Blind Adaptive Successive Interference Cancellation for Multicarrier DS-CDMA

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Abstract: A new adaptive receiver design for the Multicarrier (MC) DS-CDMA is proposed employing successive interference cancellation (SIC) architecture. One of the main problems limiting the performance of SIC in MC DS-CDMA is the imperfect estimation of multiple access interference (MAI), and hence, the limited frequency diversity gain achieved in multipath fading channels. In this paper, we design a blind adaptive SIC with new multiple access interference suppression capability implemented within despreading process to improve both detection and cancellation processes. Furthermore, dynamic scaling factors derived from the despreader weights are used for interference cancellation process. This method applied on each subcarrier is followed by maximum ratio or equal gain combining to fully exploit the frequency diversity inherent in the multicarrier CDMA systems. It is shown that this way of MAI estimation on individual subcarrier provides significantly improved performance for a MC DS-CDMA system compared to that with conventional matched filter (MF) and SIC techniques at a little added complexity. Performance evaluation under severe nearfar, fading correlation and system loading conditions are carried out to affirm the gain of the proposed adaptive receiver design approach.

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1 Introduction

CDMA is one of the promising multiple access schemes and is currently being used for the third generation cellular wireless systems. Future wireless communications systems need to meet the increasing demands for highly flexible and efficient multiple access techniques with improved performance, robustness to fading and other interference [1], [2]. Due to the broadband nature of the transmission schemes used for such systems, the propagation environment often introduces inter-symbol-interference due to the large delay spread of multipath fading channels. It is well known that Multicarrier CDMA is a very effective scheme that mitigates the effects of multipath and also provides frequency diversity that is inherent in wideband CDMA channels [3]-[4]. The main idea behind the Multicarrier CDMA is to use parallel transmission of the same data over multiple frequency flat subcarriers to avoid the multipath and hence to form a more robust system in broadband environments.

A multicarrier scheme for CDMA that uses frequency domain spreading also known as MC-CDMA was first introduced in [3]. Since then, a number of different variants of Multicarrier CDMA schemes have been proposed; studies of which can be found for example in [5]-[6]. In [5], the authors described different multicarrier CDMA schemes both for the uplink and downlink along with their relative performance advantages and tradeoffs involved. A very useful survey of multicarrier CDMA schemes for ubiquitous broadband wireless communications is carried out by Yang and Hanzo in [2]. Where it is found that for a range of practical communications scenarios the propagation channels may often become highly correlated in frequency domain and thus MC-CDMA that uses spreading purely in the frequency domain may not achieve the best performance. In this regard another multicarrier CDMA scheme referred to as Multicarrier Direct Sequence CDMA or MC DS-CDMA which is a combination of both MC-CDMA and DS-CDMA can prove to be a very effective. The performance of MC DS-CDMA is well investigated under different channel conditions and detection schemes as can be found in [2], [7], [6], [8], [4]. The performance of MC DS-CDMA using single user detection techniques are investigated and compared to that with single carrier DS-CDMA in [6], [7]. It is shown that the MC DS-CDMA offers more improved performance under the same systems settings. Adaptive filtering based receivers for multicarrier CDMA are also investigated for example in [9], [10].

It is well known that single user or conventional MF based detection scheme is suboptimal in multiuser settings as the interference arising from other users are simply treated as background noise. Multiuser detection [11] is a promising
technique and has been the subject of intense study in the last two decades for single carrier CDMA. The optimum receiver using maximum likelihood sequence estimation proposed by Verdu is known to offer substantial gain in terms of both capacity and error performance. However exponential computational complexity of the receiver has motivated the research for suboptimal but lower complexity receivers. A very useful simulation study of these suboptimal receivers have been carried out in [12]. Among these techniques, the Interference Cancellation (IC) subclass of receivers have shown to offer both low complexity, high flexibility compared with linear decorrelation based counterparts as studied by Andrews in [13]. The IC receivers are further categorized into successive (SIC) [14], [15], [16] and parallel (PIC) [17], [18], [19] techniques.

The IC techniques that were originally designed for single carrier CDMA have also recently emerged as an effective approach to improve the performance of multicarrier CDMA such as the work in [8], [20], [21], [22]. In [21] and [22] SIC technique is investigated for the MC-CDMA and MC DS-CDMA, respectively. Also recently, a weighted linear PIC for MC DS-CDMA is investigated in [20]. A well known problem with IC receivers is the imperfect MAI estimation that arises due to the bias in estimation when conventional correlators or MFs are used for this purpose. This problem is addressed for single carrier CDMA by using partial rather than full cancellation of the interference in [19], [15]. There are also adaptive IC schemes that address this problem such as the LMS-PIC in [23] proposed for single carrier CDMA. However there has been relatively less work on the adaptive IC schemes for multicarrier CDMA systems. In [8] an adaptive multistage PIC receiver for MC DS-CDMA using the LMS algorithm is investigated. The LMS based adaptive SIC technique for the single carrier CDMA also exists e.g. in [24]. These schemes use hard decision made on each stage to regenerate MAI estimates of each user for the cancellation. To the best knowledge of the authors adaptive approach to SIC for MC DS-CDMA has not yet been proposed. In addition, we address the adaptive process using blind approach and combined within the despreading process such that it also provides additional multiple access interference suppression. Recently, new techniques of coded transmission along with iterative joint decoding and interference cancellation are becoming more and more widespread such as [25] and [26]. Our focus on this paper has been to propose a simple and low complexity technique that improves the performance of the receiver from it’s design itself without using any coding and complex iterative decoding, although they can be easily incorporated within the proposed system.

Therefore, in this paper, we propose a new adaptive SIC receiver design for MC DS-CDMA employing a simple CM algorithm within the despreading process. Rather than using the hard decision of user data, scaled soft output signals are used for a better estimation of MAI for the cancellation, where the same despreader weights are used for obtaining the
dynamic scaling factors. Improved estimate of user signals on each subcarrier are combined using maximum ratio (MRC) or equal gain combining (EGC) method to maximize the frequency diversity gain from the system. We also consider the effects of problems such as nearfar and fading correlation that are commonly encountered in practice. The system performance under different step sizes of the adaptive algorithm is also investigated to reveal that the proposed receiver can be further robustified under high system loading condition with the choice of an optimum step size.

The paper is organized as follows. In section 2, the system model and principle of conventional SIC technique are described. The main ideas and detection algorithm of the proposed adaptive receiver are presented in section 3. The performance results and comparisons with other techniques are shown in section 4. Finally the paper is concluded in section 5.

2 System Description

2.1 System Model

A $K$-user synchronous MC CD-CDMA system is considered. The transmitted signal for the $k^{th}$ user is given by

$$s_k(t) = \sqrt{2P \over L} b_k(t)c_k(t) \sum_{l=1}^{L} \cos(\omega_l t + \theta_k,l)$$

where $P$ is the signal power, $L$ is the number of subcarriers, $b_k(t) = \sum_{m=-\infty}^{\infty} b_k(m)p_b(t - mT_b)$ is the data signal, where $b_k(m)$ is a binary sequence taking values $[-1, +1]$ with equal probabilities, and $p_b(t)$ is the rectangular pulse shaping function of period $T_b$. The spreading sequence is denoted as $c_k(t) = \sum_{n=0}^{N-1} c_k(n)p_c(t - nT_c)$ with antipodal chips $c_k(n)$ of pulse shaping function $p_c(t)$, period $T_c$, and normalized power over a symbol period is equal to unity $\int_0^{T_b} c_k(t)^2 dt = 1$. The spreading factor is $N = T_b/T_c$. Finally, $\omega_l$ and $\theta_k,l$ are the $l^{th}$ subcarrier frequency in radian/sec and initial carrier phase of the $k^{th}$ user uniformly distributed over $\{0, 2\pi\}$, respectively.

In the proposed MC DS-CDMA system, we assume that the channel of each subcarrier is a slowly varying frequency-nonselective Rayleigh channel which remain constant over at least one symbol period. The complex gain of the channel is given by $\beta_{k,l} = g_{k,l} \exp^{j\phi_{k,l}}$, where $g_{k,l}$ is the amplitude with zero mean and unit variance and $\phi_{k,l}$ is the phase uniformly distributed over $\{0, 2\pi\}$. We assume that the channels of subcarriers have identical but not necessarily independent
distributions. The normalized channel correlation \( \rho_{l_1, l_2}(\tau) \) can be given by [27]

\[
\rho_{l_1, l_2}(\tau) \triangleq E[\beta_{k, l_1}(t)\beta_{k, l_2}(t+\tau)] = \frac{J_0(2\pi f_D \tau)}{\sqrt{1 + \left(\frac{\Delta f}{\Delta f_c}\right)^2}}
\]

(2)

where \( E[.\] \) is the expectation operator, \( \beta^* \) is the complex conjugation of \( \beta \), \( \Delta f = |f_{l_1} - f_{l_2}| \), \( \Delta f_c \) is the coherence bandwidth of the channel, \( J_0(.) \) is the zero order Bessel function of the first kind and \( f_D \) is the Doppler frequency.

The received signal is given by

\[
r(t) = \sum_{k=1}^{K} \sqrt{2P} b_k(t)c_k(t) \sum_{l=1}^{L} \cos\{\omega_l t + \theta'_{k,l}\} + n(t)
\]

(3)

where \( \theta'_{k,l} = \theta_{k,l} + \phi_{k,l} \) and \( n(t) \) is the AWGN with two sided power spectral density of \( N_0/2 \).

We assume that the system is fully synchronized and that the carrier and fading channel phases are known perfectly at the receiver. It is important to note that imperfect estimation of these parameters and their effect on the system performance are important practical issues as considered in [21]. A downconverted (baseband) equivalent of the received signal on \( l^{th} \) subcarrier \( r^l(n) \) is obtained as follows

\[
r^l(n) = LPF\left\{\int_{nT_c}^{(n+1)T_c} r^l(t)\cos\{\omega_l t + \theta'_{k,l}\} dt\right\}
\]

(4)

where \( \{r^l(t)'\} \) is the signal obtained after \( r(t) \) is passed through \( l^{th} \) subcarrier bandpass filter. Furthermore, to simplify the presentation in the description of different receiver schemes, we use real valued signals for subsequent processes (extension to the case of complex valued or higher modulation signals can be straightforward).

2.2 Conventional SIC (CSIC) Receiver for MC DS-CDMA

In the conventional SIC as used in [21] for multicarrier DS-CDMA, the detection of user signals are performed using MFs’ or correlators’ outputs. First the estimation of the desired user is carried out, followed by the cancellation of its MAI contribution from the remaining composite received signal. For this purpose ordering is performed on the MF output signals to give the strongest user say \( k \) that gives the maximum of \( L \) combined signal output, given by

\[
z^l_k = \max\left\{\sum_{l=1}^{L} \sum_{n=0}^{N-1} r^l(n)c_i(n)\right\}, 1 \leq i \leq K
\]

(5)

The estimate of \( k^{th} \) user’s data is taken as

\[
\hat{b}_k = \text{sgn}\left[\sum_{l=1}^{L} z^l_k \lambda_k^l\right]
\]

(6)
where, \( \text{sgn} \) denotes a sign function. As noted above in (6), the final decision is taken on the sum of signals over \( L \) subcarriers weighted by the combining weights \( \lambda^l_k \). There are two main combining methods used in the literature \([1], [5], [3]\): maximum ratio combining and equal gain combining. The weights are taken as \( \lambda^l_k = g^l_k, \forall k, \forall l \) for the MRC and \( \lambda^l_k = 1, \forall k, \forall l \) in the case of EGC.

After the decision of the \( k^{th} \) user, it’s signal \( z^l_k \) is respread using its spreading sequence \( c_k = [c_k(1), c_k(2), \ldots, c_k(N)]^T \) where \( \cdot \)^T denotes a transpose operation and subtracted from \( r^l_k = [r^l_k(1), r^l_k(2), \ldots, r^l_k(N)]^T \) to form received signal for the next strongest user \( r^l_{k+1} \) as follows

\[
r^l_{k+1} = r^l_k - z^l_k(m)c_k
\]

The processes (5), (6) and (7) are carried out on all \( L \) subcarrier branches until all user’s data are detected.

3 Proposed Blind Adaptive SIC (ASIC) Receiver

3.1 Main Ideas and Design Architecture

The proposed receiver addresses the discussed problems with it’s unique design as follows. Firstly, instead of only correlating the input signal with a user specific sequence, adaptive despreading is used utilizing the constant modulus property of the desired user’s transmitted signal to reduce the variance of MAI, that is known to be zero mean and approximately Gaussian distributed signal. It also has a desirable property of generating the adaptive weights that does not allow a decision statistic signal to revert it’s sign when the presence of MAI tends to do so. The adaptive algorithm is based on CMA, which is a simple blind algorithm commonly used in the literature such as \([28], [29]\) that tries to maintain constant modulus of the signals at the output. It is used here in a different way within the despreeder to reduce MAI where the weights are also used to obtain refined MAI estimates for the cancellation. The complexity of the algorithm is only \( O(N) \) computation per symbol per user, where \( N \) is the length of the weight vector. Provided that the algorithm is fast enough to track the changes in MAI power variations with optimum weights, the decision error due the MAI effects can be completely avoided. However, this is very difficult to achieve in practice since the CM algorithm may always have some inevitable misconvergence problems. Secondly, to address this problem, the adaptive despreeder weights are used to obtain dynamic scaling factors that are suitably implemented within the SIC stages. It is intuitive that the more MAI is suppressed during the despreading, the more reliable is it’s cancellation. Finally, the improved estimates of user’s signals obtained on the individual subcarrier...
are combined using EGC or MRC method to fully exploit the frequency diversity inherent in MC CDMA systems. Our results show that the adaptive approach to the estimation and cancellation minimizes the effect of MAI even under high system loading and severe nearfar conditions.

Figure 1: Proposed Adaptive SIC receiver design for the detection of the first user

The proposed SIC architecture block diagram is shown in Figure 1 for the first user. The same processes are applied to all $K$ stages. In this architecture, the effect of strong users (interferers) are removed at each successive stage, which aids the detection and cancellation for the weaker user. At every symbol period, the received signal $r(t)$ is down converted to $L$ baseband equivalent of subcarriers signals and sampled at the chip rate to form the vector $r_l(m), 1 \leq l \leq L$ each of length $N$ chips. Bank of MF output based power sorter is employed to order user signals according to their combined strength on $L$ subcarriers. The strongest user signal is then selected for the first stage for the estimation and detection of it’s transmitted data. Adaptive algorithm based on CM criterion embedded within the despreader is used to adjust the amplitude of incoming signal at the chip rate. For example, the despreading process for the received signal at the first (strongest) user
stage on $l^{th}$ subcarrier is shown in Figure 2. The output $z_l^1(m)$ is also weighted by a scaling factor $\bar{\alpha}_l^1(m)$ utilizing the despreader weights $w_l^1(m)$, spread with $c_1(m)$ and subtracted from the received signal $r_l^1(m)$ to form the input to the next stage for the second strongest user. This process is repeated for each user until the weakest user is detected.

### 3.2 Detection Algorithm

At the first symbol period, the weights of the adaptive despreaders are initialized with user’s spreading sequence $w_k^l(1) = c_k(1)$. Without loss of generality, it is assumed that the first user (strongest among $K$ users) to be detected is user 1. Similarly next strongest user is assigned an index as user 2 and so on. At the first stage, the received signal on the $l^{th}$ subcarrier can be expressed as $r_l^1(m) = r_l^1(m)$. The remaining composite signal after $k$ cancellation stages is expressed as $r_{l,k+1}^1(m)$.

At $k^{th}$ detection stage, the decision statistic $z_{l,k}^1(m)$ is obtained by multiplying chips of $r_{l,k}^1(m)$ with the vector of weights $w_{l,k}^1(m)$ and summed over the symbol period given by

$$z_{l,k}^1(m) = \left\{w_{l,k}^1(m)\right\}^T r_{l,k}^1(m) \quad (8)$$

The CM criterion $J_{CM}$ can be written as minimization of the following cost function

$$J_{CM} = E\left\{z_{l,k}^1(m)^2 - \gamma\right\}^2 \quad (9)$$

where $\gamma$ is the dispersion constant, which is equal to unity for BPSK signals. The instantaneous error signal $e_{l,k}^1(m)$ is calculated as

$$e_{l,k}^1(m) = z_{l,k}^1(m)\left\{z_{l,k}^1(m)^2 - \gamma\right\} \quad (10)$$
The estimated gradient vector of the error signal is then calculated by

$$\nabla l_k(m) = r_l^k(m)e_k^l(m)$$  \hspace{1cm} (11)$$

Using the gradient of (11), the weight vector at next symbol $w_l^k(m + 1)$ is updated as follows

$$w_l^k(m + 1) = w_l^k(m) - \mu \nabla l_k(m)$$ \hspace{1cm} (12)$$

where, $\mu$ is the step-size used for adapting the elements of a weight vector to minimize the cost function (9).

Next, the cancellation process requires amplitude estimate $g_l^k(m)$ of the detected user’s signal along with it’s spreading sequence $c_k(m)$. To achieve an estimate as close to $g_l^k(m)$ as possible, first a scaling factor $\tilde{\alpha}_k^l(m)$ is obtained using the despreader weights and the known spreading sequence of the user $c_k(m)$ as follows

$$\tilde{\alpha}_k^l(m) = \frac{\tilde{c}_k(m)}{\tilde{w}_l^k(m)}$$ \hspace{1cm} (13)$$

where, $\tilde{c}_k(m)$ and $\tilde{w}_l^k(m)$ are the mean amplitude of chips of user’s spreading sequence and elements of the weight vector updated by the CM algorithm, respectively and are given in (14) and (15) below

$$\tilde{c}_k(m) = \frac{1}{N} \sum_{n=0}^{N-1} c_k\{ (m - 1)N + n \}$$ \hspace{1cm} (14)$$

$$\tilde{w}_l^k(m) = \frac{1}{N} \sum_{n=0}^{N-1} w_l^k\{ (m - 1)N + n \}$$ \hspace{1cm} (15)$$

The soft estimate signal $z_l^k(m)$ is then scaled with its new amplitude estimate $\tilde{\alpha}_k^l(m)$ and spread to generate the cancellation term as follows

$$x_l^k(m) = \tilde{\alpha}_k^l(m)z_l^k(m)c_k(m)$$ \hspace{1cm} (16)$$

The remaining composite signal after the interference cancellation is given by

$$r_{l+1}^k(m) = r_l^k(m) - x_l^k(m);$$ \hspace{1cm} (17)$$

After collecting $L$ samples of $z_k^l(m)$, the signals are delivered to the subcarrier combining stage to improve the final estimate of the desired user’s data. Each signal $z_k^l(m)$ is weighted by a weight $\lambda_k^l(m)$ and then combined to form the final decision variable $Z_k(m)$ as follows:

$$Z_k(m) = \sum_{l=1}^{L} \lambda_k^l(m)z_k^l(m)$$ \hspace{1cm} (18)$$
As noted earlier, the combining weights here are taken as 
\[ \lambda_{lk}(m) = g_{lk}(m), \forall k, \forall l \] for the MRC and \( \lambda_{lk}(m) = 1, \forall k, \forall l \) in the case of EGC. Finally, the decision making process performs hard decision to obtain the data as follows

\[ \hat{b}_k(m) = \text{dec}\{Z_k(m)\} \] (19)

where \( \text{dec}\{\cdot\} \) is a simple sign detector for BPSK signals.

The processes shown in (8)-(19) are repeated for each detection stage until the weakest user is detected.

We summarize the detection algorithm in Table 1 below for a more concise presentation.

| Initialize the adaptive algorithm and select the step size \( \mu \) |
| --- |
| At \( m = 1 \), set \( \mathbf{w}_{k}^{l}(1) = \mathbf{c}_{l}(1), \forall k, \forall l \) |
| for \( m = 1, 2, \ldots \) |
| Sort users based on their strength in descending order and store their indices \( k \) |
| for \( k = 1, 2, \ldots, K \) |
| for \( l = 1, 2, \ldots, L \) |
| 1. Despread \( \mathbf{r}_{k}^{l}(m) \) using the weight vector \( \mathbf{w}_{k}^{l}(m) \) and store the sample of \( z_{k}^{l}(m) \) |
| 2. Evaluate the CM cost function \( J_{CM} \) and calculate gradient vector, \( \nabla_{l}^{k}(m) \) |
| 3. Update weights for next symbol, \( \mathbf{w}_{k}^{l}(m + 1) \) |
| 4. Calculate the scaling factor \( \tilde{\alpha}_{k}^{l}(m) \) and regenerate the cancellation term \( \mathbf{x}_{k}^{l}(m) \) |
| 5. Cancel the signal \( \mathbf{x}_{k}^{l}(m) \) from the remaining total composite signal \( \mathbf{r}_{k}^{l}(m) \) |
| end for |
| Perform MRC or EGC over \( L \) samples of \( z_{k}^{l}(m) \) to form \( Z_k(m) \) and then obtain \( \hat{b}_k(m) \) |
| end for |
| end for |

Table 1. The proposed ASIC receiver algorithm steps

4 Performance Results and Comparisons

4.1 Assumptions

A synchronous uplink MC DS-CDMA system of \( K \) BPSK modulated users with \( L = 2 \) and coherent demodulation is assumed in all simulations. Raised cosine pulse shaping filter with roll factor \( \alpha = 0.5 \) is used within each subcarrier. Equal power users \( P_k = P, \forall k \) are assumed unless stated otherwise. Short binary Gold sequences of length \( N = 31 \) are used for spreading users’ data. The channel is Rayleigh flat fading on each subcarrier with normalized Doppler rate \( f_{D}T_b = 0.003 \) and perfect channel estimation is assumed for the case of MRC combing method. The generation of correlated fading of subcarriers are obtained using the method proposed in [30] that is based on Jakes model [27]. A step size of \( \mu_k = 0.0001 \), for all users is assumed in the adaptive algorithm. The selection of step size is generally based on the spreading factor,
system loading and the dynamic range of the received signal and also has direct effect on the system performance as will be shown later.

4.2 Numerical Results

**BER vs. SNR:** The BER performance of the proposed multicarrier blind Adaptive SIC (ASIC) is shown in Figure 3 for system loading of \( K = 20 \) users and \( \rho_{l_1,l_2} = 0 \) using EGC and MRC methods, denoted as ASIC-EGC and ASIC-MRC, respectively. For comparison purposes the BER obtained using conventional SIC (CSIC) and MF receivers using the two combining methods are also given. As can be clearly seen from the figure, the proposed technique offers significant improvement in the BER compared with the other techniques for both cases of EGC and MRC. It approaches much closer to the single user performance. It is also noted that the performance with EGC and MRC are very similar for all receivers under the system settings considered.

![Figure 3: BER of the Adaptive SIC receiver for MC DS-CDMA with \( L = 2 \) in Rayleigh fading channels for \( K = 20 \), \( \rho_{l_1,l_2} = 0 \), \( \mu = 0.0001 \) and Gold sequences of \( N = 31 \)](image)

**User capacity:** In Figure 4, the user capacity of ASIC is compared with CSIC and MF receivers in Rayleigh fading channels
with $\rho_{l_1,l_2} = 0$ and $E_b/N_0 = 20$ dB. It is evident that proposed ASIC-EGC and ASIC-MRC achieve much improved user capacity compared with both CSIC and MF. For example, at the BER of $2 \times 10^{-4}$, the ASIC-EGC can support 20 users compared with 16 users and 8 users with CSIC-EGC and MF-EGC, respectively. Also it is noted that the performance of the ASIC for both EGC and MRC are very similar. The CSIC-MRC is shown to outperform CSIC-EGC under low user loading conditions and the opposite for high loading conditions. MF-EGC seems to perform better than MF-MRC for the whole range of user loading conditions.

![Figure 4: User capacity performance of the Adaptive SIC receiver for MC DS-CDMA with $L = 2$ in Rayleigh fading channels under $E_b/N_0 = 20$ dB, $\rho_{l_1,l_2} = 0$, $\mu = 0.0001$ and Gold sequences of $N = 31$.](image)

**Effects of nearfar conditions:** To further affirm the performance gains of the proposed ASIC receiver for MC DS-CDMA, we also consider the system with different user nearfar conditions. Firstly, in Figure 5, we assess and compare the user capacity performance of receivers under the nearfar ratio of $\Omega = 10$ dB. This is obtained by letting the desired user which is also the weakest one to have unity power $P_k = 1$ whereas all the other users $i, i \neq k$ have their power uniformly distributed within the range $P_i \in \{0, 10\}$. The step size used in the adaptive algorithm of the proposed receiver is set as $\mu = \frac{0.0001}{11}$. 

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to compensate for the nearfar situation. The other system settings are the same as the previous equal power case. As can be noted from the figure, the ASIC-MRC shows much improved performance compared with CSIC-MRC and MF-MRC under various user loading conditions. As expected the MF-MRC shows rapid degradation in the BER as the user loading increases. The CSIC-MRC also shows improved performance compared with MF-MRC but performs much worse than the ASIC-MRC under high loading conditions.

![Figure 5: Performance of the Adaptive SIC receiver with MRC with $L = 2$ for MC DS-CDMA in nearfar condition with $\Omega = 10$ dB and with desired (weakest) user's $E_b/N_0 = 20$ dB in Rayleigh fading channels with $\rho_{l_1,l_2} = 0$, $\mu = 0.00001$ and Gold sequences of $N = 31$.](image)

Furthermore, in Figure 6 the receivers are investigated with a system consisting of $K = 20$ users and under different nearfar conditions of $\Omega \in \{0, 20\}$ dB. The step size of the adaptive algorithm used in the proposed receiver is varied according to the nearfar condition given by $\mu = \frac{0.0001}{11}$. The ASIC-MRC continues to show improved performance even under high values of $\Omega$. The performance gap between the ASIC and CSIC becomes wider in this case showing impressive performance advantage of the proposed receiver design approach. This result can also be attributed to the improved detection and MAI cancellation processes of the ASIC giving it more resilience under the nearfar conditions.

**Effects of step-size:** The step size is an important parameter of the adaptive algorithm [31] with direct effects on the
convergence. In Figure 7, we assess the impact of different step sizes on the BER performance of the proposed receiver with MRC under $E_b/N_0 = 20$ dB for $K = 10, 16, 20$ and $24$ users in Rayleigh fading channels with $\rho_{l_1, l_2} = 0$. The BER obtained using the step size of $\mu = 0.0001$ used in earlier simulations is also shown. It can be seen that the choice of step size can have significant effect on the system performance. Under low loading condition of $K = 10$, the performance is nearly identical for a range of step sizes. However as $K$ increases, the effect of step size has more significant impact on the BER performance. Interestingly, it is noted for example for $K = 24$, the BER performance of the proposed adaptive receiver can be further improved. With the choice of optimum step $\mu_{opt} = 0.0013$, BER performance as low as $8.5 \times 10^{-5}$ can be achieved which is very near to the single user performance of $6.75 \times 10^{-5}$.

Figure 6: Performance of the Adaptive SIC receiver with MRC for MC DS-CDMA for $K = 20$ users, $L = 2$ in nearfar condition with $\Omega \in \{0, 20\}$ dB and with desired (weakest) user’s $E_b/N_0 = 20$ dB in Rayleigh fading channels with $\rho_{l_1, l_2} = 0, \mu = 0.0001/\Omega$ and Gold sequences of $N = 31$.

Effects of subcarrier correlation: The results obtained so far assumed independent fading across different subcarrier channels. It is interesting to see the effect of the fading correlation on the performance of different receivers for the sake of more practical system design purposes. In Figure 8, we plot the BER of ASIC-MRC under $E_b/N_0 = 20$ dB for $K = 10$ and $20$ equal power users and investigate the effect of different correlation coefficients $\rho_{l_1, l_2} \in \{0, 0.8\}$. It can be noted that
Figure 7: Effects of step size on the performance of the Adaptive SIC receiver with MRC for MC DS-CDMA with $L = 2$ under $E_b/N_0 = 20$ dB in Rayleigh fading channels $\rho_{l_1,l_2} = 0$ for $K = 10, 16, 20, 24$ users and Gold sequences of $N = 31$
the BER performance of all receivers degrade gracefully as the magnitude of $\rho_{l_1,l_2}$ increases. This result provides useful insight on the performance of ASIC for operation in practical wireless channel conditions where some correlation between the subcarriers may always exist.

![Figure 8: Effects of subcarrier correlation $\rho_{l_1,l_2}$ on the performance of the Adaptive SIC receiver with MRC for MC DS-CDMA with $L = 2$ in Rayleigh fading channels for $K = 10$ and 20 users and Gold sequences of $N = 31$](image)

5 Conclusion

We proposed and evaluated a new adaptive receiver using successive interference cancellation method for MC DS-CDMA systems. The proposed technique employs a simple cost to perform adaptive despreading to weight each incoming chip signal in a blind manner to provide the despreading function along with the additional multiple access interference suppression capability. The same despreader weights are also used to form a more reliable MAI estimate for the cancellation stage. It is shown that this approach to multiuser detection offers significant performance gain compared with conventional SIC and MF detection techniques while retaining the low receiver complexity. For example, it is shown to support 20 users compared with 16 and 8 users with the conventional techniques. With the use of optimum step size, even for a high loading......
of 24 users it offered a BER of as low as $8.5 \times 10^{-5}$, which is very near to the single user performance. Furthermore, for a range of simulation scenarios the results showed that the adaptive receiver is also much more resilient to the near far problem. Our future work will be to combine this technique with additional error correction coding to further improve the system performance.

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