Performance Improvement of Multiuser DS-CDMA with Carrier Interferometry Codes in Frequency Selective Fading Channels

Yeon-Ho Chung, *Member, KIMICS*

Abstract—DS-CDMA is now a matured multiple access technology that utilizes spreading codes for user separation. In this paper, we attempt to improve the performance of a multiuser DS-CDMA system with a unique chip shaping code called Carrier Interferometry (CI) code. The CI codes exhibit an excellent correlation property that can be used in many applications. In DS-CDMA with CI codes (CI/DS-CDMA), the symbols are spread by a spreading code and then the chip signals are shaped using a CI code. Due to the correlation property of the CI code, a diversity gain from the shaped chip signals is achieved and the performance of DS-CDMA is significantly improved. Comparison study demonstrates that the DS-CDMA with CI outperforms the conventional DS-CDMA system in multiuser environments.

Index Terms—Multiuser, DS-CDMA, Performance, Frequency Selective Fading

I. INTRODUCTION

A DS-CDMA system has now emerged as one of the most successful terrestrial cellular systems. The rake reception and despreading process in a DS-CDMA receiver provide robust multipath fading and interference suppression. However, as the data rate increases, the channel tends to be frequency selective because the message bandwidth exceeds the coherence bandwidth. In order to overcome this adverse effect, a multicarrier transmission scheme receives much attention, due to the fact that it can effectively combat frequency selectivity as the data is simultaneously transmitted using a number of narrowband carriers [1]. In this scheme, the transmitted symbols undergo frequency nonselective fading. Recently, a CI code has been proposed and this code can be applied for enhancing the present wireless communication systems [2,3]. The CI codes provide both performance improvement and enhanced capacity via the excellent correlation property. In particular, a large number of orthogonal and pseudo-orthogonal codes are available. This paper considers the performance improvement of DS-CDMA with the CI codes. In CI/DS-CDMA, we allocate a CI code or a time shifted version of the CI code to each chip, instead of conventional chip shaping with rectangular waveforms. In this way, orthogonality between chips is ensured and the frequency diversity effect is thus obtained when the CI shaped chips are optimally combined together before despreading. This leads to performance improvement of CI/DS-CDMA, in comparison with existing DS-CDMA systems.

Section 2 describes the definition and characteristics of CI codes and CI/DS-CDMA is depicted in Section 3. Simulation results are presented in Section 4 and conclusions are drawn in Section 5.

II. CARRIER INTERFEROMETRY CODES

The CI code is defined as a superposition of N carriers separated by Δf [2,3]:

$$\begin{aligned} p(t) &= \sum_{n=0}^{N-1} A\cos\left(n2\pi\Delta ft\right) \\ &= \frac{\sin\left(\frac{N2\pi\Delta ft}{2}\right)}{\sin\left(\frac{2\pi\Delta ft}{2}\right)}\cos\left(\frac{(N-1)2\pi\Delta ft}{2}\right) \end{aligned} \tag{1}$$

Δf is typically set to be $1/T_b$, where T_b is the bit duration. The CI code has one mainlobe, which occurs at the time of $1/\Delta f$, and a number of sidelobes. The correlation function of p(t) is found to be:

$$\begin{aligned} R(\tau) &= \frac{1}{\Delta f}\sum_{n=0}^{N-1}\cos(2\pi n\Delta f\tau) \\ &= \frac{1}{\Delta f}\frac{\sin\left(N\pi\Delta f\tau\right)}{\sin\left(\pi\Delta f\tau\right)}\cos\left(\pi(N-1)\Delta f\tau\right) \end{aligned} \tag{2}$$

From (2), it is readily found that there are a large number of zeros. That is, zero correlation occurs at the following values:

$$\tau = \begin{cases} \dfrac{n}{N\Delta f}, & n = 0,1,\ldots, N-1 \\ \dfrac{2n-1}{2(N-1)\Delta f}, & n = 0,1,\ldots, N-1 \end{cases} \tag{3}$$

Thus, there are 2N-1 zeros when N is odd, and 2N-3 zeros when N is even.

Manuscript received February 18, 2004.

This work was supported by Grant No. R05-2002-000-00424-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

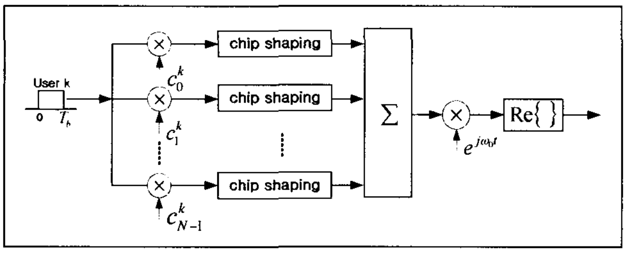
Y. H. Chung is with the Department of Information and Communications, Pukyong National University, Busan, Korea (e-mail: yhchung@pknu.ac.kr)

III. DS-CDMA WITH CI CODES

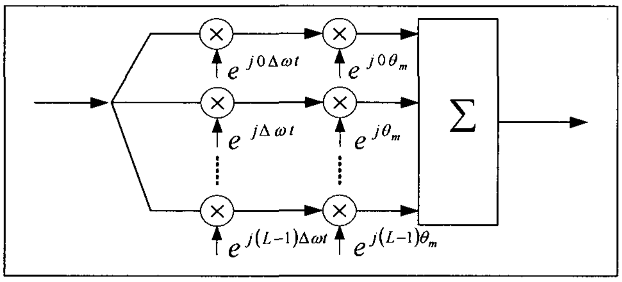
The main idea of the DS-CDMA with CI codes is to shape each chip, so that orthogonality exhibits between chip signals within bit duration and subsequently a frequency diversity gain is attained. That is, in CI/DS-CDMA, the transmitted signal of the user k is expressed as

$$s^k(t)=d_k\sum_{i=0}^{N-1}c_i^k p(t-iT_c),\quad t\in[0,\mathrm{T_b}) \tag{4}$$

where d_k is the user k's data (+1, -1 in BPSK), c_i^k is the i^th^ value of the spreading code of the user k and p(t-iT$_c$) is the CI code used as a chip shaping code.



(a) Transmitter of CI/DS-CDMA for the user k
(N: the length of a spreading code)



(b) m^{th} chip shaping (L: the number of subcarriers)

Fig. 1 DS-CDMA with CI.

When (1) is substituted in (4), we have

$$s^k(t)=d_k\sum_{i=0}^{N-1}c_i^k\sum_{n=0}^{N-1}\cos\left(2\pi n\Delta f(t-iT_c)\right) \tag{5}$$

Figure 1(a) shows the transmitter of CI/DS-CDMA for the user k. Assuming that there are K users in the system, (5) becomes

$$S(t)=\sum_{k=0}^{K-1}d_k\sum_{i=0}^{N-1}c_i^k\sum_{n=0}^{N-1}\cos\left(2\pi n\Delta ft-ni2\pi/N\right) \tag{6}$$

By shaping each chip signal with a CI code, it will undergo a flat fading. Due to the CI's correlation property, frequency diversity effect will yield. The received signal is then expressed as

$$r(t)=\sum_{k=0}^{K-1}d_k\sum_{i=0}^{N-1}c_i^k\sum_{n=0}^{N-1}\alpha_n\cos\left(2\pi n\Delta ft-ni2\pi/N+\phi_n\right) + n(t) \tag{7}$$

where α_n and ϕ_n are the channel fade and phase of n^th^ subcarrier, respectively and n(t) represents additive white Gaussian noise.

As shown in Figure 1(b), in CI/DS-CDMA, the m^th^ chip signal is separated into its N subcarrier components. Figure 2 shows the configuration of CI/DS-CDMA receiver. In the receiver, the shaped chip signals are passed into the individual chip receivers where a reverse operation to the one shown in Figure 1(b) is performed. Through a normal DS-CDMA despreading, a received data is detected. The decision variable for the n^th^ subcarrier within the m^th^ chip signal at the receiver is given by

$$r_{m,n}=\sum_{k=0}^{K-1}d_k\sum_{i=0}^{N-1}c_i^k\alpha_n\cos\left(nm2\pi/N-ni2\pi/N\right) + n_{m,n} \tag{8}$$

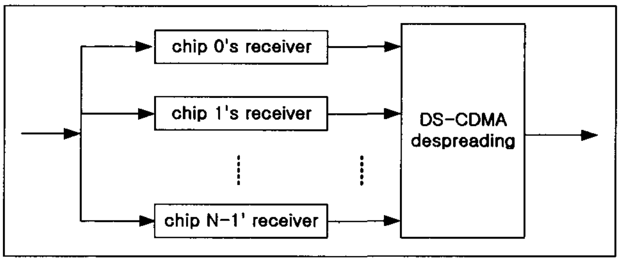
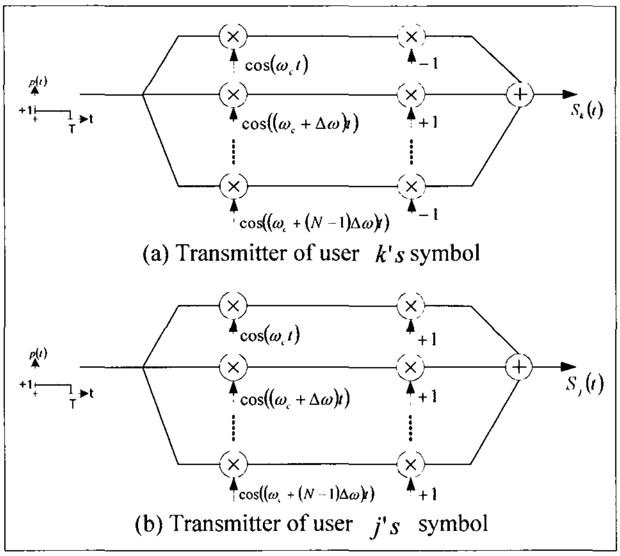


Fig. 2 The CI/DS-CDMA receiver.

In order to obtain a frequency diversity gain from the decision variables at the receiver, an efficient combining technique needs to be used. For multicarrier transmission schemes, a Minimum Mean Square Error Combining (MMSEC) technique is found to outperform other combining technologies[1]. Therefore, the identical MMSEC combining technique to the one described in the reference 1 is applied in the present evaluation. It can be said that, unlike DS-CDMA, the present scheme produces a frequency diversity gain through this combining scheme which contributes the performance improvement of a DS-CDMA system.

A. Comparison of CI/DS-CDMA and other multicarrier transmission schemes

The CI/DS-CDMA system differs from other multicarrier transmission schemes, e.g. multicarrier CDMA (MC-CDMA). MC-CDMA is designed to address a fundamental issue of system capacity in terms of the number of simultaneous users by allocating an orthogonal or pseudo-orthogonal code to each user. In addition, each chip in MC-CDMA is transmitted on a single subcarrier, whereas each chip signal in CI/DS-CDMA is transmitted on all available subcarriers, thus making the most of existing subcarriers. Figure 3 shows a multicarrier CDMA transmission scheme. Although the CI codes can be applied to MC-CDMA for further increasing system capacity, CI/DS-CDMA is aimed at reducing interchip interference from both the other chips and users by shaping each chip orthogonally and is thus aimed at improving the performance.



(a) Transmitter of user k's symbol

(b) Transmitter of user j's symbol

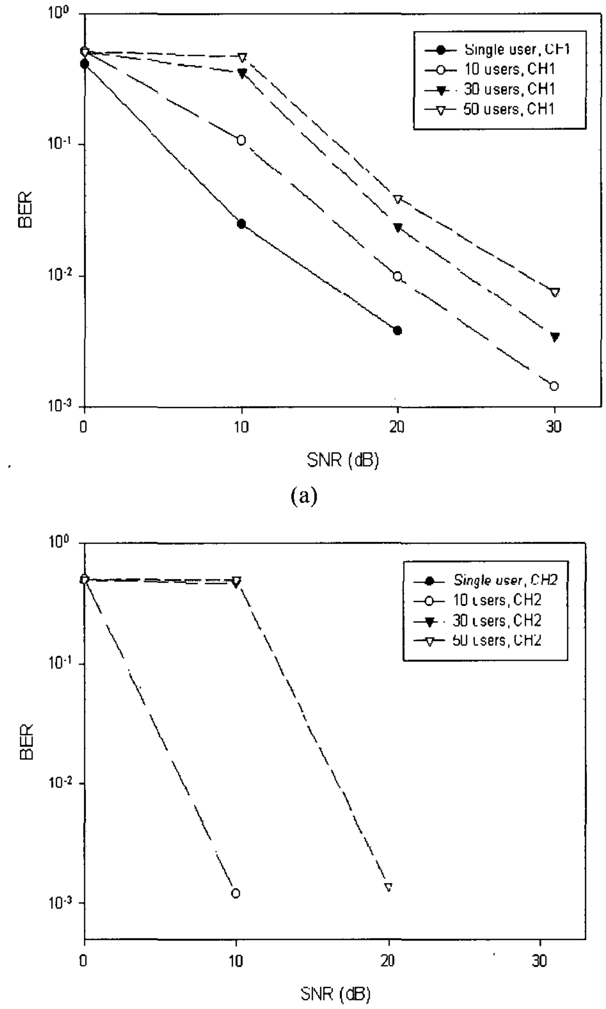
Fig. 3 MC-CDMA schemes.

IV. SIMULATION RESULTS

Computer simulations were undertaken to confirm the performance improvement via the CI codes. For the present study, two channel models with 6 taps are employed for the performance evaluation; JTC Urban Low-Rise B (CH1)[4] and UMTS Indoor Office (CH2)[5]. The delay spreads for CH1 and CH2 are found to be 4 μ and 0.035 μsec. The simulation was performed with the following parameters; a carrier frequency of 1.8 GHz, a chip rate of 6.4 Mcps and a mobile speed of 20km/h. For user separation, the Hadamard-Walsh code was employed with a processing gain of 64 and a synchronous downlink transmission as well as exact phase synchronization was assumed. Figure 4(a) and 4(b) show the BER performances of CI/DS-CDMA relative to the number of users for CH1 and CH2, respectively. It can be seen that the performance for CH2 having a smaller channel delay is significantly better than the one for CH1. Figure 5 shows the performance of the conventional DS-CDMA for CH1 and comparison reveals that the CI shaped DS-CDMA system outperforms the conventional DS-CDMA system. Figure 6 shows the performance variation of CI/DS-CDMA with respect to the number of subcarriers employed. The performance tends to degrade as the number of carriers used for chip shaping is reduced. The reason for this phenomenon is that if we use the carriers less than the number of synchronous users, then the performance is degraded and prone to be saturated, due to the fact that the MMSEC combining no longer produces an optimum result. We can also observe that when the number of carriers used is greater than the number of users, the performance is significantly improved.

V. CONCLUSIONS

In this paper, the CI chip shaping technique is applied to a DS-CDMA system and its BER performance is evaluated and compared with the performance of DS-CDMA in multiuser environments. Comparison of the results shows that the proposed CI/DS-CDMA system offers a significant performance improvement over a traditional DS-CDMA system. Hence, this scheme can be useful to enhance the present DS-CDMA systems.



(a)

(b)

Fig. 4 BER performance of CI/DS-CDMA for CH 1 (a) and CH 2 (b).

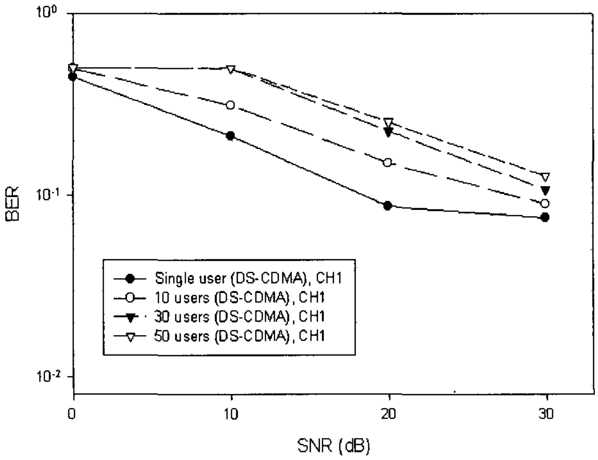


Fig. 5 BER performance of DS-CDMA for CH 1.

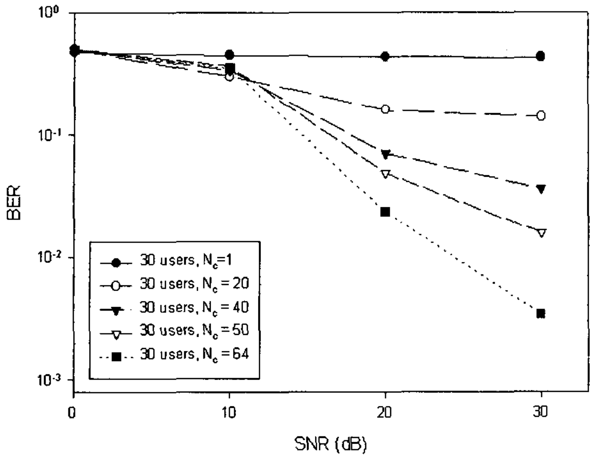


Fig. 6 BER performance of multiuser CI/DS-CDMA relative to the number of subcarriers.
(N_c : NUMBER OF SUBCARRIERS)

ACKNOWLEDGMENT

This work was supported by Grant No. R05-2002-000-00424-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

REFERENCES

[1] Hara, S. and Prasad, R., "Overview of multicarrier CDMA", IEEE Comm. Mag. Vol.35, No.12, pp. 126-137, Dec.1997.

[2] Nassar, C.R., Natarajan, B. and Shattil, S., "Introduction of carrier interference to spread spectrum multiple access", Wireless Communications and Systems 2000, Emerging Technologies Symposium, pp. 4.1-4.5, 1999.

[3] Natarajan, B., Nassar, C.R, Shattil, S., Michelini, M. and Wu Z., "High-performance MC-CDMA via carrier interferometry codes", IEEE Trans. VT, Vol.50, Nov. 2001.

[4] JTC (AIR), Radio System Characterization for the Proposed IS-95 Based CDMA PCS Standard

[5] UMTS 30.03 version 3.2.0, Annex B, ETSI R 101 112 V3.2.0, April 1998.

Yeon-Ho Chung
Received the BEng. degree in Electronic Engineering from Kyungpook National University, Daegu, Korea, in 1984, MSc. degree in Communications and Signal Processing from the Imperial College, the University of London, U.K., in 1992 and Ph.D. degree in Electrical Engineering and Electronics from the University of Liverpool, U.K., in 1996. During his study in UK, he worked as a Research Assistant. He was also a technical consultant for Freshfield Communications Ltd. UK in 1994, in the field of the design of mobile radio networks and mobile radio channel characterization. He has now been working as an assistant professor in the Division of Electronics, Computers and Telecommunication, Pukyong National University, Busan, Korea. His research interests include multicarrier transmission, adaptive modulation and coding system, carrier interferometry codes, SPW-based performance estimation and hardware implementation.