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A STUDY ON DETERMINING THE REFERENCE SPREADING SEQUENCES FOR A DS/CDMA COMMUNICATION SYSTEM

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ABSTRACT

In a direct sequence/code division multiple access (DS/CDMA) system, the role of the spreading sequences (codes) is crucial since the multiple access interference (MAI) is the main performance limitation. In this study, we propose an accurate criterion which enables the determination of the reference spreading codes which yield lower bit error rates (BER's) in a given code set for a DS/CDMA system using despreading sequences weighted by stepping chip waveforms. The numerical results show that the spreading codes determined by the proposed criterion are the most suitable codes for using as references.

Key Words : DS-CDMA, Weighted despreading sequences, Optimal code selection

BİR DOĞRUDAN DİZİLİ/KOD BÖLMELİ ÇOKLU ERİŞİM HABERLEŞME SİSTEMİ İÇİN DAYANAK YAYMA DİZİLERİNİN BELİRLENMESİ ÜZERİNE ÇALIŞMA

ÖZET

Çoklu erişim girişimi, bir doğrudan dizili/kod bölmeli çoklu erişim (DD/KBÇE) sisteminin başarımını sınırlayan temel etkidir ve yayma dizilerinin (kodlarının) bu etki üzerindeki rolü oldukça önemlidir. Bu çalışmada, adım kırmık ağırlıklandırma dalgaformlarıyla ağırlıklandırılmış toparlama dizileri kullanan bir DD/KBÇE sistemi için verilen bir kod seti içerisinde daha düşük bit hata oranları oluşturan dayanak yayma kodlarının belirlenmesine hizmet eden bir kriter önerilmektedir. Nümerik sonuçlar, önerilen kritere göre belirlenen yayma kodlarının, dayanak olarak kullanılmaya en uygun kodlar olduğunu göstermektedir.

Anahtar Kelimeler : DD-KBÇE, Ağırlıklandırılmış toparlama dizileri, En iyi kod seçimi

1. INTRODUCTION

DS/CDMA is a spread spectrum technique for simultaneously transmitting a number of signals representing information messages from a multitude of users over a channel employing a common carrier. The method by which the various users share the channel is the assignment of a unique pseudonoise (PN)-type code to each user with orthogonal-like properties (Alouini et al., 2001; Çiftlikli et al., 2001). In a DS/CDMA system with perfect power control, the major limitation in performance, and hence capacity, is due to multipath fading and MAI. Based on a noise whitening approach, a simple structure called the integral equation receiver was proposed in (Monk et al., 1994). The integral equation receiver employs a despreading function, which is the solution of a Fredholm integral equation of the second kind and consists of $2N^2$ exponential terms with $N(2N+1)$, where N is the processing gain.

Based on the property that the despreading function given in (Monk et al., 1994) emphasizes the transitions in the received signal of the reference user for MAI rejection, it is proposed to weight the despreading sequence by stepping chip weighting waveforms (Huang and Ng, 1999). This leads to easy tuning of the despreading function in practice to achieve the best performance. Despite of the success of the weighted despreading waveforms for the purpose of MAI rejection, there is no methodology to indicate the most appropriate spreading codes to use as references in a given code set.

In this study, we propose a simple criterion to determine the reference spreading codes which achieve better BER performances than other codes in a given code set for a DS/CDMA system that use despreading sequences weighted by stepping chip waveforms. For the purpose of this study, we are assumed that the receiver is perfectly capable of regenerating the transmitted codes corresponding to each of the users transmissions and as such we are ignored all synronization issues dealing with the acquisition and tracking of these codes at the receiver. In addition, it is also assumed that the number of spreading codes which provide good cross-correlation properties in a given code set are more than the number of active users.

2. SYSTEM MODEL

The system under consideration is based on the model described in (Huang and Ng, 1999). Suppose there are K DS/CDMA users accessing the channel. User k transmits a data sequence $b_k(t)$ and employs a spreading sequence $a_k(t)$ to spread each data bit. The spreading and data signals for the kth user are given by

$$a_k(t) = \sum_{j=-\infty}^{\infty} a_j^{(k)} P_{T_c}(t - jT_c) \,,$$

$$b_k(t) = \sum_{j=-\infty}^{\infty} b_j^{(k)} P_{T_b}(t - jT_b) \qquad (1)$$

Where T_c and T_b are the chip and data durations, respectively, and $P_x(y) = 1$, for $0 < y < x$, and $P_x(y) = 0$ otherwise. It is assumed that there are N chips of a spreading spreading sequence in the interval of each data bit T_b and the spreading sequence has period equal to N. The transmitted signal for the kth user is

$$S_k(t) = \sqrt{2P} b_k(t) a_k(t) \cos(\omega_c t + \theta_k) \qquad (2)$$

Where the transmitted power P and the carrier frequency ω_c are common to all users, and θ_k is the phase angle of the kth transmitter. Thus, the received signal $r(t)$ at the base station can be represented as

$$r(t) = \sum_{k=1}^{K} \sqrt{2P} b_k(t - \tau_k) a_k(t - \tau_k) \cos(\omega_c t + \phi_k) + n(t) \qquad (3)$$

Where K denotes the number of active users. The random time delays and phases along the communication links between the K transmitters and the receiver are denoted by τ_k and ϕ_k ($= \theta_k - \omega_c \tau_k$) for $1 \le k \le K$, respectively. The ambient channel noise $n(t)$ is modeled as an additive white Gaussian noise (*AWGN*) process with two-side spectral density $N_0 / 2$. The random variables τ_k and ϕ_k are independent of one another and uniformly distributed in $[0, T_b]$ and $[0, 2\pi]$, respectively.

Based on the definition given in (Huang and Ng, 1999), the weighted despreading sequence for the kth receiver is given by,

$$\hat{a}_k(t) = \sum_{j=-\infty}^{\infty} a_j^{(k)} m_j^{(k)}\left(t - jT_c \middle| \left\{c_j^{(k)}, c_{j+1}^{(k)}\right\}\right) P_{T_c}(t - jT_c) \qquad (4)$$

Where,

$c_j^{(k)} = a_{j-1}^{(k)} a_j^{(k)}$ and $m_j^{(k)}\left(t \middle| \left\{c_j^{(k)}, c_{j+1}^{(k)}\right\}\right)$, for $0 \le t \le T_c$, is the jth chip weighting waveform for the kth receiver, conditioned on the status of three consecutive chips $\left\{a_{j-1}^{(k)}, a_j^{(k)}, a_{j+1}^{(k)}\right\}$. Each $c_j^{(k)}$ is a random variable which indicates whether or not the next element of the kth spreading signal is the same as the preceding element. ($c_j^{(k)} = -1$ *if* $a_{j-1}^{(k)} \ne a_j^{(k)}$ and $c_j^{(k)} = 1$ *if* $a_{j-1}^{(k)} = a_j^{(k)}$). The jth chip conditional weighting waveform for the kth receiver is defined as

$$m_j^{(k)}\left(t \middle| \left\{c_j^{(k)}, c_{j+1}^{(k)}\right\}\right) = \begin{cases} m_1(t) & \text{if } c_j^{(k)} = +1 \text{ and } c_{j+1}^{(k)} = +1 \\ m_2(t) & \text{if } c_j^{(k)} = -1 \text{ and } c_{j+1}^{(k)} = -1 \\ m_3(t) & \text{if } c_j^{(k)} = -1 \text{ and } c_{j+1}^{(k)} = +1 \\ m_4(t) & \text{if } c_j^{(k)} = +1 \text{ and } c_{j+1}^{(k)} = -1 \end{cases} \qquad (5)$$

Where $m_p(\mathrm{t})$ for $p \in [1, 2, 3, 4]$ are the chip weighting waveforms. The elements of the chip weighting waveforms vector $\{m_1(t), m_2(t), m_3(t), m_4(t)\}$ given by the following:

$$
\begin{aligned}
m_1(t) &= L(\varepsilon)P_{T_c}(t) \\
m_2(t) &= P_{T_c}(t) - [1 - L(\varepsilon)]P_{T_c - 2T_\Delta}(t - T_\Delta) \\
m_3(t) &= P_{T_\Delta}(t) + L(\varepsilon)P_{T_c - T_\Delta}(t - T_\Delta) \\
m_4(t) &= L(\varepsilon)P_{T_c - T_\Delta}(t) + P_{T_c}(t) - P_{T_c - T_\Delta}(t)
\end{aligned}
\tag{6}
$$

Where $T_\Delta \in (0, T_c / 2]$, $\varepsilon = T_c / T_\Delta \in [2, \infty)$ is a parameter of the stepping chip weighting waveforms. The $L(\varepsilon) \in [0,1]$ is a monotonically decreasing function of ε and for ease of implementation, it is defined as $L(\varepsilon)=[C(\varepsilon/2-1)+1]^{-1}$, where the constant C is chosen equal to 10. Assuming that user i is the reference user ($\tau_i = 0$ and $\phi_i = \theta_i - \omega_c \tau_i = 0$) based on the definitions in (Huang and Ng, 1999), the conditional $SINR_i$ conditioned on $\{c_j^{(i)}\}$, is given by,

$$
SINR_i = \left\{ \frac{\varepsilon\left[2\chi + (\varepsilon - 2\chi)L^2(\varepsilon)\right]}{2\kappa_b\left[2\chi + (\varepsilon - 2\chi)L(\varepsilon)\right]^2} + \frac{(K-1)\,\Xi(\Gamma^{\{c_j^{(i)}\}}, \varepsilon)}{2\varepsilon N\left[2\chi + (\varepsilon - 2\chi)L(\varepsilon))\right]^2} \right\}^{-1} \tag{7}
$$

Where $E_b = PT_b$, $\kappa_b = E_b / N_0$, $\chi = \hat{N}_i / N$. $\hat{N}_i$, is a random variable which represents the number of times of occurrence that $c_j^{(i)} = -1$ for all $j \in [0, N-1]$. $\Xi(\Gamma^{\{c_j^{(i)}\}}, \varepsilon)$ in the eqn. (7) is given by,

$$
\begin{aligned}
\Xi\left(\Gamma^{\{c_j^{(i)}\}}, \varepsilon\right) = \frac{1}{N}\Bigg\{ & \Gamma^{(i)}_{\{-1,-1,-1\}}\left[\frac{(\varepsilon-2)^2(4+\varepsilon)L^2(\varepsilon)}{3} + \frac{8}{3} + 16\left(\frac{\varepsilon}{4} - \frac{1}{2}\right)L(\varepsilon)\right] + \\
& \left(\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}\right)\left[\frac{5}{3} + \left(3\varepsilon - \frac{16}{3}\right)L(\varepsilon) + \left(\frac{\varepsilon^2}{3} - 3\varepsilon + \frac{11}{3}\right)L^2(\varepsilon)\right] + \\
& \left(\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}\right)\left[\frac{1}{3} + \left(\varepsilon - \frac{2}{3}\right)L(\varepsilon) + \left(\varepsilon^3 - \varepsilon + \frac{1}{3}\right)L^2(\varepsilon)\right] + \\
& \Gamma^{(i)}_{\{-1,1,-1\}}\left[\frac{2}{3} + 2\left(\varepsilon - \frac{2}{3}\right)L(\varepsilon) + \left(\varepsilon^3 - 2\varepsilon + \frac{2}{3}\right)L^2(\varepsilon)\right] + \\
& \Gamma^{(i)}_{\{1,-1,1\}}\left[\frac{2}{3} + \left(2\varepsilon - \frac{8}{3}\right)L(\varepsilon) + \left(\frac{\varepsilon^2}{3} - 2\varepsilon + 2\right)L^2(\varepsilon)\right] + \varepsilon^3 L^2(\varepsilon)\Gamma^{(i)}_{\{1,1,1\}}\Bigg\}
\end{aligned}
\tag{8}
$$

Where $\Gamma^{(i)}_{\{\nu_1,\nu_2,\nu_3\}}$ is the number of times of occurrence that $\{c_{j-1}^{(i)}, c_j^{(i)}, c_{j+1}^{(i)}\} = \{\nu_1, \nu_2, \nu_3\}$ for all j in the ith user's spreading sequence and each v_n, $n \in [1, 2, 3]$, takes values +1 or –1 with equal probabilities. It is worth noting that the parameter ε of the stepping chip weighting waveforms should be tuned with respect to each signal to noise ratio, κ_b, so as to maximize the $SINR_i$ (Huang and Ng, 1999; Çiftlikli et al., 2001a).

3. BIT ERROR RATE ANALYSIS

The key objective of this section is to illustrate the BER performance of the *i*th user's receiver, when different spreading codes are employed as a reference, sequentially. It is assumed that the number of spreading codes in a given set of spreading codes are twenty-five ($i \in [1, 25]$). The spreading codes belong to the code set were chosen from a Gold code set of length $N = 63$ for their good cross-correlation properties (Kärkkäinen and Leppänen, 2000). In Table 1, we present the number of $\Gamma^{(i)}_{\{\nu_1,\nu_2,\nu_3\}}$ and $\hat{N}_i$ for the each code selected. It is worth to noting that the information's given in Table 1 correspond to each spreading code in the selected code set. Figure 1 shows the BER performance of the *i*th user's receiver, when some codes given in Table 1 are used as a reference.

Table 1. Number of $\Gamma^{(i)}_{\{\nu_1,\nu_2,\nu_3\}}$ and $\hat{N}_i$ for the Each Selected Code ($N = 63$)

code (i)	$\Gamma^{(i)}_{(-1,-1,-1)}$	$\Gamma^{(i)}_{(-1,-1,1)} + \Gamma^{(i)}_{(1,-1,-1)}$	$\Gamma^{(i)}_{(-1,1,1)} + \Gamma^{(i)}_{(1,1,-1)}$	$\Gamma^{(i)}_{(-1,1,-1)}$	$\Gamma^{(i)}_{(1,-1,1)}$	$\Gamma^{(i)}_{(1,1,1)}$	$\hat{N}_i$
1	2	12	20	6	10	13	24
2	4	8	24	4	12	11	24
3	8	8	16	4	8	19	24
4	6	12	20	2	6	17	24
5	2	20	12	14	10	5	32
6	8	16	16	8	8	7	32
7	10	20	12	6	2	13	32
8	6	20	12	10	6	9	32
9	8	16	16	8	8	7	32
10	6	20	12	10	6	9	32
11	14	12	12	6	6	13	32
12	10	12	20	6	10	5	32
13	4	16	16	12	12	3	32
14	6	12	12	14	14	5	32
15	8	16	8	12	8	11	32
16	6	12	20	10	14	1	32
17	10	12	12	10	10	9	32
18	4	24	16	8	4	7	32
19	12	16	16	4	4	11	32
20	16	16	8	12	8	3	40
21	18	20	12	6	2	5	40
22	12	24	8	12	4	3	40
23	14	20	12	10	6	1	40
24	20	16	16	4	4	3	40
25	16	16	8	12	8	3	40

Several points can be made from Figure 1. First, it is apparent that especially in relative high κ_b (> 15 dB), where the BER's are mostly caused by the MAI, the minimum BER's will be achieved by using the code which have the highest number of $\hat{N}_i$. A second and important point is although the number of $\hat{N}_i$ of some codes are equal to each other, the BER performance of the *i*th user's receiver is not almost the same. After some elaboration on Figure 1, it is

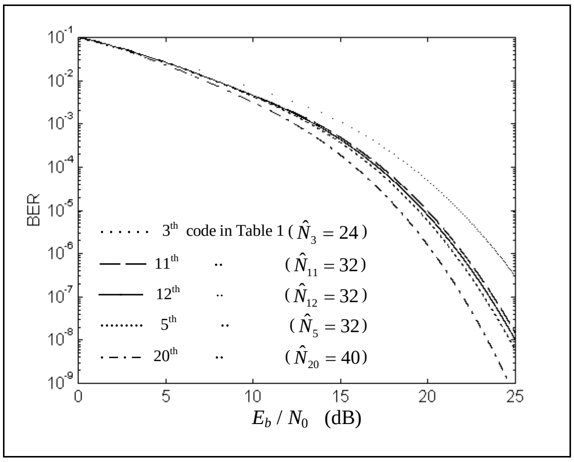

Figure 1. Performance comparison of the *i*th user's receiver using different spreading codes as references when N = 63 and K = 9

thought that the more appropriate codes are selected as references, the better BER performances might be achieved. It is worth to noting that the $SINR_i$ expression given by eqn. (7) should be solved for each code in a given code set with the $\Xi\left(\Gamma^{\left\{c_j^{(i)}\right\}}, \varepsilon\right)$ which has an apparent complexity to determine the reference spreading codes.

4. PROPOSED CRITERION

To derive a simple criterion enables to determine the reference spreading codes in a given code set; the *code* (*5*), *code* (*6*) and *code* (*7*) given in Table 1 are selected as references. The aim to select those codes was their close BER performance achievements as shown in Figure 2. Eqn. (8) can be rearranged as

$$\Xi\left(\Gamma^{\left\{c_j^{(i)}\right\}}, \varepsilon\right) = \frac{1}{N}\Big\{A(\varepsilon)\Gamma^{(i)}_{\{-1,-1,-1\}} + B(\varepsilon)\left(\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}\right) + C(\varepsilon)\left(\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}\right) + D(\varepsilon)\Gamma^{(i)}_{\{-1,1,-1\}} + E(\varepsilon)\Gamma^{(i)}_{\{1,-1,1\}} + F(\varepsilon)\Gamma^{(i)}_{\{1,1,1\}}\Big\} \tag{9}$$

Where $A(\varepsilon)$, $B(\varepsilon)$, $C(\varepsilon)$, $D(\varepsilon)$, $E(\varepsilon)$ and $F(\varepsilon)$ are the expressions in front of the elements of the $\Gamma^{(i)}_{\{-1,-1,-1\}}$, $\left[\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}\right]$, $\left[\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}\right]$, $\Gamma^{(i)}_{\{-1,1,-1\}}$, $\Gamma^{(i)}_{\{1,-1,1\}}$ and $\Gamma^{(i)}_{\{1,1,1\}}$ in eqn. (8), respectively.

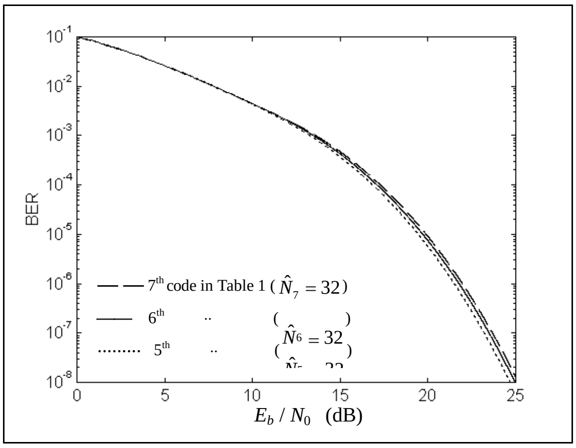

Figure 2. BER of the *i*th user's receiver using spreading codes have equal number of $\hat{N}_i$ when N = 63 and K = 9

For the sake of presentation simplicity, let

$$\Xi^{(5)} = \Xi\left(\Gamma^{\left\{c_j^{(5)}\right\}}, \varepsilon\right) \qquad \Xi^{(6)} = \Xi\left(\Gamma^{\left\{c_j^{(6)}\right\}}, \varepsilon\right)$$

$$\Xi^{(7)} = \Xi\left(\Gamma^{\left\{c_j^{(7)}\right\}}, \varepsilon\right) \tag{10}$$

For further elaboration, the relations among the $\Xi^{(6)}/\Xi^{(7)}$, $\Xi^{(5)}/\Xi^{(7)}$ and $\Xi^{(5)}/\Xi^{(6)}$, were observed versus the parameter, ε, as shown in Figure 3. If the *i*th user's receiver is accepted to be tuned to the same value of the parameter, ε_t, for these three different codes it is obvious that the best receiver performance would be achieved by using the reference code which would make the smallest $\Xi^{(i)}$ contribution, and the lowest performance would be achieved by using the code as reference which would make the highest contribution to the $SINR_i$ expression. On the basis of this fact, we could conclude that the performance situation shown in Figure 2 for these three codes can be achieved only with the ε_t value (or values) which would perform the following condition

$$\Xi^{(5)} \langle \Xi^{(6)} \langle \Xi^{(7)} \tag{11}$$

It is clear from Figure 3 that $\Xi^{(6)}$ is greater than $\Xi^{(7)}$ for ε_t values selected from an interval, $2 \le \varepsilon_t < 2.4$, before the crossing point at $\varepsilon_c \cong 2.4$. For this reason, the condition given by eqn. (11) can not be met.

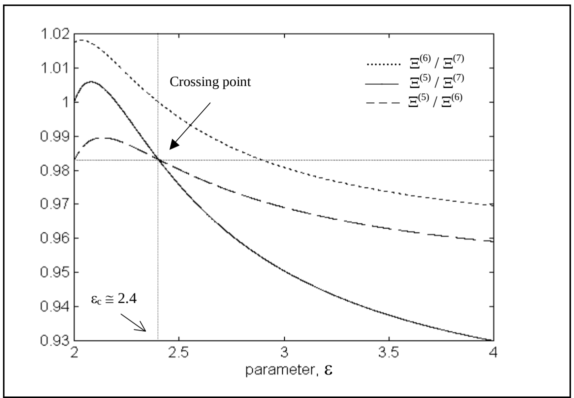

Figure 3. $\Xi^{(6)}/\ \Xi^{(7)}$, $\Xi^{(5)}/\ \Xi^{(7)}$ and $\Xi^{(5)}/\ \Xi^{(6)}$ against the parameter ε and the crossing point, ε_c.

To express more precisely, the differences among $\Xi^{(7)} - \Xi^{(5)}$, $\Xi^{(6)} - \Xi^{(5)}$ and $\Xi^{(7)} - \Xi^{(6)}$ are plotted versus the parameter in Figure 4. It is obvious that when ε_t is chosen from an area between ε_1 and ε_2, marked on Figure 4, where the derivation of $\Xi^{(7)} - \Xi^{(6)}$ is zero, the difference between $\Xi^{(7)}$ and $\Xi^{(6)}$ would be maximum and also the difference between $\Xi^{(7)}$ and $\Xi^{(5)}$ would be sufficiently large.

$$\frac{d}{d\varepsilon}\left(\Xi^{(7)} - \Xi^{(6)}\right) = 0 \ \text{ and } \ \frac{d}{d\varepsilon}\left(\Xi^{(7)} - \Xi^{(5)}\right) \cong 0 \quad (12)$$

Another important point is the values of $\Xi^{(6)}$ are greater than $\Xi^{(5)}$ values in this interval as shown in Figure 4. After these observations, there is no doubt that the condition given by eqn. (11) would satisfy.

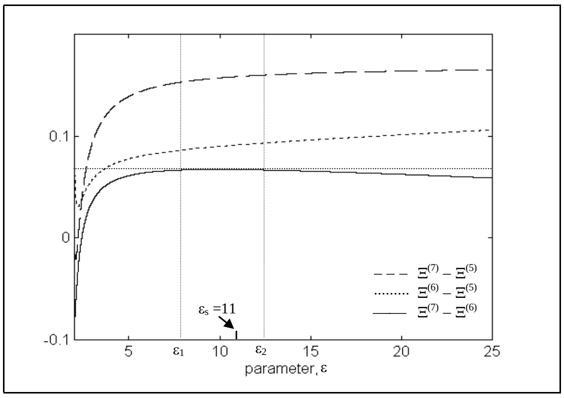

Figure 4. $(\Xi^{(7)} - \Xi^{(5)})$, $(\Xi^{(6)} - \Xi^{(5)})$ and $(\Xi^{(7)} - \Xi^{(6)})$ versus the parameter ε and the estimated ε_s.

It is assumed a criterion might help to determine the reference spreading codes achieving lower BER's for a DS/CDMA (Anon.,) system is given by

$$\Psi^{(i)}\left(\Gamma^{(i)}_{\{v_1,v_2,v_3\}}\right) = \boldsymbol{a}\,\Gamma^{(i)}_{\{-1,-1,-1\}} + \boldsymbol{b}\left(\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}\right) + \boldsymbol{c}\left(\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}\right) + \boldsymbol{d}\,\Gamma^{(i)}_{\{-1,1,-1\}} + \boldsymbol{e}\,\Gamma^{(i)}_{\{1,-1,1\}} + \boldsymbol{f}\,\Gamma^{(i)}_{\{1,1,1\}}$$
(13)

where; $\boldsymbol{a} = A(\varepsilon = \varepsilon_s)$, $\boldsymbol{b} = B(\varepsilon = \varepsilon_s)$, $\boldsymbol{c} = C(\varepsilon = \varepsilon_s)$, $\boldsymbol{d} = D(\varepsilon = \varepsilon_s)$, $\boldsymbol{e} = E(\varepsilon = \varepsilon_s)$, $\boldsymbol{f} = F(\varepsilon = \varepsilon_s)$ and ε_s is a specific value of ε. The crucial step in obtaining ε_s is to estimate an appropriate value for the *i*th user's receiver to be tuned. Based on the interval outlined above, we have chosen the value of ε_s as 11. The value of ε_s was chosen from this interval, arbitrary.

The criterion with the determined coefficient values in eqn. (13) can be rewritten as

$$\Psi^{(i)}\left(\Gamma^{(i)}_{\{v_1,v_2,v_3\}}\right) = 3.64\,\Gamma^{(i)}_{\{-1,-1,-1\}} + 2.27\left(\Gamma^{(i)}_{\{-1,-1,1\}} + \Gamma^{(i)}_{\{1,-1,-1\}}\right) + 1.18\left(\Gamma^{(i)}_{\{-1,1,1\}} + \Gamma^{(i)}_{\{1,1,-1\}}\right) + 1.73\,\Gamma^{(i)}_{\{-1,1,-1\}}$$

$$+\ 1.28\,\Gamma^{(i)}_{\{1,-1,1\}} + 0.63\,\Gamma^{(i)}_{\{1,1,1\}} \quad (14)$$

5. TESTING THE CRITERION AND RESULTS

If the number of active users is less than the total number of codes in a given code set, the determination process of the reference codes (most suitable codes for using in assignment) should be realized by the steps given below based on the results of the proposed criterion, $\Psi^{(i)}$:

i) First, begin with the code group which have the largest value of $\hat{N}_i$. If the number of the active users is less than the number of codes in this group, select the spreading codes which have *lowest* $\Psi^{(i)}$ values.
ii) If the number of the active users are more than the number of the codes in this group, follow the same procedure given above for the next group which has a $\hat{N}_i$ value closest to previous until there are no user waiting for assignment.

Table 2 shows the most appropriate codes which are determined by using the criterion, and the exact P_e 's with κ_b fixed at 20 dB of all the spreading codes in the code set (given by Table 1) when they were used as references, separately.

The probability of error P_e is defined as

$$P_e = Q(\sqrt{\max[SINR_i]})$$
$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp(-t^2/2)dt \qquad (15)$$

where max[$SINR_i$] is the maximum value of $SINR_i$.

In Table 2, the *code* (*i*) with (×) must be selected as references to achieve lower BER's when K = 15. As expected, the optimal code in a code group has the lowest value of $\Psi^{(i)}$. Because it is also possible to achieve the same BER performances with some different codes, such as the *code* (*6*) and *code* (*15*), the priority of such codes is equal on condition that identical cross-correlation properties. It should be noticed finally that the P_e 's given in Table 2 precisely prove the accuracy of the determination process based on the criterion presented in this work.

Table 2. Testing the Accuracy of the Proposed Criterion When $\kappa_b = E_b/N_0$ = 20 dB and K=15

Code Groups	code (i)	$\Psi^{(i)}$	Most suitable codes According to $\Psi^{(i)}$ (K = 15)	Exact (P_e) ($\times 10^{-7}$)
$\hat{N}_i = 24$	1	89.5		35
	2	90.2		36
	3	95.3		47
	4	94.5		45
$\hat{N}_i = 32$	5	107.0	×	5.6
	6	112.8		7.4
	7	117.0		9.0
	8	112.0	×	7.2
	9	112.8	×	7.4
	10	112.0	×	7.2
	11	118.6		9.5
	12	113.5		7.6
	13	107.7	×	5.8
	14	108.5	×	6.0
	15	112.8	×	7.4
	16	108.5	×	6.0
	17	113.5		7.6
	18	111.2	×	6.9
	19	117.8		9.2
$\hat{N}_i = 40$	20	136.8	×	1.6
	21	141.1	×	1.8
	22	135.3	×	1.4
	23	136.1	×	1.5
	24	141.9	×	1.9
	25	136.8	×	1.6

6. CONCLUSION

In this paper, we introduced a simple and efficient approach to determine the spreading codes which should be used as references in a given code set to yield better BER performances for a DS/CDMA system using despreading sequences weighted by stepping chip waveforms. The effects of the spreading codes on the receiver performance are determined before the code assignment process provides the flexibility of the selection of the codes with a high performance when the number of the users is less than the total number of the codes in a given code set. Because the criterion presented in this study is independent from *N*, it can be safely used for the other code sets have different values of *N*.

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