Relative Capacity of the Spectrum-Overlapped DS-CDMA System using the Lanczos Chip Waveform

Dong-Hun Lee · Heung-Gyoon Ryu

Abstract

Performance improvement of the DS-CDMA system by the spectrum-overlap is important for better service quality or more system capacity. In this paper, an analysis for capacity improvement is newly considered when the Lanczos chip waveform is used for the spectrum-overlapped DS-CDMA system. RC(relative capacity) is the ratio of the capacity of overlapping system to that of non-overlapping system, which is used for the expression of the capacity improvement. The optimal overlapping ratio is numerically found to make the maximum capacity improvement. When the rectangular chip waveform is used for the overlapping system, maximum capacity improvement is increased by about 10 % at the required BER = 10^{-3} and the optimal overlapping ratio is 1.23. When the 95 % power bandwidth is considered for the Lanczos chip waveform, maximum capacity improvement is increased by 34.4 % at overlapping ratio of 1.55 when the required BER is 10^{-3}. The lower required BER for the better communication quality makes gradually smaller capacity improvement.

Key words : relative capacity, spectrum overlapping, chip waveform, DS-CDMA and Lanczos waveform.

Ⅰ. Introduction

Larger DS processing gain makes the information signal more robust in interference channel. If the channel bandwidths of each cell are expanded in DS-CDMA system, it becomes partially overlapped with adjacent channels. Then, both the positive DS processing gain and the negative adjacent channel interference (ACI) are simultaneously increased. Capacity improvement by spectrum overlap has been widely investigated[1]. The overlapping technique cannot be applicable to the TDMA and FDMA except CDMA. In the DS-CDMA a channel bandwidth is wide and all users in a cell use the same wide channel bandwidth at the time. It is important to resolve the trade-offs and to find the optimum overlap ratio for the maximum system capacity. In DS-CDMA, there have been some researches on the capacity improvement using a partially spectrum-overlapped technique between adjacent channels[1][3]. However, these were mostly focused on only chip waveform with minimum interference in a single-cell DS-CDMA system without the effect of ACI. Particularly, authors of [2] analyzed the error performance of the asynchronous DS-CDMA system with the arbitrary chip waveform under the Gaussian approximation and showed that the system performance mainly depends on the chip waveform when the parameters such as the processing gain or the simultaneous number of users are fixed. As a work of the optimum chip waveform shaping, authors of [3] presented criteria for chip waveform selection and an approach to solution for the case of full-response chip pulse to obtain the optimum chip waveform under its criteria.

To our investigation, however, there is no study on the consideration of the Lanczos chip waveform[4] in the spectrum-overlapped DS-CDMA system. RC(relative capacity) can be defined as the ratio of the capacity of overlapping system to that of non-overlapping system, which is used for the expression of the capacity improvement. In this work, the optimal overlapping ratio is numerically found to make the maximum capacity improvement. The relative capacity improvement is newly analyzed according to the different required BERs for the Lanczos chip waveform in the spectrum-overlapped DS/BPSK-CDMA system. Also, the capacity of overlapping system is compared with that of non-overlapping system according to variations of required BER. It is shown that Lanczos chip waveform considerably increases the capacity of the spectrum-overlapped DS/BPSK-CDMA system.

Ⅱ. Spectrum-Overlapped DS-CDMA System

Fig. 1 shows the distribution of the overlapped power spectra. Overlapping ratio, α , is defined as

$$\alpha = \frac{W}{W_s} \tag{1}$$

Manuscript received October 16, 2001 ; revised March 14, 2002.
Dept. of Electronic Engineering and Research Institute of Computer, Information & Communication, Chungbuk National University, Chungbuk, Korea.

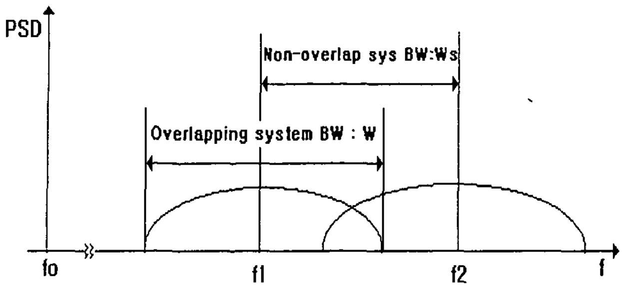

Fig. 1. Distribution of power spectra.

where W and W_s are DS spread bandwidths of the overlapping and non-overlapping system, respectively..

Due to the channel overlapping, ACI is introduced into the desired channel from both adjacent channels as follows:

$$\Delta I = \Delta I_L + \Delta I_R \tag{2}$$

where C ΔI_L and ΔI_R are ACIs caused by the left and right adjacent channels, respectively. Since both processing gain and ACI are increased proportionally to overlapping ratio, α, maximum system capacity can be obtained by controlling the overlapping ratio.

Generally, *SINR*(signal-to-interference plus noise power ratio) [5] can be written as

$$SINR = \frac{C}{N + \frac{I}{G_p}} \tag{3}$$

where C is a carrier power per user, N is an AWGN power, I is a total interference power, and G_P is a processing gain. In each cell, it is assumed that the power control is perfect and the carrier power per user, C, is constant. Then, the total channel power, P, is

$$P = MC \tag{4}$$

where M is the number of active users per channel. Since only MAI(multiple access interference) exists in non-overlapping system, the total interference power is as follows.

$$I = (M_1 - 1)C \tag{5}$$

where M_1 is the number of active users per channel in the non-overlapping system. The *SINR* of the non-overlapping system can be given by

$$SINR = \frac{C}{N + \frac{(M_1 - 1)C}{G_{p1}}} \tag{6}$$

where G_{p1} is the processing gain of the non-overlapping system. Thus, the system capacity of the non-overlapping system is expressed as

$$M_1 = \left(\frac{1}{SINR} - \frac{1}{SNR}\right) G_{p1} + 1 \tag{7}$$

where *SNR* is a signal-to-noise ratio.

In the case of overlapping system, the total interference due to ACI is given by

$$I = (M_2 - 1)C + \Delta IM_2 \tag{8}$$

where M_2 is the number of active users per channel in the overlapping system. In the eq. (8) the first and second terms are MAI and ACI of the overlapping system, respectively. Therefore, *SINR* of the overlapping system can be written as

$$SINR = \frac{C}{N + \frac{(M_2 - 1)C + \Delta IM_2}{G_{p1}\alpha}} \tag{9}$$

Thus, the system capacity of the overlapping system is

$$M_2 = \frac{(\frac{1}{SINR} - \frac{1}{SNR}) G_{p1}\alpha + 1}{(\frac{\Delta I}{C} + 1)} \tag{10}$$

From the eqs. (7) and (10), the relative capacity (RC) which means the amount of capacity improvement by spectrum overlapping is expressed as

$$RC = \frac{M_2}{M_1} = \frac{1}{(\frac{\Delta I}{C} + 1)} \frac{\left[\frac{1}{SINR} - \frac{1}{SNR}\right] G_{p1}\alpha + 1}{\left[\frac{1}{SINR} - \frac{1}{SNR}\right] G_{p1} + 1} \tag{11}$$

Since the *SINR* to satisfy the specific BER is fixed whether channel is overlapped or not, the same *SINR* in both systems is used. It is assumed that BPSK modulation is used for this overlapped DS-CDMA system. Then, *SINR* in eq. (11) is the necessary value to get the specific required BER for the BPSK modulation.

Ⅲ. Chip Waveforms

Let's assume that the power of chip waveform limited in [0, T_C] is normalized to be 1 [3]. Then, the energy is defined as

$$\int_0^{T_c} P_{Tc}^2(t)dt = T_c \tag{12}$$

Chip waveforms satisfying the eq. (12) are considered as follows.

a) Raised cosine waveform :

$$P_{T_C}(t)=\sqrt{\frac{2}{3}}\left[1-\cos\left(\frac{2\pi t}{T_c}\right)\right]u(t) \quad (13)$$

b) Lanczos waveform [4]:

$$P_{T_C}(t)=c_3\left[\frac{\sin\left(\frac{2\pi t}{T_c}\right)}{\frac{2\pi t}{T_c}}\right]^2 u(t) \quad (14)$$

where T_C is the period of chip waveform and c_3 is constant ($\sqrt{5.9345}$) to satisfy the normalization condition of the eq. (12).

Ⅳ. Numerical Results and Discussions

At first, both processing gain and *SNR* in the non-overlapping system are assumed to be 20 dB. The carrier power per user, *C* is 0.95 for 95 % power bandwidth since total carrier power is normalized to 1.0. In Fig. 2, the relative capacities of overlapping system for several required BERs are shown when the power of each channel is the same. In case of the required BER=10^{-3}, the optimum overlapping ratio is about 1.23 and the amount of capacity improvement is 10 %. That is, overlapping system can accomodate more users or support better service quality thannon-overlapping system. Also, the smaller capacity improvementis obtained, as the required BER becomes lower. This is because the larger signal-to-noise power ratio isnecessary for better service quality. Hence, the total interference is increased.

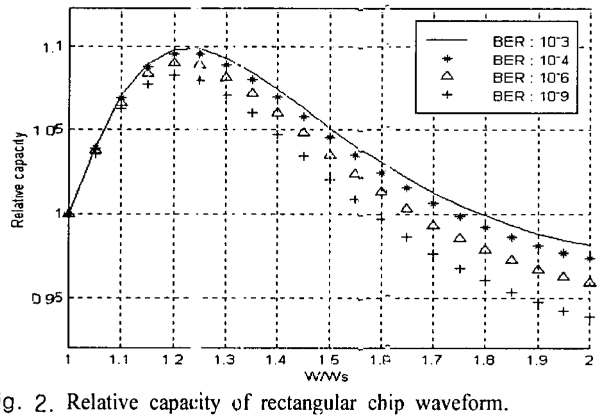

Fig. 2. Relative capacity of rectangular chip waveform.

In Fig. 3 and Fig. 4, the relative capacities are shown for two chip waveforms at three required BERs. In the case of the raised

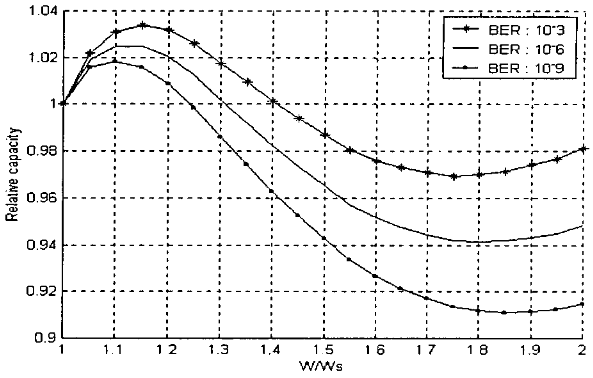

Fig. 3. Relative capacity of raised cosine chip waveform.

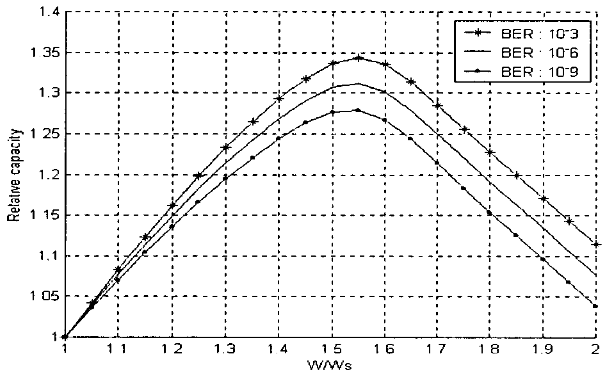

Fig. 4. Relative capacity of Lanczos chip waveform.

cosine chip waveform, maximum relative capacity is 103.4 % at the required BER =10^{-3}. Therefore, capacity improvement is negligible. However, the maximum relative capacity of Lanczos chip waveform is increased by 34.4 % at the optimum-overlapping ratio of 1.55 more than non-overlapping system. In Fig. 4, Lanczos chip waveform always makes the capacity improvement in the overall range of overlapping ratio. The relative capacity gets smaller, as the required BER becomes lower for the better signal quality.

Ⅴ. Conclusion

In this paper, the system capacity improvement by the spectrum overlapping technique is analyzed for several chip waveforms. Optimum overlapping ratio and maximum capacity improvement are found and They are changed to the variation of the required BER. Lower required BER makes smaller capacity improvement for each chip waveform. From the above numerical results and reference[4], Lanczos chip waveform is regarded as a very good candidate for the purpose of system capacity and signal quality improvement in DS-CDMA mobile communication system. Conclusively, it can be easily seen that the amount of capacity improvement depends on both required specific BER and overlapping ratio and the overlapped system can accommodate more users or support better service quality than non-overlapping system.

References

[1] A. Taghol and H. A. Aghvami, "Bandwidth efficiency and capacity estimation of a multi-band W-CDMA system with partial spectral overlap", *VTC 2000 IEEE*, vol. 3, pp. 1768-1772, 2000.

[2] Ha H. Nguyen and E. Shwedyk, "On Error Probabilities of DS-CDMA Systems with Arbitrary Chip Waveforms", *IEEE Communications Letters*, vol. 5, no. 3, pp. 78-80, March 2001.

[3] M. A. Landolsi and W. E. Stark, "DS-CDMA Chip Waveform Design for Minimal Interference Under Bandwidth, Phase, and Envelope Constraints", *IEEE Transactions on Communications*, vol. 47, no. 11, pp. 1737-1746, Nov. 1999.

[4] P. I. Dallas and F. N. Pavlidou, "Innovative Chip waveforms in Microcellular DS/CDMA Packet Mobile Radio", *IEEE Transactions on Communications*, vol. 44, no. 11, pp. 1413-1416, Nov. 1996.

[5] R. E. Ziemer and W. H. Tranter, *Principles of Communications, 4th ed.*, Wiley, pp. 573-576, 1995.

Dong-Hun Lee

was born in Koesan, Korea in 1978. He received the B.S. degree in the department of electrical and electronics engineering from Chungbuk National University in February 2001. He is currently working towards M.S. degree in digital communication system. His research interests also include CDMA communication system, 4G mobile communication systems and nonlinearity analysis in OFDM system.

Heung-Gyoon Ryu

was born in Seoul, Korea on July 10, 1959. He received the B.S. and M.A. and Ph.D. degrees in electronic engineering, Seoul National University, Seoul, Korea in 1982, 1984 and 1989. In February 1988, he joined the Department of Electrical and Electronics Engineering of Chungbuk National University, Korea. He currently is a Porfessor. His research and teaching interests are in the field of digital communication systems, wireless network, circuit design and spread spectrum communication.