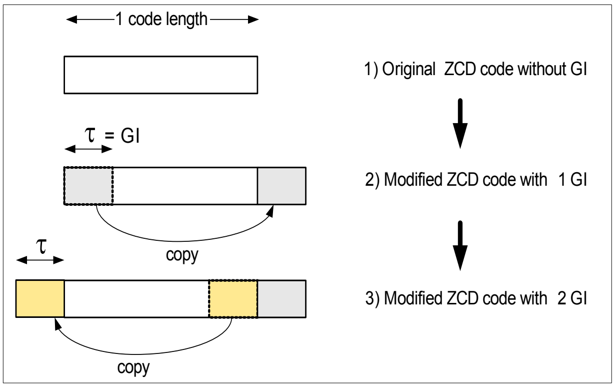

Fig 5. GI adding process and modified ZCD codes

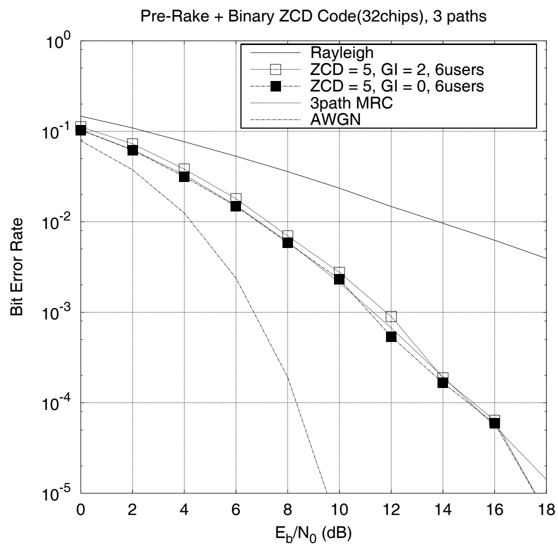

Fig 6. BER performance of the proposed system with binary ZCD code for 3-path environment

Fig. 6 shows the performance for binary ZCD code under the condition of 3 paths. In lower E_b/N_0 the BER performance of the modified ZCD code with 2 GI is slightly worse than that of the original ZCD code. With GI the modified code length is longer than the original code one which results in the power loss and the degradation of the BER performance. However, in higher E_b/N_0 there is no difference of performance between two codes.

Fig.7 shows the performance of ternary ZCD code for 8 users under the condition of 4 paths. The same ZCD code (ZCD = 5) shown in Fig. 5 is employed so that the channel output exceeds the ZCD ($L > L_{ZCD}$), which results in MIP and MUI. From the figure we can see that the relative performances of ZCD code without GI and with 2 GI have a crossing point around 15 dB.

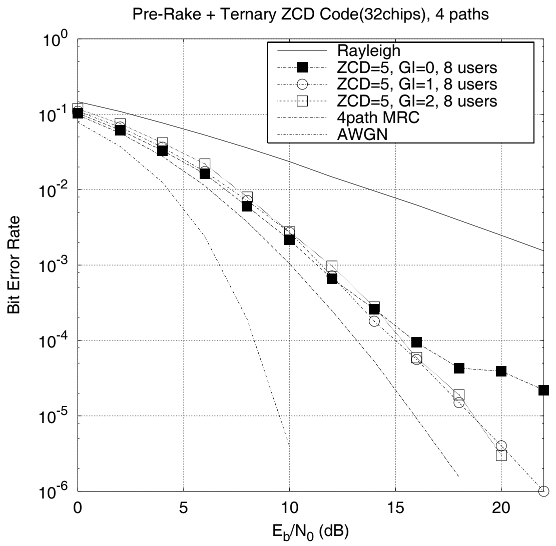

Fig 7. BER performance of the proposed system with ternary ZCD code for 4-path environment

Ⅴ. Conclusion

A Pre-Rake TDD-CDMA system with ZCD spreading code has been proposed to overcome the problem of the conventional Pre-Rake system severely affected by its increased multipath interference. From the simulation results, it is found that the BER performance of the proposed Pre-Rake TDD-CDMA system using binary/ ternary ZCD spreading code with 32 chips does not degrade when up to 6 users (8 users for ternary code) are allowed to be simultaneously active in the network under 3-path environment and the proposed system perfectly achieves the MRC diversity effect without causing any other interference to other users in the given conditions. Modified ZCD codes have been proposed for the Pre-Rake system and the performances have been evaluated by computer simulation under the condition that the channel output exceeds ZCD. From the simulation result it is found that there is crossing point between the performances of the ZCD codes with GI and without GI.

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