A Selective Parallel Interference Cancellation Receiver to mitigate Multiple Access Interference in a MC-DS/CDMA system

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Abstract

In this paper, we consider a MultiCarrier DS-CDMA system, with Gold codes employed as spreading sequences, in combination with a Selective Parallel Interference Cancellation (S-PIC) receiver to obtain good BER and throughput performance. Multiple Access Interference (MAI) is the major limitation in CDMA systems: with Interference Cancellation (IC) techniques, we can achieve system performance better than classical matched filter based solutions and with a moderate increase in computational complexity, also with respect to other MultiUSer Detection (MUD) strategies. The S-PIC receiver shows BER performance comparable and even better than simple MF and SIC solutions, in all the environments considered. We show that in a Rayleigh fading environment, even when fading is correlated among subcarriers, the S-PIC is able to outperform different receivers.

INTRODUCTION

It is well known that the major concern in a CDMA based system is the Multiple Access Interference (MAI), because it limits the maximum available capacity in terms of number of user simultaneously handled by a same base station. MultiUser Detection (MUD) schemes [1] seem the most profitable means to achieve an effective improvement, both in performance and capacity, but the large computational complexity required in optimal solutions, leads to research and investigation of sub-optimal approaches. In particular, a large effort has been reserved to Interference Cancellation (IC) algorithms [2], [3], due to their acceptable computational complexity.

In recent years [4], [5], Multi Carrier (MC) schemes have received increasing consideration by researchers: OFDM and its combination with CDMA are undergoing extensive research because of their inner simplicity in implementation, promising capabilities to effectively combat frequency selective fading, and greater spectral efficiency with respect to a classical single carrier scheme. Different solutions for spreading domain and frequency separation among sub-bands were proposed in literature [5]. In this work, we have considered a MC Direct- Sequence Code Division Multiple Access (DS/CDMA) scheme as proposed in [6], [7].

In [7], the authors employ a Successive Interference Cancellation (SIC) [2] receiver in an MC-DS/CDMA system, and showed that this solution achieves good BER performance. The method described in [7] has its major drawback in the computational complexity required, in particular, to perform the sorting algorithm for interferes on every sub-band. In this paper, we propose a simpler but more effective solution of performing IC in a MC scheme. In fact, we apply the idea, illustrated in [8], of a Selective Parallel Interference Cancellation (S-PIC) receiver. The S-PIC groups users in reliable and unreliable comparing their received power with an aptly chosen threshold. Reliable users are then demodulated, reconstructed and cancelled from the whole received signal; finally, demodulation of unreliable users takes place.

We analyze perfomance of the S-PIC under various system configurations. We also evaluate the effect of varying sub-carrier correlation fading values, and compare the proposed S-PIC receiver with an MF-MRC and a SIC-MRC [7]. At last, we introduce amplitude and phase errors at the receiver to simulate a real environment.

Section I deals with the system model while section II describes the proposed receiver. Section III presents performance of our solution, and, finally, section IV draws conclusions of our work.

I. SYSTEM MODEL

We consider a K-users synchronous and asynchronous uplink system. Spreading sequences of all the users are assumed known at the base station. In MC-DS/CDMA systems [6], spectra of sub-carriers may be disjoint in frequency or partially overlapped to increase spectral efficiency, as depicted in fig. 1. Main differences between the two schemes are in the spectral efficiency and in the InterCarrier Interference (ICI) introduced by the tails of the sub-bands. To make reasonable comparisons with the model presented in [7], we consider disjoint carriers. Another feature of MC-DS/CDMA schemes, is that the same symbols is replicated on all the sub-bands in which the allocated spectrum is partitioned [6], [7]. Spreading operation is performed in the time domain [5], [6], and we have considered Gold codes [7].

The total transmitted signal can be expressed as:

$$s(t) = \sum_{k=1}^{K} \sum_{n=1}^{N} A_k a_k(t-\tau_k) b_k(t-\tau_k) e^{j(\omega_n t + \phi_k)} \tag{1}$$

where A_k is the user energy, $a_k(t)$ the user spreading sequence, with unit energy chips of rectangular shape, length T_c and values ± 1, $b_k(t)$ is information sequence, with BPSK antipodal modulation, rectangular shape and bit epoch T_s, N is the total number of carriers, τ_k is the user delay, ω_n is the n^{th} carrier pulse and ϕ_k is the phase offset, uniformly distributed in $[0, 2\pi)$. While performing simulations, we have assumed $\phi_k = 0, \quad k = 1, \ldots, K$, which is the worst case.

Choice of ω_n must respect the condition $\omega_n = \omega_0 + 2n\pi\Delta f \quad (n = 0, \ldots, N-1)$, and $\Delta f = \frac{1}{T_c}$. $\tau_k, \quad k = 1, \ldots, K$ are independent random variables, uniformly distributed over $[0, T_s)$.

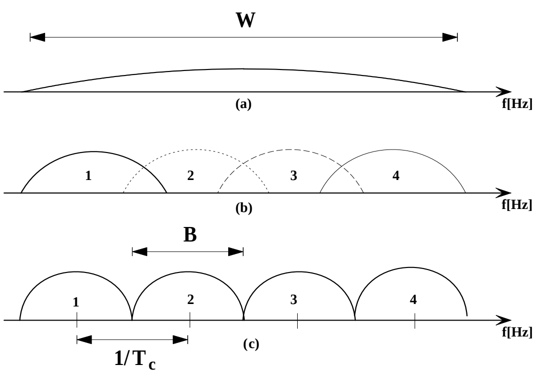

Fig. 1. *(a) Single carrier CDMA with total bandwidth W. (b) MC-DS/CDMA with 4 partially overlapping sub-bands. (c) MC-DS/CDMA with 4 disjoint sub-bands, each of bandwidth B.*

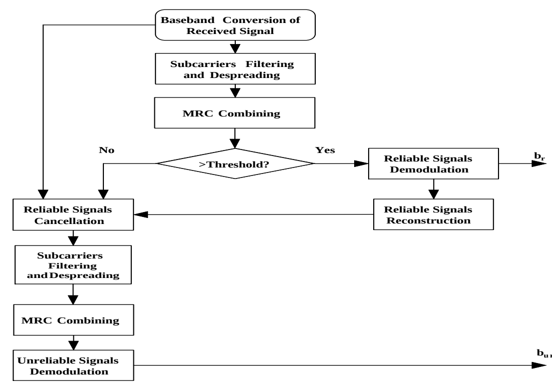

Fig. 2. *Flow chart of S-PIC operation.*

The n^{th} channel is described by:

$$h_{k,n}(t) = \alpha_{k,n}(t) e^{j\theta_{k,n}(t)} \tag{2}$$

where $\alpha_{k,n}(t)$ is a Rayleigh random variable with unit power density, and $\theta_{k,n}(t)$ is the phase rotation, which is uniformly distributed in $[0, 2\pi)$. The fading process is assumed flat on each subcarrier [7]. We have considered both the cases of correlated and uncorrelated fading: correlated fade has been generated according to the models described in [9].

II. S-PIC Receiver Structure

The total received signal is described by:

$$r(t) = \sum_{k=1}^{K} \sum_{n=1}^{N} \alpha_{k,n} A_k a_k(t-\tau_k) b_k(t-\tau_k) e^{j(\omega_n t + \theta'_{k,n})} + n(t) \tag{3}$$

where $\theta'_{k,n} = \phi_k + \theta_{k,n}$ and $n(t)$ is a complex AWGN process, with zero mean and two-sided power spectral density $N_0/2$. At the receiving end, the decision variable at the output of each MF can be expressed as follows:

$$d_n(t) = \sum_{k=1}^{K} \alpha_{k,n} A_k a_k(t-\tau_k) b_k(t-\tau_k) e^{j\theta'_{k,n}} + \widetilde{n}(t) \quad n = 1 \ldots N \tag{4}$$

The basic idea of the S-PIC is to group users into two distinct sets: a *reliable* and an *unreliable* one [8]. The former is composed of users that have been received with a power level higher than a selected threshold S. The latter comprises all the remaining users. Reliable users are more likely to have been correctly received. Hence, they are immediately demodulated and reconstructed. After reconstruction, reliable signals are subtracted from the whole received signal. Then, demodulation is performed again only for unreliable users, which are now affected by a reduced amount of MAI, and can be demodulated with more accuracy. Choice of the threshold is made according to channel and interference condition, to optimize BER performance. There exists an optimum choice of this threshold, as shown in figure 8, which is not much affected by system parameters. The functional block diagram of the S-PIC is presented in fig. 2.

III. NUMERICAL RESULTS

We have resorted to computer simulation to show advantages of our solution as compared to other schemes. We have assumed the following parameters:

- runs of 10000 bits per user per simulation were generated;
- ideal power control to guarantee equal power energy users or a fixed *Signal-to-Interference-Ratio* (SIR) among users to simulate an imperfect power control;
- Gold spreading sequences, with processing gains of 31, 63, and 127;
- 2 and 4 carriers are assumed for MC-DS/CDMA.

In a synchronous system, IC receivers show their advantages when users are unbalanced in power. Fig. 3 show that, in a 2 and 4 carriers MC-DS/CDMA, with 20 users and a SIR of 20dB[1], the S-PIC behaves better than a SIC receiver. Moreover, advantages of increasing the number of carriers are evident. Gold 31 codes have been employed as spreading sequences. Fig. 4 compare performance of the S-PIC in equal-power, equal-band, equal-load conditions in 3 different CDMA schemes, namely single carrier CDMA, 2 and 4 carriers MC-DS/CDMA. Gold 127, 63 and 31 codes and 20 active users have been used. It is evident that, as the number of carriers increases, also BER performance of the analyzed scheme improves. This is due to the higher robustness to fading of MC schemes, since there is a bigger ”diversity” exploitable introduced by replicating N times the transmitted symbol.

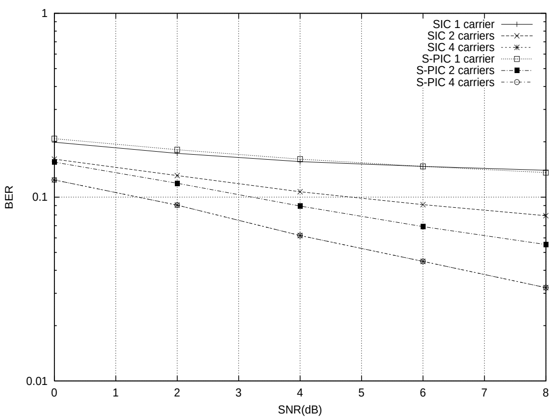

Fig. 3. *Receiver performance comparison: 20 synchronous users in Rayleigh fading channel. SIC and S-PIC.*

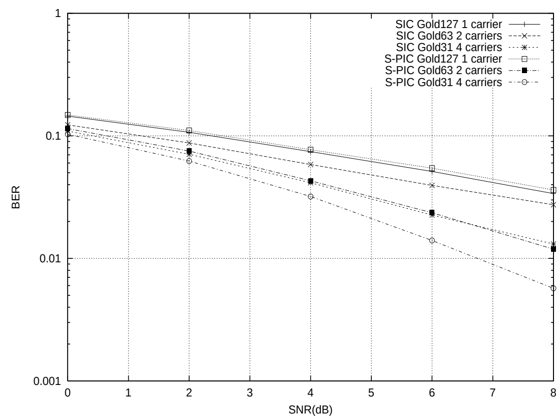

Fig. 4. *Performace comparison with different SF and equivalent load conditions in a synchronous channel. SIC and S-PIC*

Fig. 5 presents results obtained in a correlated fading environment for 10 synchronous users with SIR = 20dB, when 2 carriers and Gold 31 codes are used. We have chosen a correlation index ρ of 0.3 and 0.8 to simulate a moderately and high correlated fading, respectively. We can observe a worsening in performance due to the more hostile condition of the channel. As the fade correlation index increases, thus reducing the available order of diversity, BER performance decreases. It is evident that the S-PIC receiver still retains its advantages over other schemes.

Fig. 6 considers 20 users, Gold 127 and 63 spreading codes for the 1 and 2 carrier(s) schemes, respectively. Moreover, the second system is affected with a relative greater amount of MAI since the spreading sequences have lower interference rejection capabilities. Finally, it is also evident that our S-PIC receiver reaches performance better than the MF even at low SNRs. Fig. 7 shows the effect of a phase offset at the receiver: BPSK modulation is more sensible to such errors than amplitude ones [10] Finally, fig. 8 shows that there exist an optimum choice of the threshold for the S-PIC. This value lets the S-PIC achieve the best BER performance and it is independent from the number of carriers. Moreover, the slope of the curves around S_{opt} is almost flat, thus slight errors in the choice of this parameter will not significantly affect system performance.

Concerning the computational complexity, we can say that the number of cancellations necessary for the S-PIC to operate is equal to K_r, the number of reliable users. The condition $K_r \leq K$ always holds. In a MC system, the total number of cancellation is $M * K_r$. The SIC algorithm, on the contrary, is more computational cumbersome, because of the sorting algorithm to re-order interfereson each carrier and for each user. Moreover, the SIC solution requires a number of cancellations much greater than that of an S-PIC. The total number of cancellation in a SIC can be expressed as $\frac{K*(K-1)}{2}$ on each sub-channel. Hence, we need to perform a total of $\frac{K*(K-1)}{2}$ cancellations in a SIC scheme. Thus, the S-PIC has advantages also in the lower computational complexity.

[1] i.e., interferes are received with a greater power than the desired user.

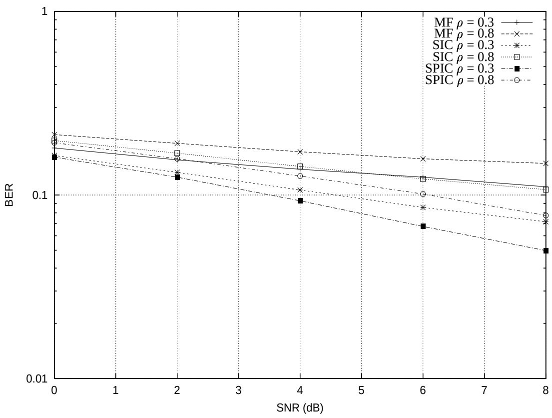

Fig. 5. *BER performance comparison in correlated fading channel.*

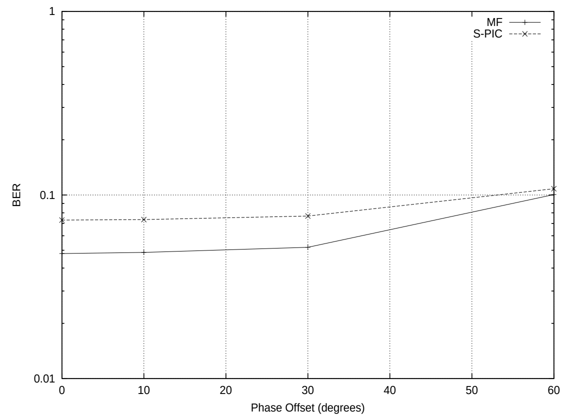

Fig. 7. *Effects of phase offsets errors. 10 asynchronous users and 4 carriers.*

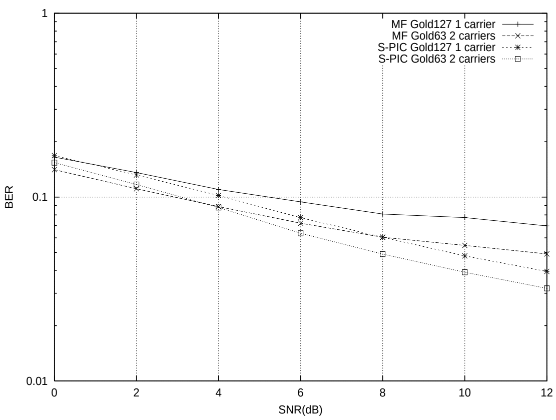

Fig. 6. *BER comparison with different SF in an asynchronous system.*

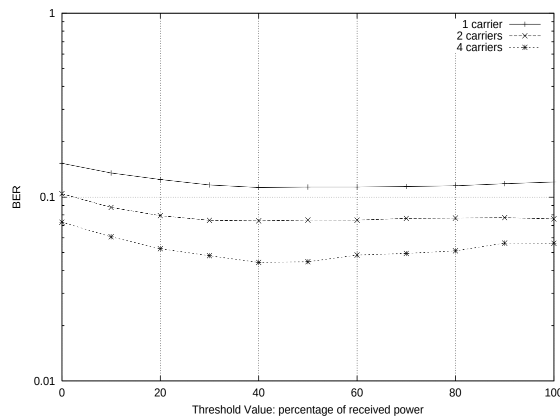

Fig. 8. *Optimization of the threshold value.*

IV. Conclusion

In this paper, we described the design and the performance of an S-PIC receiver for MC-DS/CDMA systems, both in correlated and uncorrelated fading channels, and synchronous and asynchronous environments.

It has been shown that the S-PIC outperforms both the MF and SIC receivers in all the scenarios under analysis. The S-PIC retains its advantages with respect to the MF even when channel estimation errors are introduced, but such gains reduces as the error, especially the estimate on phase offset, increases. Moreover, the S-PIC has a lower computation complexity as compared to SIC or other MUD receivers.

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