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Multiuser Detection with Decision-feedback Detectors and PIC in MC-CDMA System

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Abstract

In this paper we propose an iterative parallel decision feedback (P-DF) receivers associated with parallel interference cancellation (PIC) for multicarrier code division multiple access (MC-CDMA) systems in a Rayleigh fading channel (cost 207). First the most widely detection techniques, minimum mean-squared error MMSE, Maximum Likelihood ML and PIC were investigated in order to compare their performances in terms of Bit Error Rate (BER) with parallel feedback detection P-DFD. A MMSE DF detector that employs parallel decision-feedback (MMSE-P-DFD) is considered and shows almost the same BER performance with MMSE and ML, which present a better result than the other techniques. In a second time, an iterative proposed method based on the multi-stage techniques P-DFD (parallel DFD with two stages) and PIC was exploited to improve the performance of the system.

Keywords: *MC-CDMA, multiuser detection, parallel feedback detection, MMSE, PIC*

1. Introduction

There is a vast demand for higher data rates in multi-user wireless communication system. To attain it, a promising solution is through the mixture of Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) technologies which results in Multi Carrier-CDMA (MC-CDMA) system. The MC-CDMA is an efficient technique that mitigates problems like spectral limitation and distortion due to multipath fading channels. Advantages of this technique are its robustness in case of multipath propagation, improve security and minimize the intersymbol interference ISI [1, 2].

In a MC-CDMA system, several users simultaneously transmit information over a common channel using pre-assigned orthogonal codes. It uses spread spectrum modulation and distinct spreading codes to separate different users using the same channel [3, 4]. But at the receiver, there is a loss of orthogonality among users due to the increase of the number of the active users and the channel effect. This is known as multiple access interference (MAI) which causes performance degradation over the system [5]. To overcome this problem, some optimal and sub-optimal strategies of multiuser detections (MUDs) have been proposed for MC-CDMA systems; like the linear detection receivers, the interference canceller (IC), decision feedback detection (DFD) and the multistage detector [6, 7, 8].

In order to advance the performance of MC-CDMA systems, many previous work was investigated: In linear detectors two techniques have been recommended, these are decorrelating detector and the minimum mean squared error (MMSE) detector [9], but it present a difficulty when increasing the number of users and high computation complexity in MMSE channel estimation [10]. A novel multi-path multi-carrier decorrelator (MMD) receiver structure is proposed in [11] include the maximum likelihood (ML), Wiener filter (WF) and matched filter (MF) techniques. For an uplink communication in cellular network, iterative receivers with parallel interference cancellers (PIC) detectors or Successive interference cancellers (SIC) detectors are adopted in [4, 12, 13].

In other hand, multiuser decision feedback detection has been exploited for channel estimation and linear interference suppression in DS-CDMA [14]. A decision-feedback receiver was evaluated in Time-Selective Fading CDMA Channels in [8]. A multistage decision-feedback detection for DS-CDMA with MMSE design criterion was proposed in [15]. An adaptive iterative multiuser decision feedback detection was developed in [16]. Minimum mean-squared error

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associated with iterative successive parallel arbitrated decision feedback detectors is considered in DS-CDMA systems [17]. In order to refine the symbol estimates, multistage and iterative DF schemes are combined based on the successive interference cancellation S-DFD and parallel interference cancellation P-DFD [18].

In this work, multiuser detection in MC CDMA system for an uplink scenario was performed using the combinations of minimum mean squared error MMSE detectors with non-linear detectors such as, decision feedback detection DFD and parallel interference cancellation (PIC). In order to improve the performance of the MC-CDMA system in Rayleigh fading channel different processing are suggest, first we adopt in the analyze usually detections techniques MMSE, the maximum likelihood (ML), PIC, P-DFD and MMSE-P-DF detector. The results in terms of performance show that MMSE and ML present better performance than the other method detection. In the second time we propose an iterative method established on the multi-stage techniques MMSE-PIC, P-DFD-PIC to evaluate the system.

This paper is organized as follows: In section 2 we first review the MC-CDMA data model and formulate the problem of interest. In section 3 we examine the multiuser decision-feedback receiver, where we develop mathematical concepts of MMSE decision feedback detector and the parallel feedback detector P-DFD. Section 4 is devoted to the iterative technique and the proposed model. Section 5 presents and discusses of the simulation results, then a comparison of recently studies is made. Finally, section 6 contains conclusions.

2. MC-CDMA System Model

We consider a synchronous MC-CDMA in uplink system with binary phase shift keying (BPSK) modulation in a Rayleigh fading channel as shown in Figure 1.

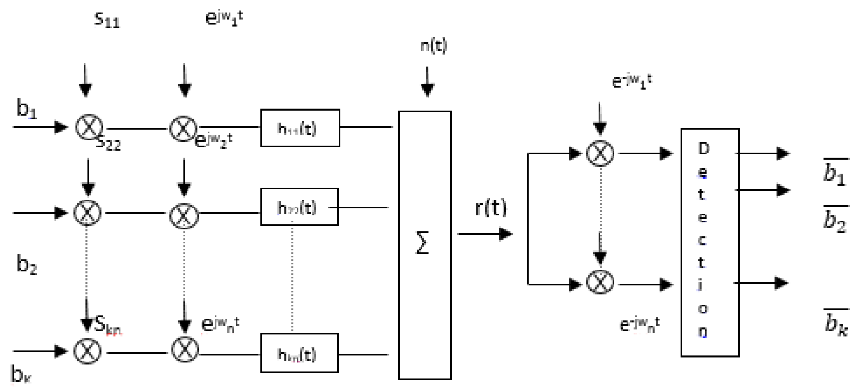

Figure 1. MC-CDMA system model

First, user bits bk are multiplied by a spreading code Skn and then inverse fast Fourier transform (IFFT) is performed. The number of sub-carriers and all users has the same spreading factor. Finally, the signal is transmitted through a Rayleigh fading channel. At the receiver, after the fast Fourier transform (FFT) operation, received vector r(t) is expressed as [19]:

$$r(t) = \sum_{k=1}^{K}\sum_{n=1}^{N} A_k b_k S_{kn} h_{kn} e^{jw_n t} + n(t), t \in [0, T_s] \quad (1)$$

where b_k is the input bit of the kth user, b_k € {1, −1}, A_k is the received amplitude of the kth user, Ts is the symbol interval and w_n=2πn/Ts. S_{kn} denotes the nth component of the kth user's spreading code, the spreading code length is the same size of the IFFT length N. The Rayleigh fading channel is denoted by h_{kn} complex coefficients and assumed frequency-flat fading for each subcarrier of all users.

$$h_{kn}(t) = C_K e^{-j\varphi_{kn}} \delta(t - t_k) \quad (2)$$

C_{kn} is amplitude of kth user that Rayleigh distribution, $\varphi_{kn}$is the phase in the range [0,2π] and t_k is the delay in range[0,T] and the additive white Gaussian noise (AWGN) is denoted n(t). Matrix form can be written (1):

$$r_n = \sum_{k=1}^{K} A_k b_k S_{kn} h_{kn} + \eta_n \quad (3)$$

where η_n a complex Gaussian random variable with zero mean and variance 2σ2/Ts. Matrix notation can be shown in (3) such as [19]:

$$r = CAb + n \quad (4)$$

$$\begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_N \end{bmatrix} = \begin{bmatrix} s_{11}h_{11} & s_{21}h_{21} & \cdots & s_{K1}h_{K1} \\ s_{12}h_{12} & s_{22}h_{22} & \cdots & s_{K2}h_{K2} \\ \vdots & \vdots & \ddots & \vdots \\ s_{1N}h_{1N} & s_{2N}h_{2N} & \cdots & s_{KN}h_{KN} \end{bmatrix} \begin{bmatrix} A_1 & 0 & \cdots & 0 \\ 0 & A_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A_K \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_K \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_K \end{bmatrix} \quad (5)$$

where

$$C = \begin{bmatrix} s_{11}h_{11} & s_{21}h_{21} & \cdots & s_{K1}h_{K1} \\ s_{12}h_{12} & s_{22}h_{22} & \cdots & s_{K2}h_{K2} \\ \vdots & \vdots & \ddots & \vdots \\ s_{1N}h_{1N} & s_{2N}h_{2N} & \cdots & s_{KN}h_{KN} \end{bmatrix} \quad (6)$$

In (4), A is the amplitude matrix which consist of amplitude values of each user, b is the original message matrix that consist of bits of each user’s message and n is noise matrix.

3. Multiuser Decision-Feedback Receiver

3.1. MMSE Decision Feedback Detector

In this part the design of synchronous MMSE decision feedback detector is described. The input to the hard decision device corresponding to the ith symbol is for:

$$z(i) = W^H r(i) - F^H \hat{b}(i) \quad (7)$$

where the input $z(i) = [z_1(i) \dots \dots z_k(i)]^T$, $W(i) = [w_1(i) \dots \dots w_k(i)]$ is the M×k feedforward matrix, $\hat{b}(i) = [\hat{b}_1(i) \dots \dots \hat{b}_k(i)]^T$ is the k×1 vector of estimated symbols, which are fed back through the k×k feedback matrix $F(i) = [f_1(i) \dots \dots f_k(i)]$. The block diagram of MMSE decision feedback receiver is shown in Figure 2.

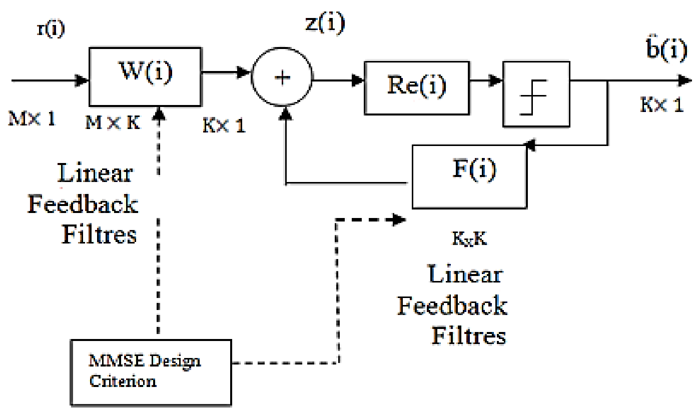

Figure 2. Block diagram of MMSE decision feedback receiver [17]

Specifically, the DF receiver design is equivalent to determining for user k a feedforward filter $w_k(i)$ with M elements and a feedback one $f_k(i)$ with k elements that provide an estimate of the desired symbol

$$z_k(i) = w_k^H(i)r(i) - f_k^H(i)\hat{b}(i), k = 1,2,\dots,K \quad (8)$$

where $\hat{b}(i) = sgn[R(W^H r(i))]$ is the vector with initial decisions provided by the linear section, w_k and f_k are optimized by the MMSE criterion. The final detected symbol is

$$\hat{b}_k^f(i) = sgn(R[z_k(i)]) = sgn(R[w_k^H(i)r(i) - f_k^H(i)\hat{b}(i)]) \quad (9)$$

where the operator $(.)^H$ denotes Hermitian transpose, R(.) selects the real part and sgn(.) is the signum function. To describe the optimal MMSE filters we will initially assume perfect feedback, that is $\hat{b} = b$,

$$e_{DFD} = b(i) - z_k(\boldsymbol{i}) \quad (10)$$

The error at DFD output. The error covariance matrix is then:

$$\epsilon_{DFD} = E[e_{DFD}e_{DFD}^H] \quad (11)$$

Then will consider a more general framework. Consider the following cost function: the MSE for user k is:

$$J_{MSE} = [\epsilon_{DFD}]_k = E\left[\left|b_k(i) - w_k^H r(i) + f_k^H \hat{b}(i)\right|^2\right] \quad (12)$$

Similarly, to Figure 2, the users are divide into two sets:

$$D = \{j: \hat{b}_j is\ fed\ back\} \quad (13)$$

$$U = \{j: j \notin D\} \quad (14)$$

where the two sets D and U correspond to detected and undetected users, respectively. Let us also define the matrices of effective spreading sequences$= [P_1 \dots\dots P_K], P_D = [P_1 \dots\dots P_D],\ P_U = [P_1 \dots\dots P_U]$. The minimization of the cost function in (12) with respect to the filters w_k and fk yields:

$$w_k = R_U^{-1} P_k \quad (15)$$

$$f_k = P_D^H w_k \quad (16)$$

where the associated covariance matrices are $R = [r(i)r_H(i)] = PP^H + \sigma^2 \mathrm{I}$

$$R_U = P_U P_H + \sigma^2 I = R - P_D P_D^H \quad (17)$$

The associated MMSE for the DF receiver with assuming perfect feedback is given by:

$$J_{MMSE} = \sigma_b^2 - p_k^H R_U^{-1} p_k \quad (18)$$

3.2. The Parallel Feedback P-DFD:

In order to design P-DFD receivers and satisfy their constraints, the designer must obtain the vector with initial decisions $\hat{b}(i) = sng[R(W^H(i)r(i)]$ and then resort to the following cancellation approach. The non-zero part of the filter f_k corresponds to the number of used feedback connections and to the users to be cancelled.

In the P-DF, the feedback connections used and their associated number of non-zero filter coefficients in f_k are equal to K−1 for all users and the matrix F(i) has zeros on the main diagonal to avoid cancelling the desired symbols. The parallel feedback interference cancellation (P-DF) receiver can offer uniform performance over the users but it suffers from error propagation (14). For the P-DF in a single cell, we have:

$$D = \{1, \dots, k-1\ k+1, \dots, K\}, U = \{k\} \quad (19)$$

$$w_k = R_U^{-1} p_k = \frac{p_k}{A_k^2 + \sigma^2} \quad (20)$$

The MMSE associated with the P-DF system is obtained by substituting $R_U = R - P_D P_H$ D into (15), which yields:

$$J_{MMSE} = \sigma_b^2 - p_k^H (p_k p_k^H + \sigma^2 I)^{-1} p_k = \frac{\sigma^2}{A_k^2 + \sigma^2} \quad (21)$$

Now let us consider a more general framework, where the feedback is not perfect. The minimization of the cost function in (8) with respect to w_k and f_k leads to the following filter expressions:

$$w_k = R^{-1}(p_k + Bf_k) \quad (22)$$

$$f_k = (E[\hat{b}\hat{b}^H])^{-1} B^H w_k \approx B^H w_k \quad (23)$$

where
$P_K = E[B_k^*(i) r(i)] = S_{kn} h_{kn}$ (effective spreading sequences)
$R = E[r(i) r^h(i)]$, The receiver input covariance matrix
$B = E[r(i)\hat{b}^H(i)]$,et $E[\hat{b}\hat{b}^H] \approx \mathrm{I}$
for small error rates. The associated MMSE for DF receivers subject to $E[\hat{b}\hat{b}^H] \approx \mathrm{I}$ and imperfect feedback is approximately given by

$$J_{MMSE} \approx \sigma_b^2 - p_k^H R^{-1} p_k - p_k^H R^{-1} B f_k \quad (21)$$

Note: The MMSE associated with DF receivers that are subject to imperfect feedback depends on the matrix $B = E[r\hat{b}^H]$ and the feedback filter f_k or set of filters F.

4. Iterative Section

In this section, we present iterative Decision Feedback DFD based on parallel feedback with hard decisions, defined by the recursion:

$$x^{(m+1)}(i) = F^H r(i) - B^H \hat{b}^{(m)}(i)\} \quad (22)$$

where F and B are the P-DFD filters, and $\hat{b}^{(m)}$ is the vector of tentative decisions from the preceding iteration. For the uncoded P-DFD with hard decisions and binary signaling, have:

$$\hat{b}^{(1)}(i) = sng\{F^H r(i)\} \quad (23)$$

$$\hat{b}^{(m)}(i) = sng\{x^m(i)\}\ m>1 \quad (24)$$

where the number of stages m depends on the application. More stages can be added and the order of the users is reversed from stage to stage.

4.1. P-DFD-PIC Receiver

The detection of the MAI is calculated for each user and subtracts from the outputs of the adapted filter. it is applied for all users in a bit period even the uncorrected bits are also considered correct, so the BER performance of a PIC of one stage is not better. We can improve the performance of the PIC receiver with a multi-stage structure but the system will become more complex.

In the PIC, the output of the filter bank (matched filter) is taken as input of the corresponding stage, the BER performance of the PIC is degraded when the number of active user's increases, errors increase in the input of the PIC, so BER performance of the PIC degrades. In the proposed receiver P-DFD-PIC is an iterative method with P-DFD (with two stage) and PIC is considered. P-DFD decision device is used between the output of the matched filter and the PIC input. In this case, PIC uses more correct bits than the output of the matched filter.

5. Results and Discussion

In this part: the performances of the multiuser MUD detection techniques are exposed for an uplink MC-CDMA system, in Rayleigh fading channel (cost 207 channel). For uplink mobile channel with BPSK modulation scheme and Walsh Hadarmad orthogonal codes of processing gain of 16 is used. The binary source data rate of 512 kbit/s are considered. With serial to parallel conversion factor of 4,8 and processing gain of 16, Number of actives user is 8,16 and 32, plus an appropriate CP.

Figures 3, 4 ,5 below on the left show the BER value versus SNR for MMSE, ML, parallel DFD (non-iterative) and multiuser bound(MUB) compared with an estimation of the channel using an adaptive Least Square filter (LS), this form of estimation with adaptive filter is generally adopted in multi-pilot MIMO-OFDM systems [14].

The results of performances show perfectly that the ML and MMSE techniques offer better results compared to the two other techniques SL and the P-DFD which gives a less efficient result. In Figures 3, 4, 5 below on the right, we represent combination of the two techniques MMSE and P-DFD (MMSE-P-DFD) receivers which makes the performances similar to those of the ML and MMSE techniques, which stays even better with the SNR less than 10 dB for k=8. The MMSE detector offers the best performance. For this reason, the performance of this technique is presented in the results which will follow for comparison.

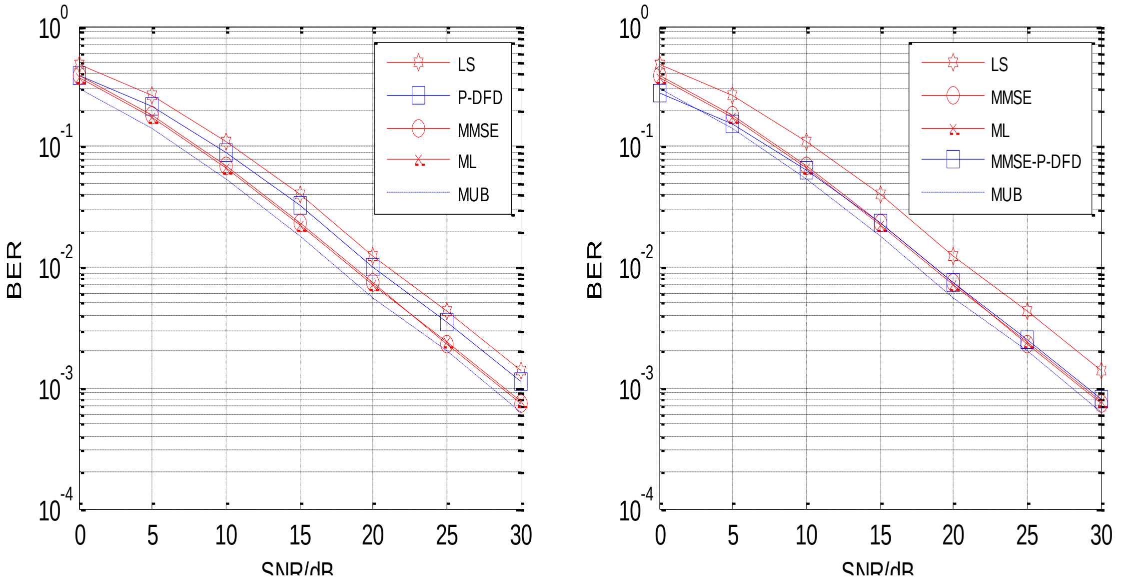

Figure 3. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=8)

In order to exploit interference cancelation an iterative section is investigated with a comparative study between two methods which are the PIC and the P-DFD (with two additional iterations). Figures 6, 7, 8 below on the left, Show a comparison of the BER performance of the linear MMSE, PIC, the three stages PIC (3 PIC), and iterative P-DFD (with two additional iterations). The 3PIC and the P-DFD always give the best performance compared to the other techniques and the result of these receivers follows the MMSE performance. With the evolution of the number of users (8, 16 and 32), there is a degradation of performance for all techniques but the 3PIC, P-DFD and MMSE always remain the methods that give the most correct performances.

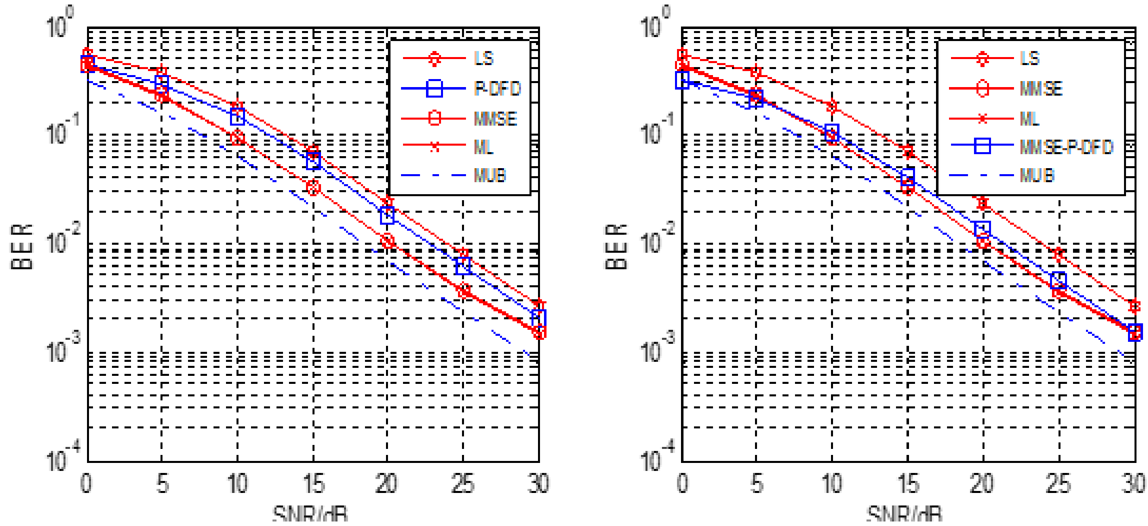

Figure 4. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=16)

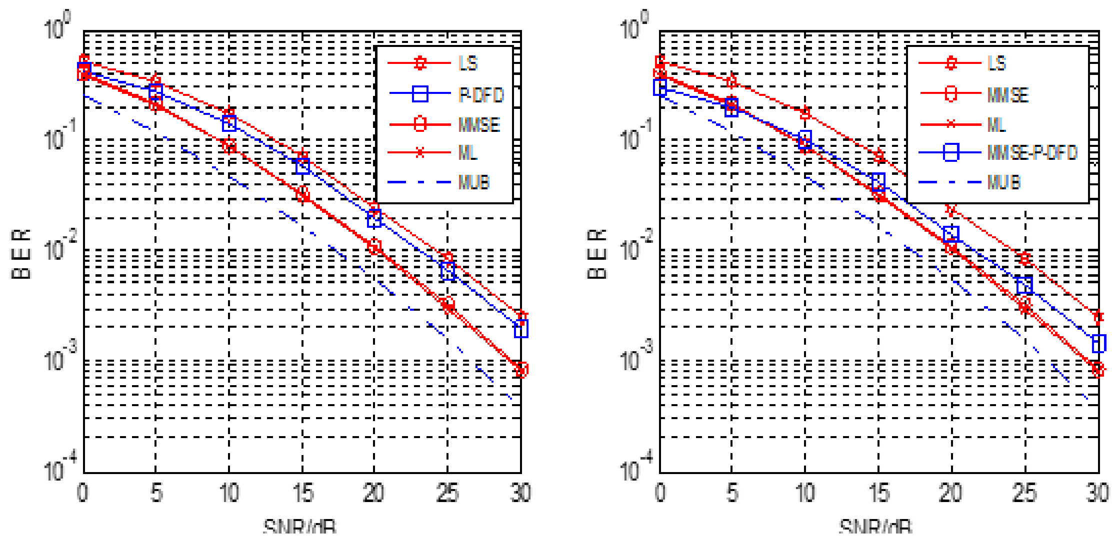

Figure 5. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=32)

In Figures 6, 7, 8 below on the right, the curves show the combinations of the MMSE-P-DFD and P-DFD-PIC techniques, compared with the PIC and 3 PIC. The performance variations in the iterative combination of the proposed method P-DFD-PIC gives performances results superior to other techniques but still close to the MMSE-P-DFD combination, and hence a significant improvement over all other exposed receivers. Increasing the number of users causes a degradation in the performance results, however the combination

MMSE-PIC always gives the best results, for k=32 we observe a superposition of graphs, the receiver P-DFD-PIC is almost the same with MMSE-P-DFD.

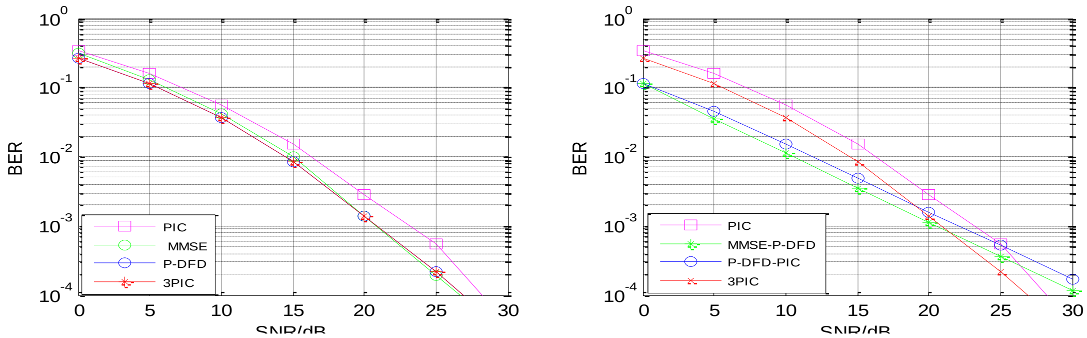

Figure 6. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=8)

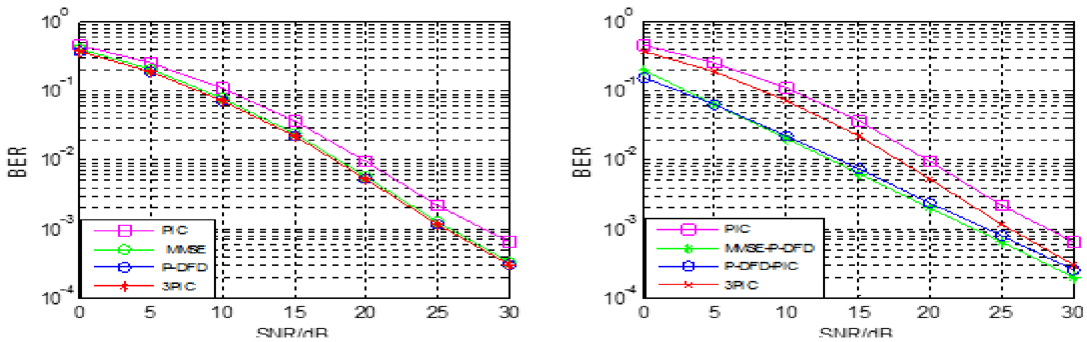

Figure 7. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=16)

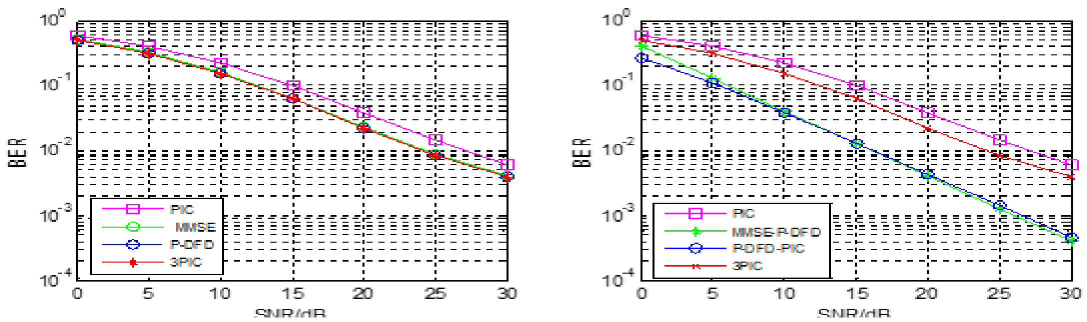

Figure 8. Performance comparison of different receivers for synchronous MC-CDMA (BER versus SNR, k=32)

5.1. Comparison of results

In the same concept of multistage detection, in [20] they employed multi -level detection with the PIC multi-user detection's performance comparison, which uses the maximum ratio combining (MRC), de-correlation (DEC) and minimum mean square error (MMSE) in first-level detection. The result exhibit that the detection which uses MMSE have the best performance than the others detection. When the previous level detection is not effective the performance of the following levels will be seriously affected.

In addition, in [12] a PIC with neural network receiver are investigated for AWGN and Rayleigh fading asynchronous channels in MC-CDMA system. it shows that multi-stage detection improves performances of system specifically when the PIC is established in the last stage with neural network receiver.

Considering the use of high dimensional systems in the next generation of wireless systems, such as massive multi-user MIMO systems where cdma is one modulation technique candidate for the next generation of wireless systems, used to improve complexity detectors algorithm [21]. Moreover, a multiple of recent studies advised the minimum mean-square error (MMSE) and different combining schemes with parallel interference cancellation (PIC), decision feedback detectors (DFD), frequency domain equalization (FDE) and zero forcing (ZF) on the performance of MC-CDMA system among different scenario (MC-CDMA cellular systems, uplink of MC-CDMA systems, and multicarrier complementary-coded MC CC-CDMA).

The performance of the proposed OFDM-CDMA joint detectors with orthogonal and non-orthogonal spreading sequences are investigated in mobile radio channels in [22]. Simulation examples are given to demonstrate the effectiveness of the proposed detectors zero forcing (ZF) and minimum mean square error (MMSE) detectors with decision feedback (DF) structures. The channel sorting method offers approximately 2 dB gain for the decision feedback detectors (DFD) and reduces the impairing effect of error propagation. The bit error rate (BER) performance of orthogonal codes is better than that of non-orthogonal ones in time varying channels.

In [23], the aim to enhance the performance of downlink MC CC-CDMA system by mitigating MAI in frequency-selective Nakagami-m fading channels. A comparison among different combining schemes is suggested to show the impact of PIC with minimum mean square error combining (MMSEC) and maximal ratio combining (MRC) on the performance of MC CC-CDMA system. The simulation results show that the combination of general combining schemes with PIC provides an efficient solution to suppress MAI in downlink MC CC-CDMA system than conventional MC-CDMA systems using Walsh codes under frequency-selective channels.

In [24] the paper proposed a new algorithm to improve Modified Minimum Mean Square Error Frequency Domain Equalization (Modified MMSE-FDE) performance in mitigating multiuser interference (MUI) in single cell MC-CDMA uplink system. In order to get signal processing more efficient, in Carrier Frequency Offset Estimation-Minimum Mean Square Error Frequency Domain Equalization (CFO Estimation-MMSE FEQ). Takes only the real trace of equalization coefficient matrix makes better performance of Estimation-MMSE FEQ in MC-CDMA with CFO, than MC-CDMA with Modified MMSE-FDE.

6. Conclusion

Our first contribution focused on the study of the multiuser MMSE, ML and P-DFD (Parallel decision-feedback detector) based on structures of synchronous MC-CDMA system receivers were applied on an uplink scenario in the Rayleigh fading channel. The results are compared with an estimation of channel using an adaptive Least Square filter (LS) and an association of two methods MMSE and P-DFD which gives better performance in large loaded system compared with MMSE and ML.

Another so-called iterative receiver technique based on the multistage techniques PIC and P-DFD (parallel DFD with two additional iterations) was proposed in the second section. The results of exploiting the possibility of combining the two techniques (P-DFD and PIC) allow us to conclude that the combination of methods contributes to improve the performance of the system which remain stable with the evolution of the number of users (8, 16 and 32) and even better than MMSE-P-DFD in the first part.

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