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Performance Analysis of Groupwise Successive Interference Cancellation Scheme with Groupwise Power Disparities in a DS/CDMA System

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Abstract

In this paper, we analyze the BER performance of Groupwise Successive Interference Cancellation (GSIC) scheme in a DS/CDMA system. Groupwise Power Disparity (GPD) is considered for each group size in order to improve the BER performance of GSIC scheme. The results show that there exists an optimum GPD value that minimizes the average BER performance for a certain number of concurrent users and a certain number of group size. It is demonstrated that the complexity and decoding delay can be greatly reduced by the GSIC scheme, while the BER performance is slightly degraded.

1. Introduction

Recently, wireless communication systems have been greatly developed with the increase of commercial use. Direct Sequence/Code Division Multiple Access (DS/CDMA) is considered as an efficient multiple access method for wireless systems owing to its capacity increase. Several commercial land mobile systems, such as IS-95(A,B), WCDMA and cdma2000, make use of CDMA for their multiple access method [1].

It is a crucial problem that DS/CDMA systems suffers from the interference caused by multiple access users, where the interference is inevitable while the multiple users share the available frequency band during the whole access time. This interference is generally called Multiple Access Interference (MAI). MAI can be mitigated by an accurate power control, sectorization, smart antenna and multiuser detection, and among these techniques multiuser detection schemes have been received great attention in view of their potential for decreasing the MAI, cones - quently, increasing the capacity [2]. In this paper, we focus our discussion on the multiuser detection.

Among the various types and strategies of the multiuser detection techniques, Successive Interference Cancellation (SIC) scheme is specially considered in this paper, because of its ease of implementation compared with optimum and other sub-optimum multiuser detectors. Performance of SIC scheme is extensively researched in literature and it is shown that the SIC scheme can improve the Bit Error Rate (BER) performance of a DS-CDMA system compared with the conventional single-user detection scheme [3-4]. In order to further improve the BER performance, geometric power disparities are considered in the received signal power profile [5], and the optimum geometric power disparities are analyzed in [6].

One drawback of the SIC scheme is that it requires large amount of hardware and delay in order to cancel the MAI sequentially, and because of one-by-one serial cancellation of the SIC scheme it produces large cancellation delay. In [7], the Groupwise SIC (GSIC) scheme is proposed where the interference cancellation is performed as a manner of group-by-group instead of one-by-one. Compared to the SIC scheme, the complexity and decoding delay can be reduced by a factor equal to the group size.

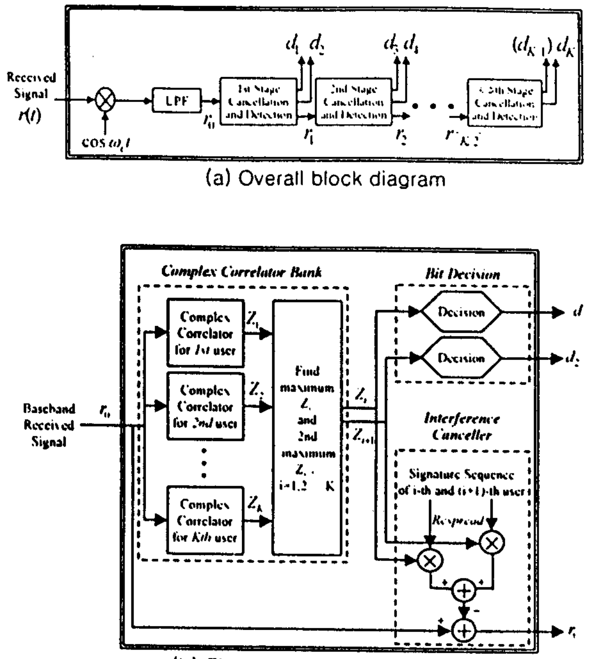
In this paper, we adopt the geometric Groupwise Power Disparity (GPD) in the received signal power profile in order to enhance the BER performance of the GSIC scheme. We investigate the optimum GPD that minimizes the average BER performance for each group size. Finally, we will compare the BER performance of the GSIC scheme with those of the SIC scheme and conventional single-user detection scheme. This paper is organized as follows : In Section 2, we describe the performance analysis of the GSIC scheme with the GPD. Section 3 is devoted to show the numerical analysis results. Finally, we conclude this paper in Section 4.

2. Performance Analysis of GSIC Scheme with Groupwise Power Disparity (GPD)

In this section, we analyze the performance of GSIC scheme in a DS/CDMA system. We consider a typical reverse link of a DS/CDMA system with Binary Phase Shift Keying (BPSK) modulation. The received signal, $r(t)$, at a base station can be represented as follows [4]:

$$r(t)=\sum_{k=1}^{K}\sqrt{2S_k}\,a_k(t-\tau_k)b_k(t-\tau_k)\cos(\omega_c t+\theta_k)+n(t) \quad (1)$$

where K is the number of concurrent users in the system, S_k



(a) Overall block diagram

(b) First cancellation block

Figure 1 Block diagram of GSIC scheme with group size of 2

is the received signal power. a_k is the spreading code, b_k is the information bit, τ_k is the time delay, and θ_k is the phase of the k-th user, respectively, and $n(t)$ is the additive white Gaussian noise (AWGN) with the two-sided power spectral density of $N_0/2$. We assume that the time delay, τ_k, and the received phase, θ_k, of each user are uniformly distributed over $[0,T)$ and $[0,2\pi)$, respectively, where T is the bit period.

In the receiving part of the base station, GSIC scheme is used in order to mitigate MAI. Figure 1 (a) shows the overall block diagram of GSIC scheme with the group size of 2, i.e., 2 users' signals are detected and cancelled in every stage. Received signal, $r(t)$, is down-converted and passes through the low pass filter (LPF), then the baseband signal, r_0, passes though the cancellation and detection blocks until the last user's signal is detected. Figure 1 (b) depicts the first stage of the GSIC scheme, where we assume the group size of 2, i.e., 2 users' signals are cancelled in a single stage. The baseband received signal, r_0, passes through the *Complex Correlator Bank* block. Two signals with higher correlation are selected, then they are detected into binary bit through the *Bit Decision* block. At the same time, they are respread and cancelled out from the received signal in the *Interference Canceller*, so that the signal r_1 is fed into the second cancellation block, where the first and second largest correlation signals are cancelled out.

Signal to Interference plus Noise Ratio (SINR) of the user who is assigned $(j+1)$-th strongest power in the received signal power profile, γ_{j+1}, is represented as [7]:

$$\gamma_{j+1} = \frac{S_{j+1}}{\eta_{j+1}} \qquad (2)$$

where

$$\eta_{j+1} = \frac{1}{6N}\sum_{\substack{k=\delta+1 \\ k\neq j+1}}^{K} S_k + \frac{N_0}{2T} + \frac{1}{6N}\sum_{i=1}^{\delta}\eta_i \qquad (3)$$

In Eq.(3), N is the processing gain, and δ is defined as follows :

$$\delta = \left\lfloor \frac{j}{G_j} \right\rfloor \cdot G_j \qquad (4)$$

In Eq.(4), G_j is the groupwise factor. According to the groupwise factor, G_j, the number of calcelled signal in each cancellation stage is determined. Hence, as discussed in [7], the groupwise factor plays a significant role to determine the performance of the GSIC scheme as well as the reduction of the computational complxity and calcellation delay. In Eq.(3), the first two terms represent the amount of uncancelled interference, the third term represents the AWGN normalized by the bit duration, and the last term represents the remaining interference after cancellations, respectively.

BER of $(j+1)$-th strongest power user, P_e^{j+1}, and the average BER, $P_{e,ave}$, can be evaluated as follows, respectively :

$$P_e^{j+1} = Q\left(\sqrt{\gamma_{j+1}}\right) \qquad (5)$$

$$P_{e,ave} = \frac{1}{K}\sum_{j=0}^{K-1} P_e^{j+1} \qquad (6)$$

By the power control performed between the base station and the mobile users, the received signal power can be controlled to have the following relations :

$$S_{j+1} = \alpha_G^{\left\lfloor \frac{j}{G_j} \right\rfloor} \cdot S_1 \qquad (7)$$

where S_1 and S_{j+1} are the received signal powers of the user who is assigned the largest and $(j+1)$-th strongest received signal power among the K concurrent users, respectively, and α_G is the GPD value, which is assumed to be

$$0 < \alpha_G \leq 1 \qquad (8)$$

In the above equation, the received signal power disparity is identical to the users who belong to same calcellation group. It is notable that the disparity should be bigger than or equal to 1 in order to maintain the detection order, because in the SIC scheme the larger correlation signal is detected first.

3. Numerical Results

In order to analyze the average BER performance of GSIC scheme together with geometric GPD, we assume the following system model : BPSK modulation is used between the base station and users. The received signal power is maintained at the desired level once the power level is determined from Eq.(7). Intercell interference is not considered. E_b/N_0 of the user who is assigned the largest signal power is 15dB. Processing gain is 31 and voice activity is assumed to be 1, so that all users are active during the whole access time.

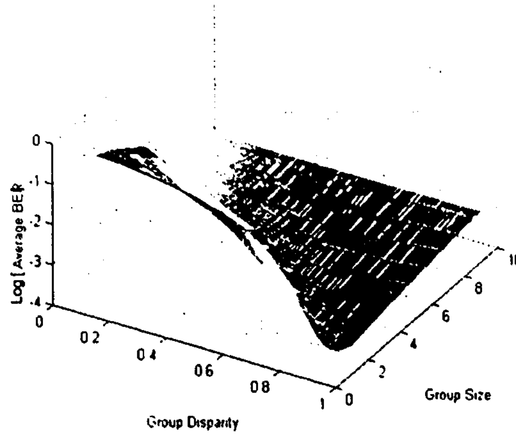


Figure 2. Average BER performance for different group sizes and groupwise disparities under 9 concurrent users

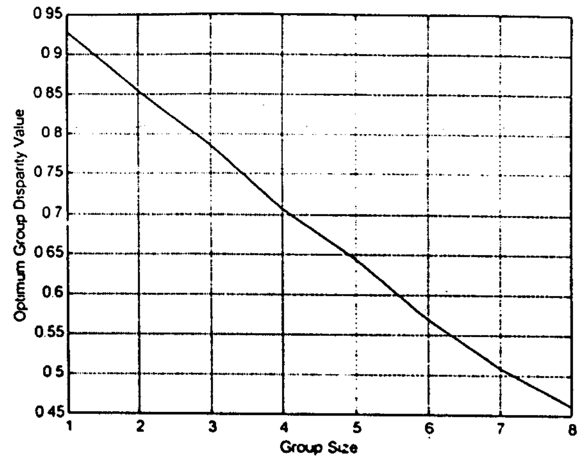


Figure 4. Optimum geometric group disparity for different group sizes under 9 concurrent users

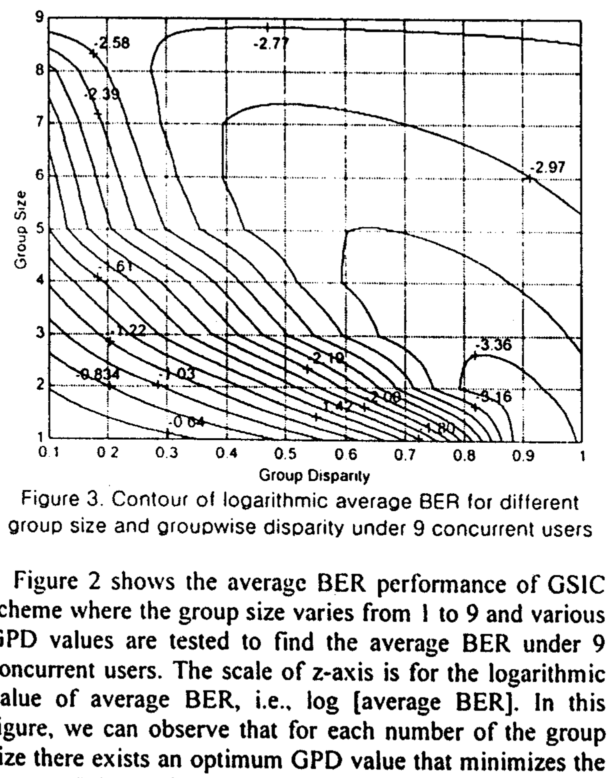


Figure 3. Contour of logarithmic average BER for different group size and groupwise disparity under 9 concurrent users

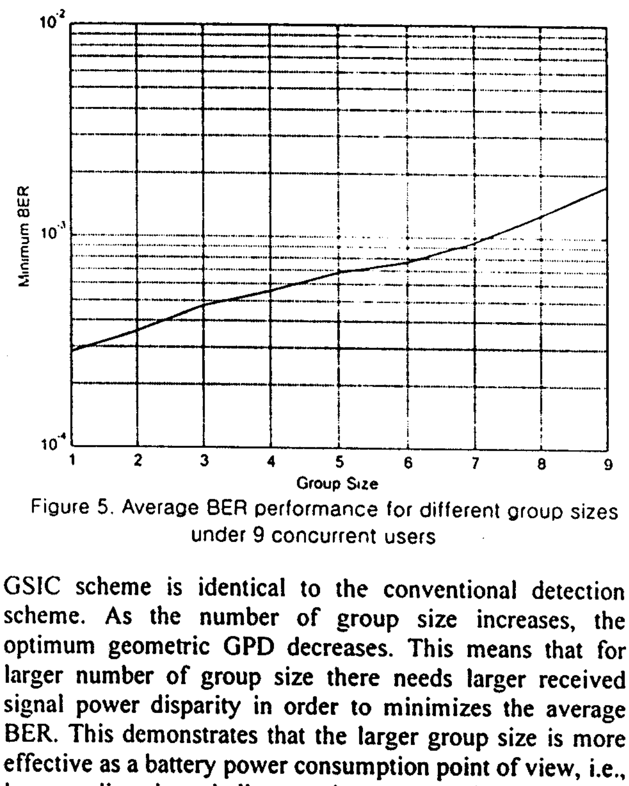


Figure 5. Average BER performance for different group sizes under 9 concurrent users

Figure 2 shows the average BER performance of GSIC scheme where the group size varies from 1 to 9 and various GPD values are tested to find the average BER under 9 concurrent users. The scale of z-axis is for the logarithmic value of average BER, i.e., log [average BER]. In this figure, we can observe that for each number of the group size there exists an optimum GPD value that minimizes the average BER. Referring Figure 3, which is the contour plot of Figure 2, the existence of the optimum disparity can be easily observed. In Figure 2, the average BER of the group sizes of 1 and 9 corresponds to those of the one-by-one SIC scheme and conventional single-user detection scheme, respectively.

Figure 3 shows the contour plot of Figure 2. Contours are labeled according to the log [average BER] as like in Figure 2. For each discrete number of group size, we can see that there is an optimum GPD value that minimizes the average BER.

Figure 4 shows the obtained optimum geometric GPD value that minimizes the average BER for the group size of 1 to 8 under 9 concurrent users. Group sizes (x-axis) are examined only for 1 to 8 because the group size of 9 in the GSIC scheme is identical to the conventional detection scheme. As the number of group size increases, the optimum geometric GPD decreases. This means that for larger number of group size there needs larger received signal power disparity in order to minimizes the average BER. This demonstrates that the larger group size is more effective as a battery power consumption point of view, i.e., larger disparity indicates less transmission power consumption with the cost of performance degradation as will be depicted in next figures.

Figure 5 shows average BER performance that can be achievable by the GSIC scheme with optimum GPD for the group size of 1 to 9 under 9 concurrent users. Again, the average BER performances for the group size of 1 and 9 are identical to those of the one-by-one SIC scheme and conventional detection scheme, respectively.

Figure 6 shows the obtained optimum geometric GPD values for several number of concurrent users. Note that the optimum disparity for G_f of 1 corresponds to that of the one-by-one SIC scheme [6]. As the group size increases, optimum groupwise geometric power disparity decreases. Figure 7 shows the average BER performance of the GSIC

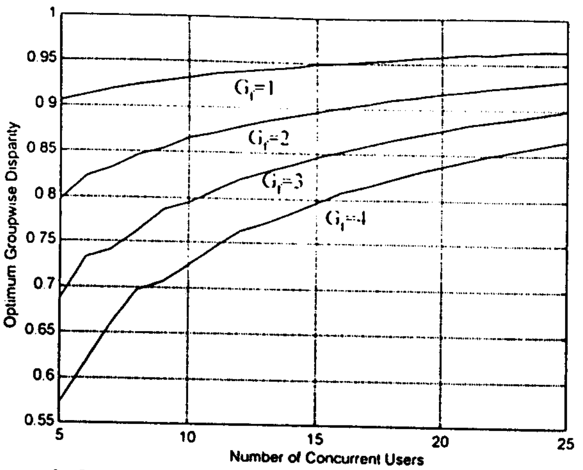


Figure 6. Optimum geometric groupwise disparity for different number of concurrent users

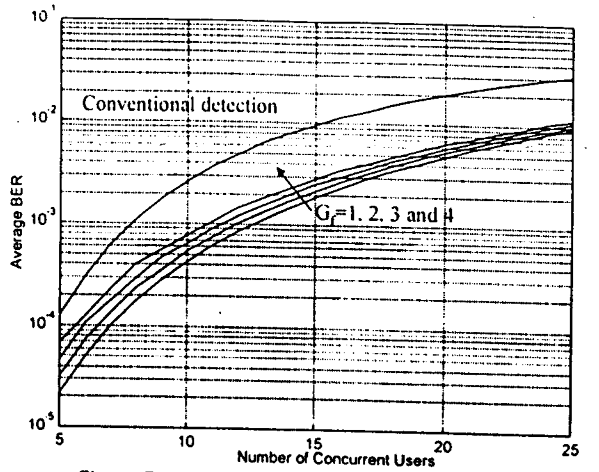


Figure 7. Average BER performance comparisons

scheme for the group size of 1, 2, 3 and 4, where the optimum geometric GPD value obtained in Figure 6 is applied in the GSIC scheme, and it is compared with the BER of the conventional single-user detection scheme. We can observe that the BER performance improvement obtained by the groupwise cancellation is slightly degraded, while the amount of correlation computation and decoding delay can be greatly reduced. In [7], the hardware and delay reduction due to the groupwise cancellation is inversely proportional to the group size. As an example, if we compare two systems such as G_r of 1 and G_r of 2, we can reduce the amount of computation and decoding delay required for cancelling the MAI by half. One interesting observation in this figure is that the BER degradation due to the groupwise cancellation becomes almost negligible as the number of concurrent users increases. This is preferable because, if the number of concurrent users is small enough, the amount of MAI is quite small, the BER performance degradation is less important compared with the case with larger number of concurrent users.

For the case of our example, the advantage of the GSIC scheme with optimum GPD can be summarized in Table 1, where the capacity is evaluated at the average BER of 10^{-3} and the complexity and delay of the conventional detection scheme, K and D, are used as references for comparison.

Table 1. Comparison of capacity, complexity and delay among the conventional detection scheme, SIC scheme and GSIC scheme

	Capacity at ave. BER=10^{-3}	Computational Complexity	Decoding Delay
Conventional Detection	7.8	K	D
SIC (G_r=1)	10.8	K^2	K·D
GSIC (G_r=2)	11.4	$K^2/2$	K·D /2
GSIC (G_r=3)	12.0	$K^2/3$	K·D /3
GSIC (G_r=4)	12.5	$K^2/4$	K·D /4

4.Concluding Remarks

In this paper, we investigate the average BER performance of the groupwise SIC scheme. In order to improve the BER performance, we consider the GPD in the GSIC scheme. Numerical results show that the amount of required computation and decoding delay can be greatly reduced by properly selecting the group size in the GSIC scheme, while the BER performance is slightly degraded compared with SIC scheme.

As a further research, it is interesting to investigate the GSIC scheme that can satisfy the delay constraint, i.e., fixed-delay GSIC scheme. Further, the application of the GSIC scheme into the voice/data DS-CDMA system is another interesting issue.

5. References

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