Capacity Improvement of DS-CDMA System by Spectrum Overlapping Method between Adjacent Channels

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Abstract

The capacity improvement in the DS-CDMA system can be obtained by allowing spectrum-overlap between adjacent channels. In this paper, an analysis for capacity improvement is newly considered according to the various chip waveforms in the partial spectrum-overlapped DS-CDMA system. Optimum-overlapping ratio is numerically found to obtain maximum capacity improvement for each chip waveform. Assuming the bandwidth containing 95 % of the total power, i.e., 95 % power bandwidth, rectangular chip waveform has the largest capacity improvement in the considered chip waveforms and then the amount of improvement is 136.5 % at overlapping ratio 1.5 for BER = 10^{-3}. Furthermore, as the required BER becomes lower, the capacity improvement gets smaller for all of chip waveforms. For the unequal power channels, it is shown that the larger capacity improvement is achieved as the power of desired channel becomes larger than that of adjacent channels. And the capacity improvement can be obtained even though the desired channel power is lower than the adjacent channel power.

I. Introduction

It is always important to improve system capacity or QoS (quality of service) in digital communication system. In fact, there have been so many papers to research and develop the signal design for high power efficiency and bandwidth efficiency. In DS-CDMA system, all users in a cell occupy the same wide channel bandwidth at the time. An important feature of CDMA is its soft capacity limit. In FDMA and TDMA , the maximum number of users is fixed once the channel bandwidth or the time slots are defined. In CDMA, however, increasing the number of users only gradually or linearly raises the noise floor. In CDMA system, larger DS processing gain makes the information signal more robust in interference channel. If the channel bandwidth of each cell or channel is expanded, it becomes partially overlapped with the adjacent channels. Then, the positive DS processing gain and the negative adjacent channel interference (ACI) are simultaneously increased. In this reason, it is important to resolve the trade-offs and to find the optimal overlapping ratio for the maximum system capacity. In DS-CDMA, there have been some researches on the capacity improvement using a partial spectrum-overlapped technique between adjacent channels [1],[2].

There is no study on the consideration of the various required BER and chip waveforms in the partial spectrum-overlapped DS-CDMA system. In this paper, the relative capacity improvements are novelly analyzed according to the different power level and the several required BER for the various chip waveforms.

II. Spectrum-Overlapped DS-CDMA System

Overlapping ratio, α, is defined as

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

where W and W_s are DS spread bandwidth in overlapping and non-overlapping systems, respectively. From 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 ΔI_L and ΔI_R are ACIs caused by one user from left and right adjacent channels, respectively. Since both processing gain and ACI are increased proportional to overlapping ratio, a, maximum system capacity can be obtained by selecting the appropriate value of overlapping ratio.

Generally, $SINR$(signal-to-interference plus noise power ratio) can be written as [3]

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

where C is a carrier power per user, N is an AWGN power,

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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 multiple access interference (MAI) 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 $SINR$ to get the specific BER in the non-overlapping system can be written as

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

where G_{p1} is the processing gain in the non-overlapping system. Thus, the system capacity in 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 and written as $SNR=C/N$. In the case of overlapping system, the total interference due to ACI is given by

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

where M_2 is the number of active users per channel in the overlapping system. In eq. (8) the first and second terms in the right side are MAI and ACI in overlapping system, respectively.

Therefore, $SINR$ to get the specific BER in the overlapping system can be written as

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

Thus, the system capacity in overlapping system is

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

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

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

Since the $SINR$ to get the specific BER is fixed whether channels is overlapped or not, the same $SINR$ in both systems is used. Furthermore, $SINR$ in eq. (11) is the value to obtain the specific required BER for BPSK modulation.

Ⅲ. Capacity Improvement for Several Chip Waveforms

There are several chip waveforms to be applied into the DS-CDMA system. In this paper, the capacity improvement is analyzed for rectangular and other chip waveforms[4]. Let's assume that the power of chip waveform limited in $[0, T_C]$ is normalized to be 1. Then, the energy is defined as [5]

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

The considered chip waveforms satisfying eq. (12) are considered as following

a) Rectangular

$$P_{Tc}(t) = u(t),$$

$$\text{where} \begin{cases} u(t) = 1 & 0 \le t \le T_c \\ \quad = 0 & otherwise \end{cases} \tag{13}$$

b) Half-Sine

$$P_{Tc}(t) = \sqrt{2}\sin\left(\frac{\pi t}{T_c}\right)u(t) \tag{14}$$

c) Raised Cosine

$$P_{Tc}(t) = \sqrt{\frac{2}{3}}\left[1 - \cos\left(\frac{2\pi t}{T_c}\right)\right]u(t) \tag{15}$$

d) Blackman

$$P_{Tc}(t) = c_1\left[0.42 - 0.5\cos\left(\frac{2\pi t}{T_c}\right) + 0.08\cos\left(\frac{4\pi t}{T_c}\right)\right]u(t) \tag{16}$$

e) Kaiser

$$P_{Tc}(t) = c_2 \frac{I_0\left\{\beta\pi\sqrt{1 - \left[\frac{t - T_c/2}{T_c}\right]^2}\right\}}{I_0(\beta\pi)}u(t) \tag{17}$$

Table 1. Constants c_i to satisfy normalization condition ($T_c = 1$).

Waveform / Constant	Blackman (c_1)	Kaiser (c_2)	Lanczos (c_3)
c_i	1.8119	2.1137 ($\beta = 20$)	$\sqrt{5.9845}$

where β is a real positive number and $I_0(\cdot)$ is the modified Bessel function of the first kind and *zeroth* order.

f) Lanczos

$$P_{Tc}(t) = c_3 \left[\frac{\sin\left(\frac{2\pi t}{T_c}\right)}{\frac{2\pi t}{T_c}} \right]^2 u(t) \tag{18}$$

where T_c is the period of chip waveform and $c_i (i = 1, 2, 3)$ is the constant used for the purpose of satisfying the normalization condition eq. (12).

Table 1 shows the constants, $c_i (i = 1, 2, 3)$ to satisfy the normalization condition and Table 2 is about null-to-null, 90 %, 95 %, 99 %, and 99.9 % channel bandwidth of each chip waveform at $T_c = 1$, respectively. In the case of chip waveforms with high spectral efficiency, ACI is much more increased than the processing gain as the overlapping ratio is increased.

On the other hand, in the case of the chip waveforms with low spectral efficiency, the increasing rate of processing gain is larger than that of ACI and then relatively larger capacity is archived. And it is shown from the numerical results that relative capacity is dependent on the required BER, increase rate of ACI, processing gain, power level of neighboring adjacent channel and defined signal bandwidth.

Ⅳ. Numerical Results and Discussions

It is assumed that processing gain, *SIR*(signal to noise ratio) in both systems are 20 dB and 95 % power bandwidth is used. And the *SINR* to get specific BER for 10^{-3}, $10^{-6}$and 10^{-9} is 6.78 dB, 10.53 dB and 12.55 dB respectively. Since total carrier power is normalized to 1.0 the carrier power per user, C , is 0.95 for 95 % power bandwidth. In Fig. 1 to Fig. 6, the relative capacities of the several chip waveforms for three required BER are shown. In the case of the rectangular chip waveform, the optimum overlapping ratio, a is about 1.5 and then the amount of relative capacity is 136.5 % for required BER $=10^{-3}$. When Lanczos chip waveform is used, the optimum overlapping ratio, a is about 1.55 and then the amount of relative capacity is 134.4 % for required BER = 10^{-3}.

In Fig. 6, Lanczos chip waveform always makes the improvement of the system capacity in overall range of overlapping ratio unlike the other chip waveforms.

Table 3 shows the maximum relative capacities of each chip waveforms for three required BER. The smaller relative capacity is obtained, as the required BER becomes lower. Since the increasing rate of the ACI is reduced in Fig. 2, 3, 4 and 5, the maximum relative capacity is oppositely increased from the overlapping ratio 1.8.

Table 4 shows the maximum relative capacities for various

Table 2. Several channel bandwidths of each chip waveform.

Chip waveform	null-to-null	90 %	95 %	99 %	99.9 %	Notes
Rectangular	1	0.8440	2.0868	10.1662	92.2585	$T_c = 1$
Half-Sine	1.5	0.7725	0.9139	1.1778	2.3842	
Raised Cosine	2	0.9441	1.1255	1.4019	1.7166	
Blackman	2.5	1.1015	1.3143	1.6708	2.0504	
Kaiser	3.5	1.4648	1.7502	2.2821	2.8885	
Lanczos	None	3.1738	6.1283	29.3026	231.8745	

Table 3. Maximum relative capacities of each chip waveforms for three required BER.

BER	Rectangular		Half-Sine		Raised Cosine		Blackman		Kaiser		Lanczos	
	a	RC	a	RC	a	RC	a	RC	a	RC	a	RC
10^{-3}	1.5	136.5 %	1.15	102.7 %	1.15	103.4 %	1.15	103.2 %	1.2	104.1 %	1.55	134.4 %
10^{-6}	1.5	133.5 %	1.15	101.8 %	1.15	102.5 %	1.15	102.3 %	1.15	103.1 %	1.55	131.2 %
10^{-9}	1.5	130.4 %	1.1	101.1 %	1.1	101.8 %	1.1	101.6 %	1.15	102.2 %	1.55	128.0 %

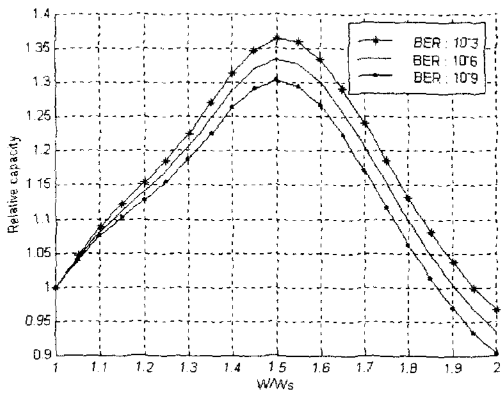

Fig. 1. Relative capacity of rectangular waveform.

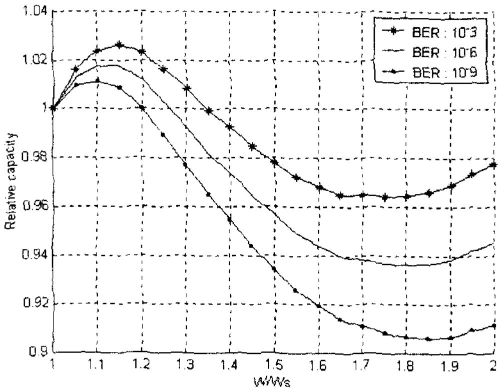

Fig. 2. Relative capacity of half-sine waveform.

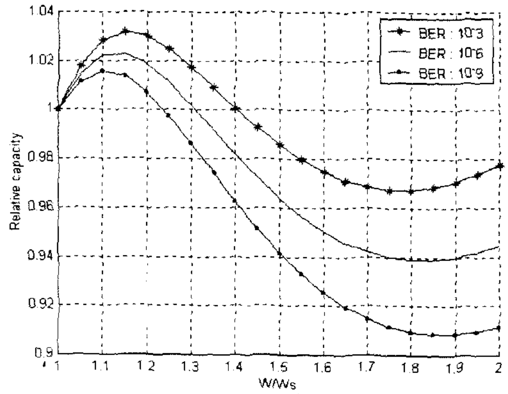

Fig. 3. Relative capacity of raised cosine waveform.

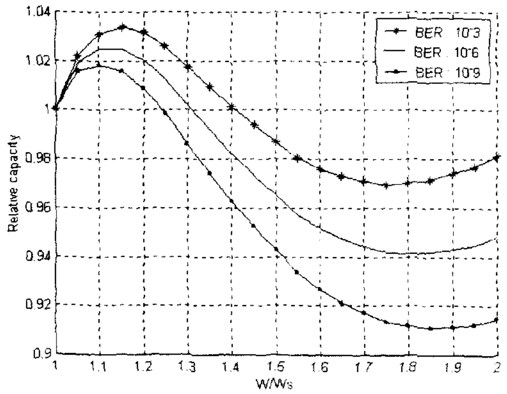

Fig. 4. Relative capacity of Blackman waveform.

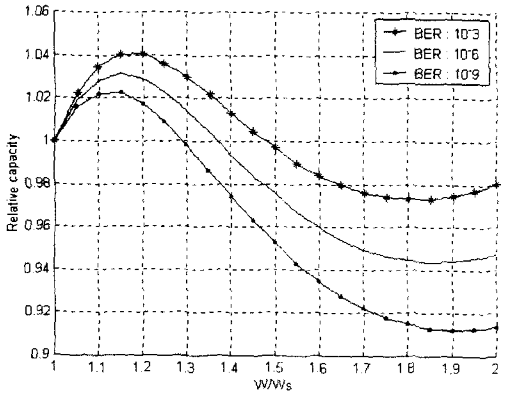

Fig. 5. Relative capacity of Kaiser waveform.

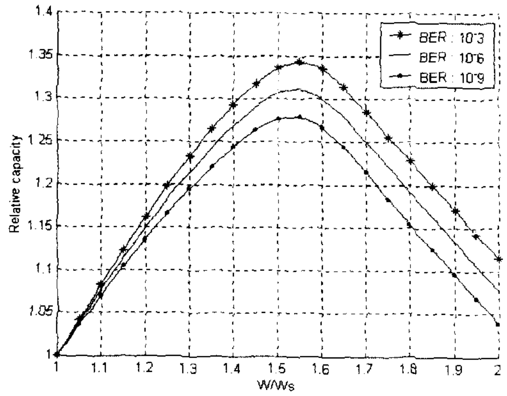

Fig. 6. Relative capacity of Lanczos waveform.

chip waveforms when the power of the adjacent channels is higher than that of desired channel by 1.1, 1.2 and 1.3 times, respectively at the required BER of 10^{-3}. Since the ACI is greatly increased due to the high power level of the adjacent channel, the maximum relative capacity for each chip waveforms is smaller than that of equal power level. However, capacity improvement can be obtained even in this case at certain optimal overlapping ratio.

Table 5 shows the maximum relative capacities for various chip waveforms when the power of the adjacent channel is smaller than that of desired channel by 0.7, 0.8 and 0.9 times, respectively at the same required BER of 10^{-3}. Since the ACI

Table 4. Maximum relative capacities of each chip waveforms when power of adjacent channels has higher than that of desired channel (BER=10^{-3}).

Power	Rectangular		Half-Sine		Raised Cosine		Blackman		Kaiser		Lanczos	
	a	*RC*	*a*	*RC*	*a*	*RC*	*a*	*RC*	*a*	*RC*	*a*	*RC*
1.1 times	1.5	135.5 %	1.1	101.7 %	1.1	102.5 %	1.1	102.2 %	1.15	103.1 %	1.55	132.8 %
1.2	1.5	134.4 %	1.1	101.1 %	1.1	101.9 %	1.1	101.6 %	1.1	102.3 %	1.55	131.3 %
1.3	1.5	133.5 %	1.05	100.7 %	1.05	101.5 %	1.1	101.0 %	1.1	101.8 %	1.5	130.0 %

Table 5. Maximum relative capacities for each chip waveforms when the power of adjacent channels has lower than that of the desired channel (BER=10^{-3}).

Power	Rectangular		Half-Sine		Raised Cosine		Blackman		Kaiser		Lanczos	
	a	RC	a	RC	a	RC	a	RC	a	RC	a	RC
0.7 times	1.55	141.0 %	2	115.0 %	2	115.3 %	2	115.0 %	2	115.2 %	1.6	139.8 %
0.8	1.55	139.0 %	2	108.6 %	2	109.0 %	2	108.6 %	2	108.9 %	1.6	137.7 %
0.9	1.5	137.5 %	2	102.9 %	2	103.3 %	2	102.9 %	2	103.2 %	1.55	136.0 %

is decreased due to the low power level of adjacent channel but the processing gain, the relative capacities for each chip waveform are larger than that of equal power level.

From the combinational evaluation of the above results and reference paper[4], Lanczos chip waveform is considered to be the best one for the purpose of system capacity and signal quality improvement in DS-CDMA mobile radio system.

V. Conclusions

In this paper, the system capacity improvements for various chip waveforms are analyzed when the partial spectrum overlapping technique is used in DS/BPSK CDMA system. From the above numerical results, Lanczos chip waveform is the most proper candidate to apply the spectrum overlapping technique. Also, lower required BER makes smaller capacity improvement for each chip waveform. The larger capacity improvement can be achieved when desired channel has high power than the neighboring adjacent channels. In addition, the capacity improvement can be made even though the desired channel power is lower than the adjacent channel power.

References

[1] F. Behbehani and H. Hashemi, "On spectral efficiency of CDMA mobile radio systems",. *ICC '94*, vol. 1, pp. 505 -509, 1994.

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

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

[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] 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.

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