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Multi-user Detection with Different Linear Equalizers for the Downlink MIMO MC-CDMA Systems over Frequency Selective Fading Channel

By

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Abstract:

Modern wireless communications require an efficient spectrum usage and high channel capacity and throughput. Multiple input and multiple output (MIMO), Linear equalizers, multi-user detection (MUD) and multicarrier code-division multiple access (MC-CDMA) are possible solutions to achieve spectral efficiency, high channel capacity, eliminate MAI , eliminate ISI and robustness against frequency selective fading. In this paper, we combine all these techniques and investigate BER performance. We propose a low complexity receiver structure for Single-input Multiple-output (SIMO) downlink MC-CDMA systems. It employs an interference cancellation scheme to suppress the interference caused by the multipath fading channel. Also, the proposed scheme is developed for Multiple-input Multiple-output (MIMO) MC-CDMA system. The performance analysis of Downlink MIMO MC-CDMA systems with V-BLAST over frequency selective fading channel is investigated under various number of transmit and receive antennas. The simulation results show that MIMO MC-CDMA with V-BLAST multi-user detection provides high data rate and the BER significant improvement when MIMO-MC CDMA with multi user detection and different linear equalizers is applied.

Keywords:

MC-CDMA, SIMO, MIMO, MMSE, RZF, PIC, ISI,MAI and rake receiver.

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1. Introduction:

High data rate and high quality multimedia services are demanded in a fourth generation mobile communication, since application services are increasing. To meet this demand, multi carrier code division multiple access (MC-CDMA) is attractive and widely studied in recent years [1,2].
The combination of multicarrier and code division multiple access (MC-CDMA) has been preliminarily successful because it incorporates the benefits of orthogonal frequency-division multiplexing (OFDM) and spread-spectrum presents good potentialities to make it the best technology to support broadband applications [1,2,4]. Moreover, MC-CDMA systems relieve the limitations on system capacity that occur in direct-sequence code division multiple access (DS-CDMA) systems.
The major advantages of MC-CDMA which lie behind its success are robustness in the case of multipath fading, a very reduced system complexity due to equalization in the frequency domain, and the capability of narrow-band interference rejection. It also has an ability to reduce users
signal power during transmission using a spreading so that the user can communicate using a low-level transmitted signal, which is closer to the noise power level [4].
Multiple-input multiple-output (MIMO) spatial multiplexing systems [3] increase the capacity significantly over single-input single-output (SISO) systems by employing multiple transmit and receive antennas.
SIMO architecture is one of the most solutions for high data rate due to there enormous potential for capacity gains relative to single input single output (SISO) architecture.
Also the use of MIMO for wireless communications produces significant performance improvements, including the reduction of bit error rates and the increase of capacity [5–6, 7].
However, channel equalization in broadband MIMO systems can potentially be very complex due to the superposition of all of the transmitted streams at each receive antenna. The complexity of the equalization process can be mitigated somewhat by performing equalization in the downlink MC-CDMA at the receiver [2,11]. In this paper, we propose a low Complexity interference cancellation architecture for downlink SIMO and MIMO downlink MC-CDMA systems. The proposed scheme uses the parallel interference cancellation (PIC) to subtract the interference before equalization. The efficiency of this scheme comes from the frequency domain implementation of all filters. The performance of this scheme is studied and compared.
The difference between downlink MC-CDMA with PIC in our proposed scheme and frequency domain interchip interference cancellation (FD-ICI) in Takeda & Adachi’s scheme [11] is that in FD-ICI, the residual ICI is regenerated and subtracted in the frequency domain from each frequency component after FDE. But, in downlink MC-CDMA with PIC, another type of interference (MAI) is regenerated in downlink MC-

CDMA and subtracted before equalization.
The rest of this paper is organized as follows. Section 2 investigates some different decision functions. Section 3 describes interference cancellation for SIMO downlink Mc-CDMA System. In Section 4, interference cancellation for MIMO downlink MC-CDMA system is discussed. Simulation results and conclusion are presented in Sections 5 and 6, respectively.

***Notations*:** The symbols $(.)^H, (.)^T, and\ (.)^{-1}$ designate complex conjugate transposition, transposition of a matrix, and the inverse of a matrix, respectively. Vectors and matrices

are represented in boldface**.** denote the inverse fast Fourier transform and the fast Fourier transform operators, respectively.

2. Decision Functions

The performance of PIC depends on the tentative decision function used. So, due to error propagation, PIC with a hard decision function may perform worse than PIC with linear or soft decision functions [8,10]. Hard-decision interference cancellation can completely cancel interference only when the hard decisions made are correct which not the case in all decisions is. The most popular decision functions are:

2.1 The hard decision function:

$$y = f_{dec}(x) = \begin{cases} 1, & x \geq 0 \\ -1, & x < 0 \end{cases}$$
(1)

It makes a hard decision in the favor of one of the two possible symbols.

2.2 The null zone decision function:

$$y = f_{dec}(x) = \begin{cases} 1, & x > C_n, \\ 0, & x \in [-C_n, C_n], \\ -1, & x < -C_n. \end{cases} \qquad (2)$$

It makes a hard decision when the soft bit estimate lies outside the interval $[-C_n, C_n]$, and sets the decision result to zero when the soft bit estimate lies inside this interval. C_n is the null zone decision threshold ($0 \leq C_n \leq 1$) [8, 10].

2.3 The linear decision function:

$$y = f_{dec}(x) = x. \tag{3}$$

It performs worse than the other decision functions.

2.4 The unit clipper decision function:

$$y = f_{dec}(x) = \begin{cases} 1, & x > 1, \\ x & x \in [-1, 1], \\ -1, & x < -1. \end{cases} \tag{4}$$

It makes a soft bit decision when the soft bit estimate lies inside the interval [-1,1] to avoid the propagation of errors, and makes a hard decision when the soft bit estimate lies outside the interval [-1,1] to avoid the noise enhancement [10].

2.5 The tanh decision function:

$$y = f_{dec}(x) = \tanh(x). \tag{5}$$

It is adopted as the optimum decision function for non frequency selective fading channels with the MAI modeled as AWGN in the systems having a large number of users.

3. SIMO Mc-CDMA System:

3.1. System Model

The downlink MC-DMA block transmission with K active users and N_r receiver antennas over a frequency selective fading channel is considered. A schematic diagram of the baseband block transmission system is depicted in Fig. 1. Each user transmits BPSK information symbols. Those symbols are spread using a certain spreading code. After spreading, the resulting signal is scrambled using a complex scrambling sequence, after that the inverse fast Fourier transform(IFFT) is applied to the resulting signal and a cyclic prefix of N_{CP} chips is added at the beginning of each block. The length of the cyclic prefix must be greater than the maximum excess delay of the channel to accommodate for the interblock interference (IBI). At the receiver, the cyclic prefix is removed and the received symbols are sent to an FFT block to demultiplex the multicarrier signal.

The propagation channel is assumed to be a frequency selective block fading channel having chip-spaced L discrete paths, each subjected to independent fading. The assumptions of block fading means that the path gains remain constant over at least one block duration. The discrete-time impulse response $h_j(t)$ of multipath channel observed by the jth $(1 \le j \le Nr)$ receive antenna can be expressed as [11]:

$$h_j(t) = \sum_{l=0}^{L-1} h_{j,l}\,\delta(t - \tau_l) \qquad (6)$$

Where $h_{j,l}$ and τ_l represent the complex-valued path gain experienced at the jth antenna and the propagation delay of the lth path (l=0~L-1), respectively and L is the number of multipath components of the channel impulse response h. In this paper, we assume block fading with three multipath L=3, where the path gains stay constant over each block duration.

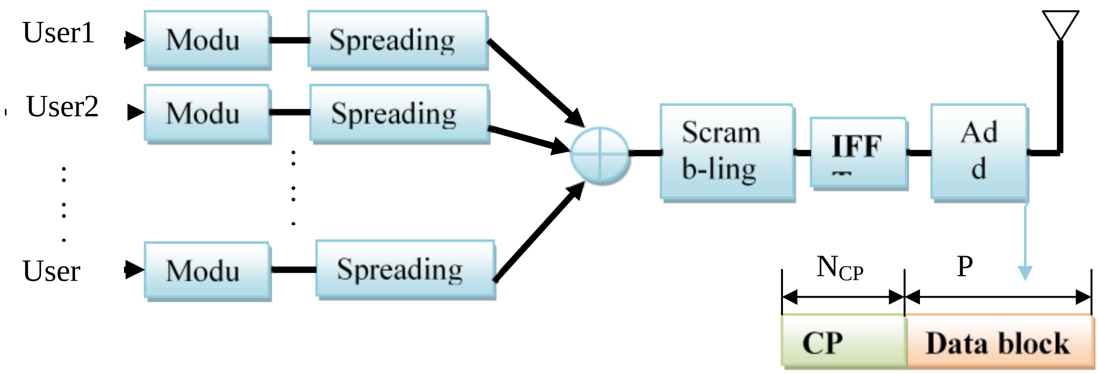


Figure (1): *Downlink MC-CDMA transmitter and transmit block*

The chip sequence received on the jth antenna can be expressed as [11]:

$$\mathbf{r}_j(t) = \sum_{l=0}^{L-1} \mathbf{h}_{j,l}\,\mathbf{d}(t - \tau_l) + \mathbf{n}_j(t) \qquad (7)$$

where n_j is the noise, and $d(t)$ is the transmitted signal. In matrix notation, the received signal is represented as:

$$\mathbf{r} = \mathbf{H}_{CT}\mathbf{d} + \mathbf{n} = \mathbf{H}_{CT}\mathbf{d}_{des} + \mathbf{H}_{IT}\mathbf{d}_{int} + \mathbf{n} \qquad (8)$$

The notations are listed below:

$$\mathbf{r} = [\mathbf{r}_1 \;\cdots\; \mathbf{r}_{N_r}]^T$$
$$\mathbf{H}_{CT} = [\mathbf{H}_{C1} \;\cdots\; \mathbf{H}_{CN_r}]^T \qquad (9)$$

(10)

$$\mathbf{n} = [\mathbf{n}_1 \; \dots \; \mathbf{n}_{N_r}]^T \qquad (11)$$

where:

H_{Cj} : is a circulant Toeplitz matrixof the *j*th channel.

d: is the data vector.

n_j : is the noise vector.

d_{des}: is a vector of the desired bits.

d_{int}: is a vector of the interference bits.

The vector d can be represented as:

$$\mathbf{d} = \mathbf{F}^{-1}(\mathbf{CSb}) \qquad (12)$$

where **C** is a scrambling code matrix, **S** is a block diagonal matrix whose diagonal consists of the spreading codes, and **b** is a vector consisting of the users' amplitudes and the transmitted bits. After removal the cyclic prefix from the received signal, the received signals are transformed into frequency domain, and the FFT of the received signal is given by:

$$\mathbf{R} = \mathbf{ED} + \mathbf{N} = \underbrace{\mathbf{ED}_{des}}_{\text{useful diversity}} + \underbrace{\mathbf{ED}_{int}}_{\text{MAI}} + \underbrace{\mathbf{N}}_{\text{Noise}} \qquad (13)$$

Where:

$$D_{des} = F(CS_d b_{des}) = F(d_{des}) \qquad (14)$$

$$D_{int} = F(CUb_{int}) = F(d_{int}) \qquad (15)$$

$$N = [N_1 \; \dots \; N_{Nr}]^T \qquad (16)$$

$$E = [E_1 \; \dots \; E_{Nr}]^T \qquad (17)$$

$$R = [R_1 \; \dots \; R_{Nr}]^T \qquad (18)$$

where $\mathbf{S_d}$ is the spreading code of the desired user, **U** is a matrix containing the spreading codes of the interfering users, $\mathbf{b_{des}}$ is the desired user data, $\mathbf{b_{int}}$ is a vector containing the interfering users' data, and $\mathbf{E}_j$ is a diagonal matrix containing the FFT of the circulant sequence of $\mathbf{H}_{Cj}$.

From Eq. (13), it is found that only the first term contains the desired data, the second term is due to the MAI, and the third term is a noise term.

3.2 Interference Cancellation for Downlink SIMO MC-CDMA Systems:

The block diagram (two-antenna example) of the proposed receiver for SIMO downlink MC-CDMA systems is depicted in figure 2. It uses SIMO equalization to estimate the interfering bits. Then, PIC is used to regenerate, and cancel the MAI in the frequency

domain. After that, the SIMO equalization is used to provide a better estimate of desired user's data. The proposed scheme is called SIMO EQUALIZATION-PIC scheme and the proposed equalizers are the minimum mean square error (MMSE) and regularized zero forcing (RZF) [8, 10].
Based on the received signal in Eq. (13), the SIMO equalization (MMSE, RZF) can be employed as follows:

$$\hat{\mathbf{D}} = \square\mathbf{R} \quad (19)$$
$$\mathbf{W} = [\mathbf{w}_1, \dots, \mathbf{w}_{\square r}] \quad (20)$$

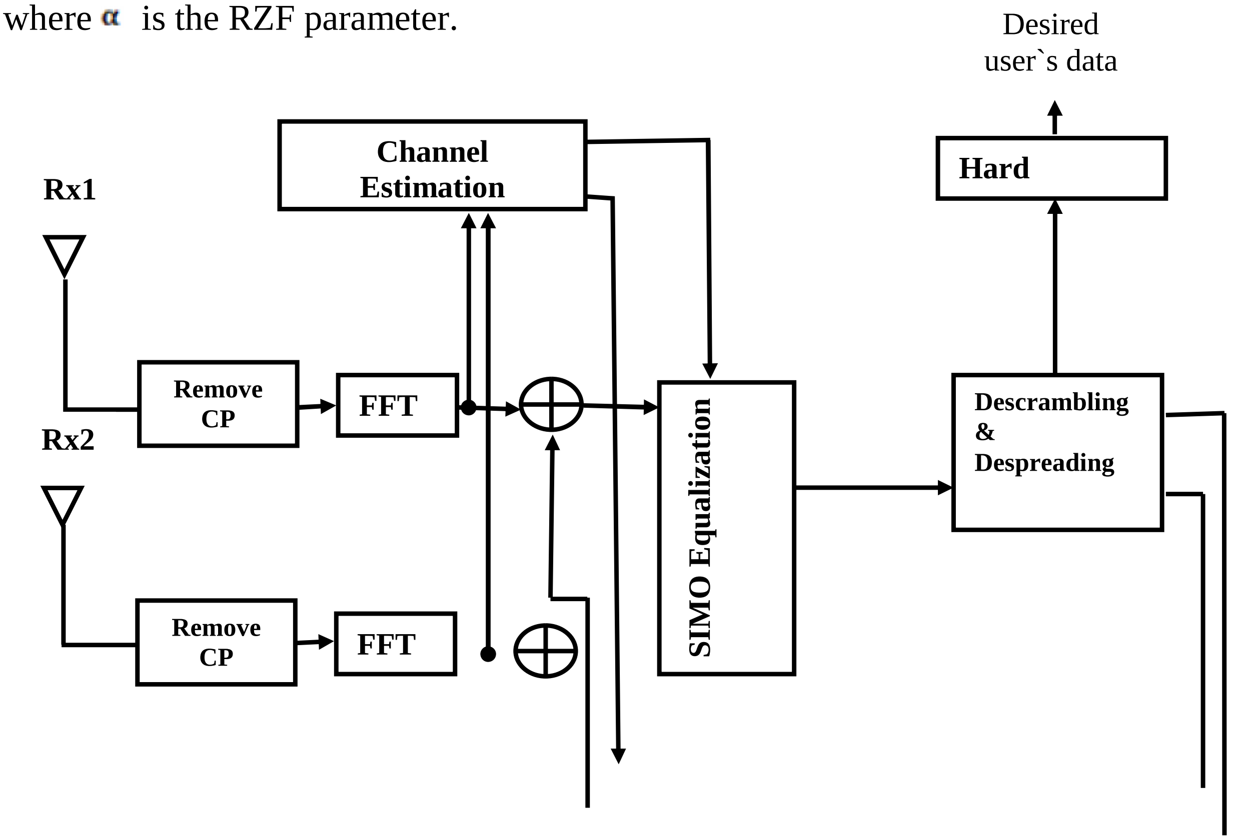
$\mathbf{W}_j$ can be chosen according to the channel parameter $\mathbf{E}_j$ and minimum mean square error (MMSE) criterion:

$$\mathbf{W}_j = \mathbf{E}_j^H \left(\mathbf{E}_j \mathbf{E}_j^H + \frac{\sigma_j^{\square}}{\sigma_d^2} \mathbf{I} \right) \quad (21)$$

where σ_j^2 is the variance of the additive noise at the *j*th antenna, and σ_d^2 is the variance of the transmitted signal.
And $\mathbf{W}_j$ can be chosen according to the channel parameter $\mathbf{E}_j$ and regularized zero forcing (RZF) criterion:

$$\mathbf{W}_j = \mathbf{E}_j^H \left(\mathbf{E}_j \mathbf{E}_{\square}^H + \alpha \mathbf{I} \right) \quad (22)$$

where α is the RZF parameter.



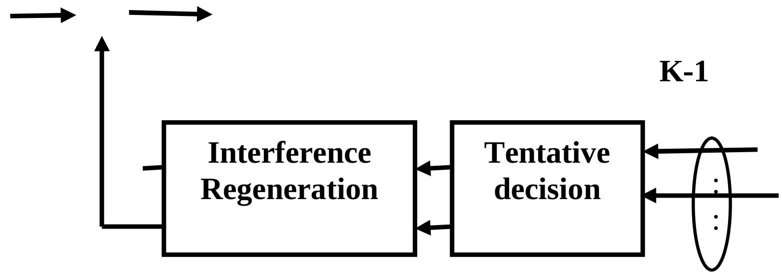


Figure (2): *The proposed SIMO EQUALIZATION-PIC scheme when Nr = 2 FOR downlink MC-CDMA systems*

The transmitted data symbols of the interfering users are obtained after descrambling and despreading. The estimates of the symbols obtained here are the first decision made, and we refer to this as tentative decision. This step can be written as:

$$\hat{\mathbf{b}}_{int} = f_{dec}\,(\mathbf{U}^{T}\mathbf{C}^{□}\hat{D}) \qquad (23)$$

Where f_{dec} is a tentative decision. The tentative decision data is then spread and scrambled using the corresponding codes and a replica of the interfering signal is reconstructed with the channel parameters and FFT operation. The interfering signal can be written as:

$$\mathbf{R}_{MAI} = \mathbf{EF}^{-1}\,\hat{□}_{int} \qquad (24)$$

$$\hat{\mathbf{D}}_{int} = \mathbf{CU}\hat{□}_{int} \qquad (25)$$

The interfering signal is subtracted from the original received signal as follows:

$$\mathbf{Z} = \mathbf{R} - \mathbf{R}_{□AI} \qquad (26)$$

After interference cancellation, SIMO Equalization is performed as follows:

$$\mathbf{D}_{Final} = \mathbf{W}F(\mathbf{Z}) \qquad (27)$$

Finally, the desired user's symbols can be obtained after equalization operation, descrambling and despreading as follows:

$$\hat{\mathbf{b}}_{1}des = sign(real(S_{1}d^{T}\,T\,C^{H}\,H\,(\hat{□}_{1}Final)))$$
(28)

We refer to this decision as the final decision. In order to improve the performance further, the suggested algorithm can be implemented in multistage. However, multistage

implementation leads to increase the complexity.
The main advantages of this receiver are that, in addition to provide greater performance and capacity when compared to the Equalization-PIC in SISO scenarios, all filters in the receiver are implemented in the frequency domain. However, its complexity increases if the number of receiving antennas increased.

4. MIMO MC-CDMA System:

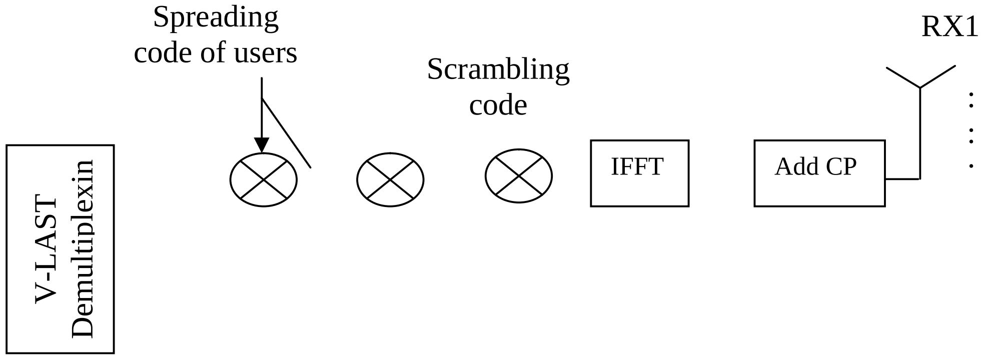
MIMO transmission techniques are divided into two classes: space time coding (STC) and spatial multiplexing. So far most researchers in MIMO CDMA focus on the STC CDMA system [8]. This paper proposes a MIMO MC-CDMA system that employing Vertical Bell labs Layered Space Time architecture (V-BLAST).

4.1 System Model

The structure of MIMO MC-CDMA transmitter that employing VBLAST with K users can be depicted as in Fig. 3. In this system, three types of interference should be suppressed at the mobile station: (1) multiple access interference (MAI) (2) inter antenna interference (IAI); (IAI exists between different base station's antennas) (3) Inter symbol interference (ISI) due to the multipath distortion. As shown in Fig. 3, each user's data are demultiplexed to N_t substreams by the V-BLAST demultiplexer. Then the substreams of one user are spread by the same signature sequence. After spreading, the resulting signal is scrambled using complex scrambling sequence. After scrambling the inverse Fast Fourier transform operation is applied to the resulting signal and a cyclic prefix of N_{CP} chips is added at the beginning of each block to form a transmit block. The result substreams are transmitted through N_t antennas.
In order to prevent inter-cell interference scrambling code is applied to the transmission data streams. At the receiver, the cyclic prefix is discarded to prevent the interblock interference. The *m*th ($m = 0, \ldots, M-1$) sample of the received signal at the *j*th receiver antenna ($1 \leq j \leq Nr$) elements can be expressed as [6]:

$$r_j[m] = \sum_{i=1}^{Nt} \square . \sum_{l=0}^{L-1} d_i(m-l) h_{\square,i}[l] + z_j(m) \qquad (29)$$

where $di(m)$ are the chips transmitted by the *i*th antenna, $hj,i(l)$ is the channel impulse response coefficient between the *i*th transmit antenna and the *j*th receive antenna.



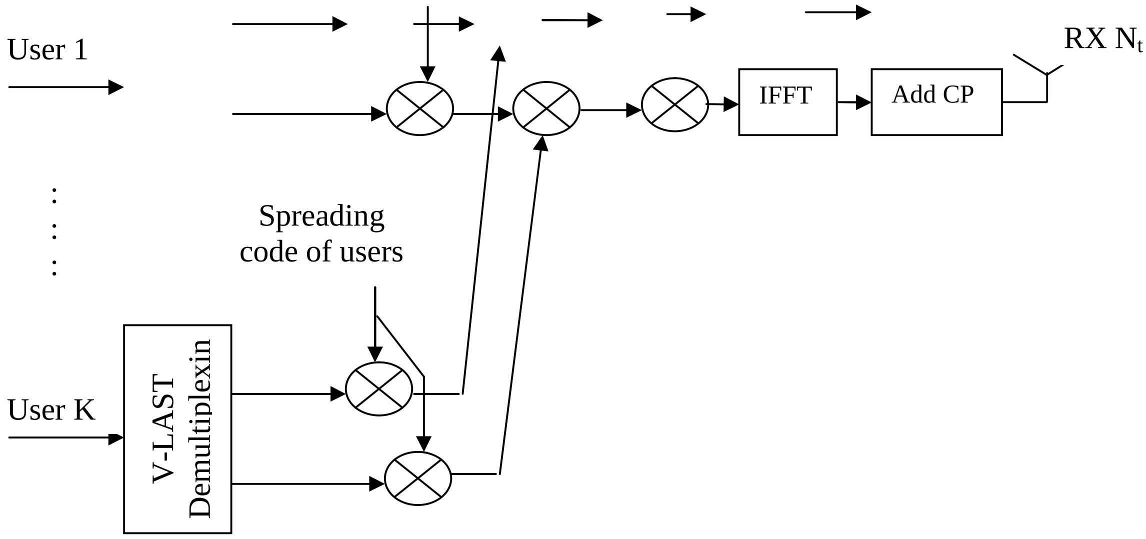


Figure 3. *Multi-carrier assisted MIMO downlink MC-CDMA system*

4.2. Interference Cancellation for Downlink MIMO MC-CDMA Systems

This section describes the suggested frequency domain interference cancellation for downlink MIMO CDMA systems. The suggested scheme is called MIMO Equalization (MMSE, RZF)-PIC and it is shown in Figure 4. It consists of two stages. At the first stage, the cyclic prefix is discarded to prevent the interblock interference (IBI). Then, the received signals are transformed into frequency domain, and the *p*th frequency tone of the received signal can be written as:

$$\mathbf{R(p) = H(p)D(p) + N(p)} \tag{30}$$

where**:**

$$\mathbf{R(p) = [R_1(p), R_2(p), \dots, R_{N_r}(p)]^T} \tag{31}$$

$$\mathbf{D(p) = [D_1(p), D_2(p), \dots, D_{N_t}(p)]^T} \tag{32}$$

$$\mathbf{N(p) = [N_1(p), N_2(p), \dots, N_{N_r}(p)]^T} \tag{33}$$

And

$$\mathrm{H(p)} = \begin{pmatrix} H_{1,1}(p) & H_{1,2}(p) & \dots & H_{1,N_t}(p) \\ H_{2,1}(p) & H_{2,2}(p) & \dots & H_{2,N_t}(p) \\ \dots & \dots & \dots & \dots \\ H_{N_r,1}(p) & H_{N_r,2}(p) & \dots & H_{N_r,N_t}(p) \end{pmatrix} \tag{34}$$

$R_j(p)$: is the pth frequency tone at the jth receive antenna. $\mathbf{H}(p)$ can be simply expressed as:

$$\mathbf{H(p) = [H_1(p)\ H_2(p) \ldots \square_{N_t}(p)]} \tag{35}$$

After that, a series of MIMO-Equalization, descrambling, despreading and tentative decision is carried out to obtain the tentative decisions. The output of the MIMO Equalization can be written as:

$$\mathbf{\hat{D}(p) = W(p)\square(p)} \tag{36}$$

where [6] for MMSE**:**

$$\mathbf{W(p) = H^H(p)\left(H(p)H^H(p) + \square_0 I\right)^{-1}} \tag{37}$$

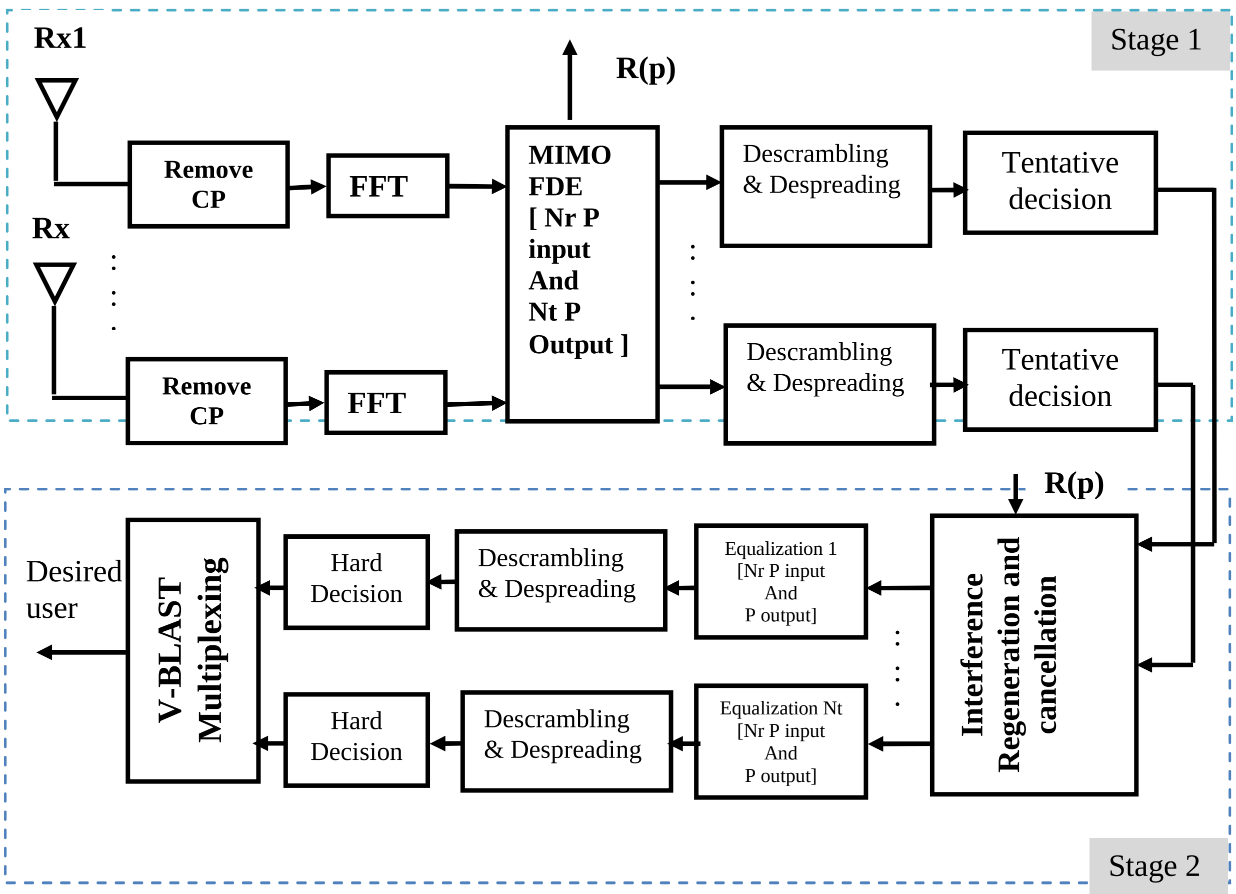


Figure (4): *The structure of the suggested MIMO Equalization-PIC for downlink MIMO MC-CDMA systems*

And for RZF:

$$\mathbf{W}(\mathbf{p}) = \mathbf{H}^{\mathbf{H}}(\mathbf{p})\left(\mathbf{H}(\mathbf{p})\mathbf{H}^{\mathbf{H}}(\Box) + \alpha\mathbf{I}\right)^{-1} \qquad (38)$$

At the second stage of the MIMO Equalization-PIC, the tentative decisions of the interferers from the first stage are cancelled from the received signal. The regenerated interference signals from the *i*-th transmit antenna can be written as:

$$\mathbf{V}^{(\mathbf{i})}(\mathbf{p}) = \mathbf{H}_{\mathbf{i}}(\mathbf{p})\widehat{\mathbf{D}}_{\mathbf{i}}(\mathbf{p}) \qquad (39)$$

The modified received signal associated to the *n*-th transmit antenna is given by:

$$\mathbf{Z}^{(\mathbf{n})}(\mathbf{p}) = \mathbf{R}(\mathbf{p}) - \sum_{\mathbf{i}=1,\mathbf{i}\neq\mathbf{n}}^{\mathbf{Nt}} \mathbf{V}^{(\mathbf{i})}(\mathbf{p}) \qquad (40)$$

The MMSE based Equalization weight with the *i*th transmits antenna is then:

$$W_i(p) = \mathbf{H}_i^{\mathbf{H}}(p)\left(\mathbf{H}_i(p)\mathbf{H}_i^{\mathbf{H}}(p) + N_0\Box\right)^{-1} \qquad (41)$$

And the RZF based Equalization weight with the *i*th transmits antenna is then:

$$\mathbf{W}_{\mathbf{i}}(\mathbf{p}) = \mathbf{H}_{\mathbf{i}}^{\mathbf{H}}(\mathbf{p})\left(\mathbf{H}_{\mathbf{i}}(\mathbf{p})\mathbf{H}_{\mathbf{i}}^{=}(\mathbf{p}) + \alpha\mathbf{I}\right)^{-1} \qquad (42)$$

Finally, the desired user's data can be obtained after descrambling, despreading, hard decision, and VBLAST multiplexing.

5. Simulation Results:

Simulations have been carried out in two different ways: BER of the desired user versus the SNR, and BER of the desired user versus the number of active users. The channel is assumed to be frequency selective Rayleigh fading channel having chip-spaced 3-path uniform power delay profile (i.e., $E[|h_l|^2] = 1/L$ for all l). More details of the simulation parameters are given in Table 2. All users are assigned the same power.

Table (1): *Simulation parameters*

Modulation	BPSK, QPSK
Spreading codes	OVSF codes with processing gain 16
Scrambling codes	Complex scrambling sequence
Multipath channel	*L* = 3-path, uniform power delay profile
FFT points	*P* = 256
Cyclic prefix	*NCP* = 16
Equalization	MMSE equalizer, RZF equalizer

Case1: SIMO: In this case, the performance of the proposed SIMO MMSE-PIC with different tentative decision functions studied. And the performance of the proposed SIMO Equalization-PIC is compared to that of SIMO Equalization (MMSE, RZF), SISO Equalization (MMSE, RZF)-PIC, and the RAKE receiver. In this case, each user transmits BPSK information symbols.
Figure 5 illustrates the BER versus the threshold of the null zone decision function (c_n) at different SNR values and different number of users for the MMSE-PIC algorithm.
The observation from this figure is show that c_n opt = 0.2 is always the best choice regardless of the value of the SNR until SNR ≥ 20dB the value of threshold point is decreased but in this figure we choose optimum at c_n =0.2 in general. Fig. 4 shows that c_n opt is non-sensitive to SNR-changes and to system-load changes.

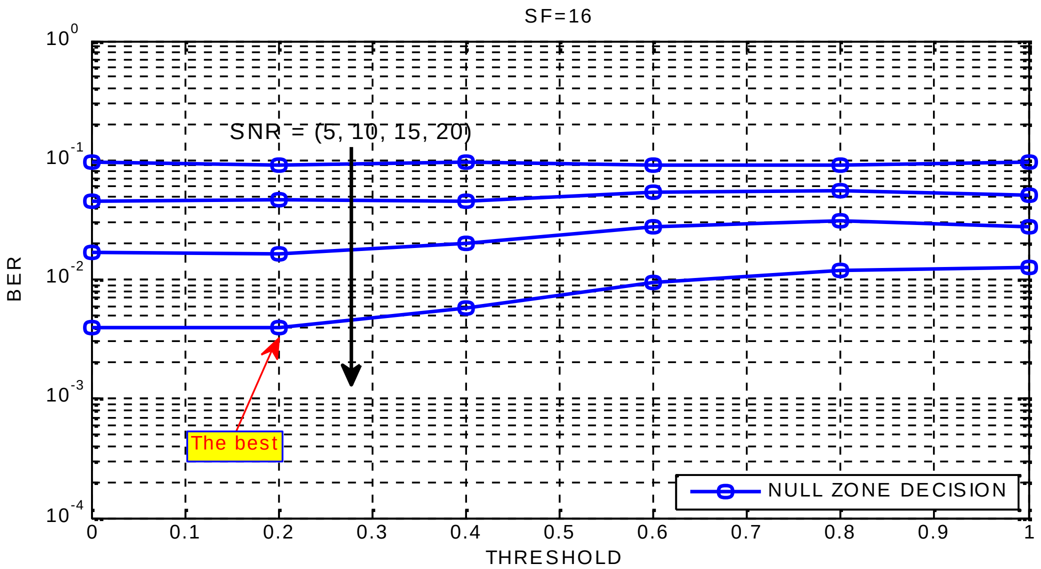


Figure (5): *BER vs null zone decision threshold at different SNRs, K (users) = 32*

The effect of the tentative decision function on the performance of the SIMO MMSE-PIC algorithm for *K* = 8 (half load) and K=16 (full load) is studied and shown in Figure

6 and 7 respectively and compared to the MMSE equalizer for SIMO,SISO MMSE, SISO MMSE-PIC and the SISO rake receiver.

It is found that for half load of users the performance of all tentative decision algorithms are nearly the same and for the full load of users the better performance of the MMSE-PIC algorithm can be obtained with the unit clipper, soft and tanh decision functions outperform the performance obtained functions with all other decision functions at BER=10^{-4} by 1dB of SNR. In general all decision function have the convergent performance results so the suggested decision function can be used is the hard decision function because is a simple decision function. Also these figures show that the performance of the SISO rake receiver is the worst performance.

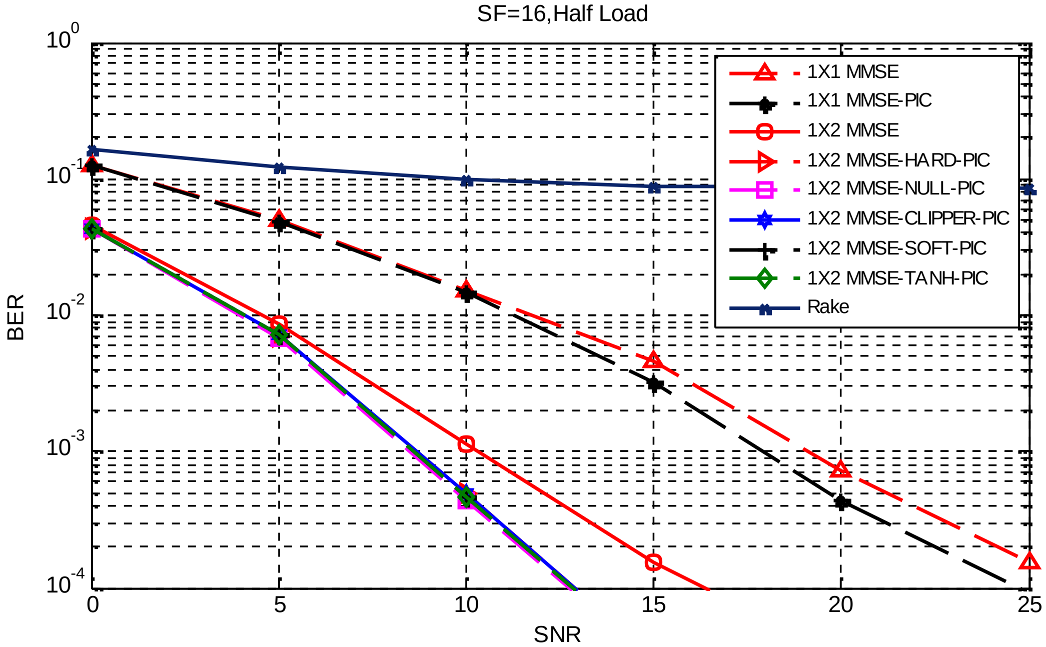


Figure (6): *SNR vs. BER Performance of MMSE and MMSE with different decision functions of SIMO MMSE-PIC, for (a) K=8 (half load)*

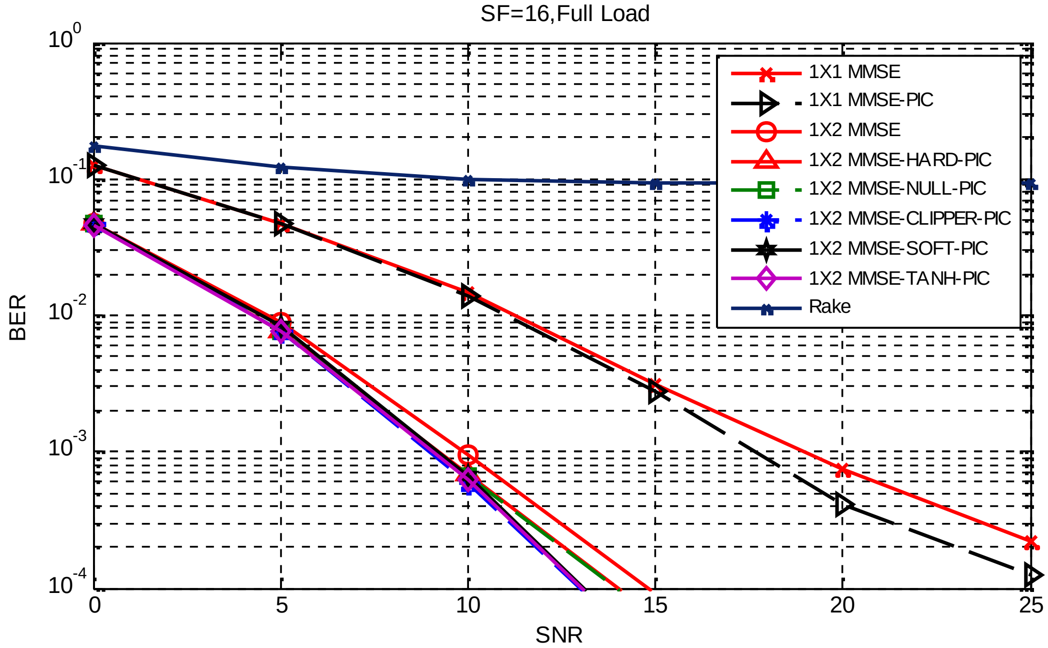


Figure (7): *SNR vs. BER Performance of MMSE and MMSE with different decision functions of SIMO MMSE-PIC, for (a) K=16 (full load)*

The relation between the regularization parameter (α) and the BER for the RZF-PIC algorithm in the downlink MC-CDMA systems at different SNR values and different load of users is illustrated in figure 8. The best choice of α is found at α = 0.1 for SNR=(5,10,15) dB but at SNR> 15dB the better α is found at α=0.01. Thus, the best choice of α is applicable for the following of experiment.

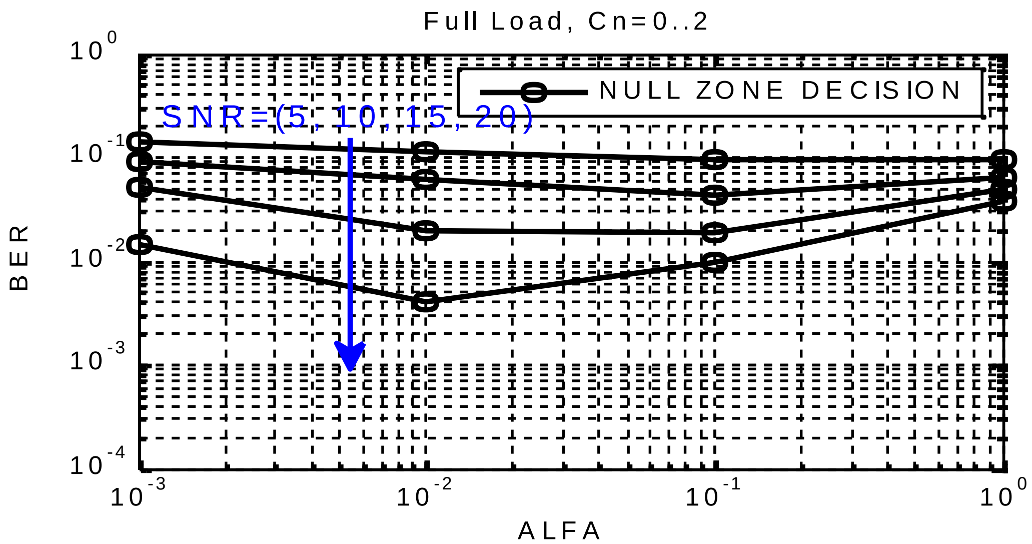


Figure (8): *BER vs Regularization Parameter (α) at different SNRs (full load of users).*

Figures 9 and 10 show the BER as a function of the SNR for K = 8 (half load), and K = 16 (full load), respectively. As shown in Figs. 9 and 10, the proposed SIMO Equalization (MMSE,RZF)-PIC scheme is effective in reducing the ISI and the MAI. It improves the performance significantly, especially at high SNR. With the proposed scheme, an SNR reduction of about 2 dB is achieved for BER = 10−4 from the SIMO Equalization (MMSE, RZF). For a full loaded case, with a typical BER level of 10−3, the required SNR for SISO Equalization- PIC detector has to be no less than 20 dB, whereas the required SNR for SIMO Equalization-PIC is about 10 dB, which demonstrates a 10 dB improvement. And for SIMO system in the figures 9 and 10 we observe for the MMSE and MMSE-PIC reception schemes at SNR< 10 dB are outperform the RZF and RZF-PIC reception schemes respectively by 2 dB improvement. But for the SISO system at SNR<15dB the MMSE and MMSE-PIC reception schemes performance is the same for RZF and RZF-PIC reception schemes and at SNR> 15 dB the MMSE and MMSE-PIC reception schemes are outperform the RZF and RZF-PIC reception schemes respectively.

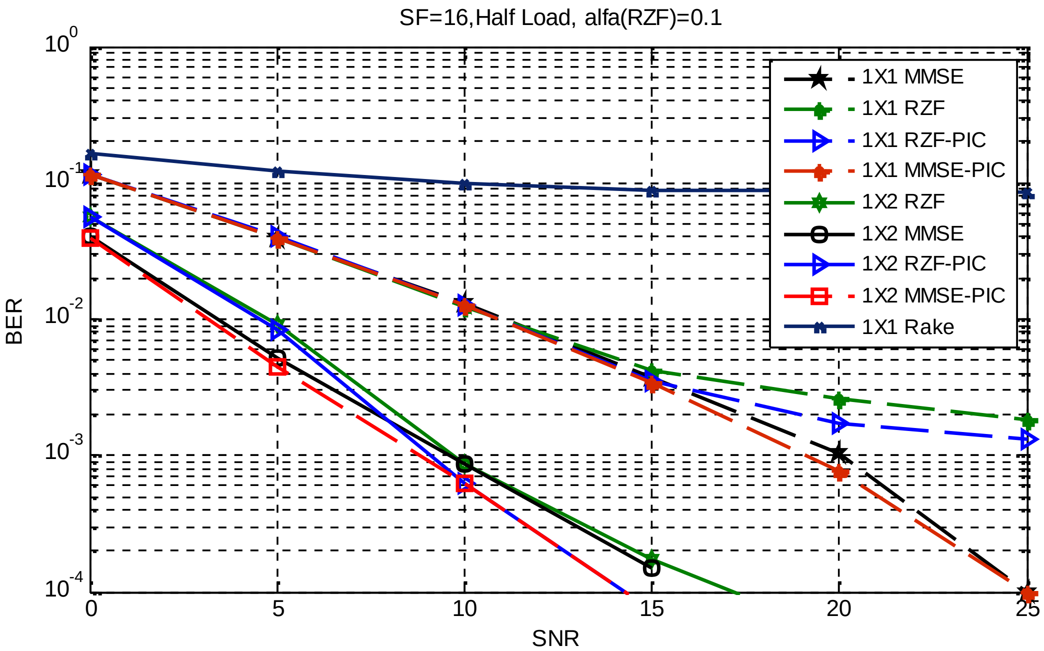


***Figure (9):** Performance of different reception schemes Vs the SNR for K = 8 (half load).*

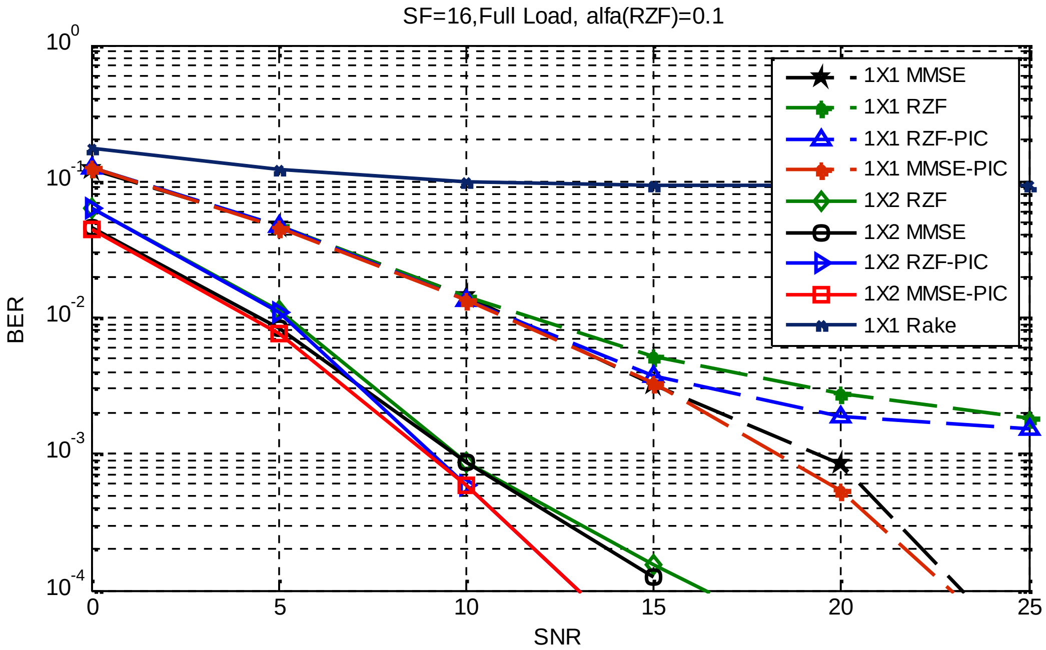


Figure (10): *Performance of different reception schemes Vs the SNR for K = 16 (full load)*

Case 2 MIMO*:* In this case, we compare the performance of MIMO Equalization-PIC, and MIMO Equalization under synchronous MIMO channels. Simulation environment is based on the downlink synchronous MIMO MC-CDMA system in which each user transmits QPSK information symbols. Perfect channel estimation, $Nt = 2$, and $Nr = 2$ are assumed. The Rayleigh frequency selective fading channel is considered.

Figures 11and 12 depicts the BER performance as a function of SNR. The figures show that the MIMO Equalization-PIC receiver achieves a remarkable gain compared to the MIMO Equalization receiver. For K = 8 (half load), and SF = 16 for figure 11, with a BER level of 10^{-3}, the required SNR for the MIMO MMSE Equalization receiver has to be 18 dB, whereas the required SNR for the suggested MIMO MMSE-PIC is 15 dB, which demonstrates a 3 dB improvement.

For K = 16 (full load), and SF = 16 for figure 12, with the SNR=20 dB the BER performance is10^{-4} for the suggested MIMO MMSE-PIC but for the MIMO MMSE Equalization receiver at SNR=20 dB the BER is down. In general the performance of the suggested MIMO MMSE-PIC for MC-CDMA is enhanced with full load of users (i.e. when no. of users increased).

Figure 13 show the effect of the different regularized parameter on the MIMO RZF receiver and suggested MIMO RZF-PIC performance. From this figure, for the value of α=0.1 the performance of the different proposed schemes at low SNRs is better than the performance of the different proposed schemes at α=0.01, in details at SNR <16 dB, and vice versa.

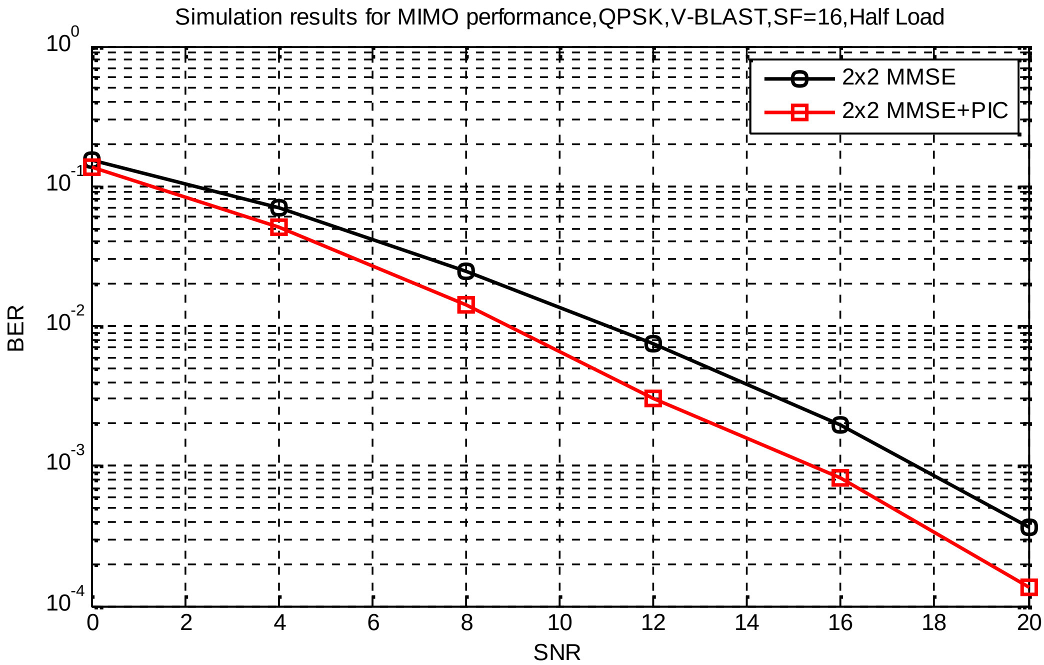


Figure (11): *Performance of different reception schemes Vs the SNR for MIMO MC-CDMA, for K = 16 (half load)*

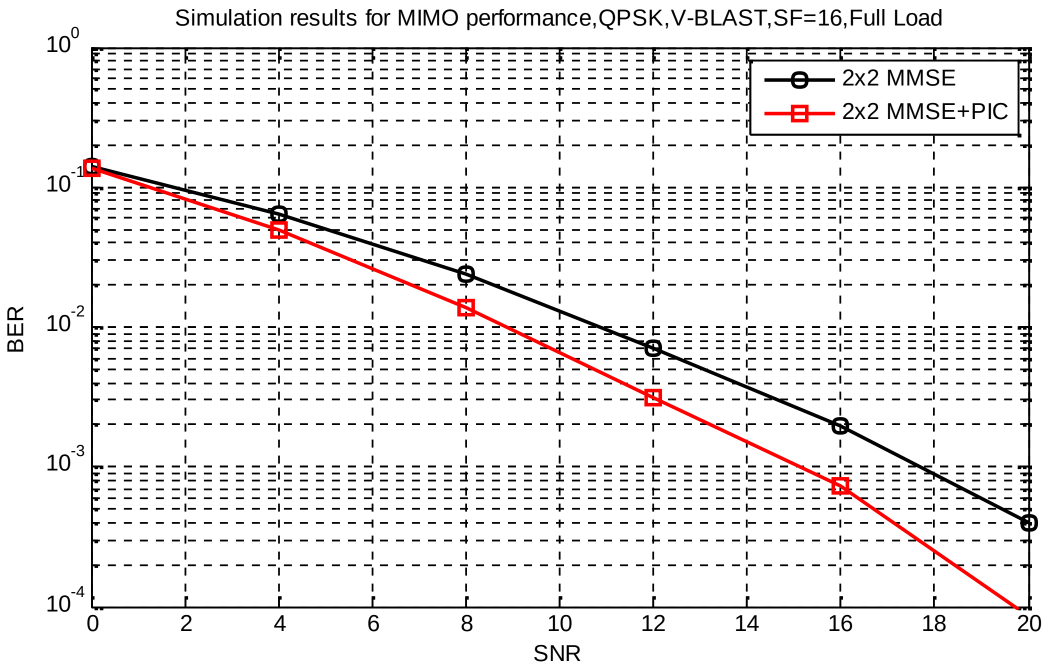


Figure (12): *Performance of different reception schemes Vs the SNR for MIMO MC-CDMA, for K = 16 (full load)*

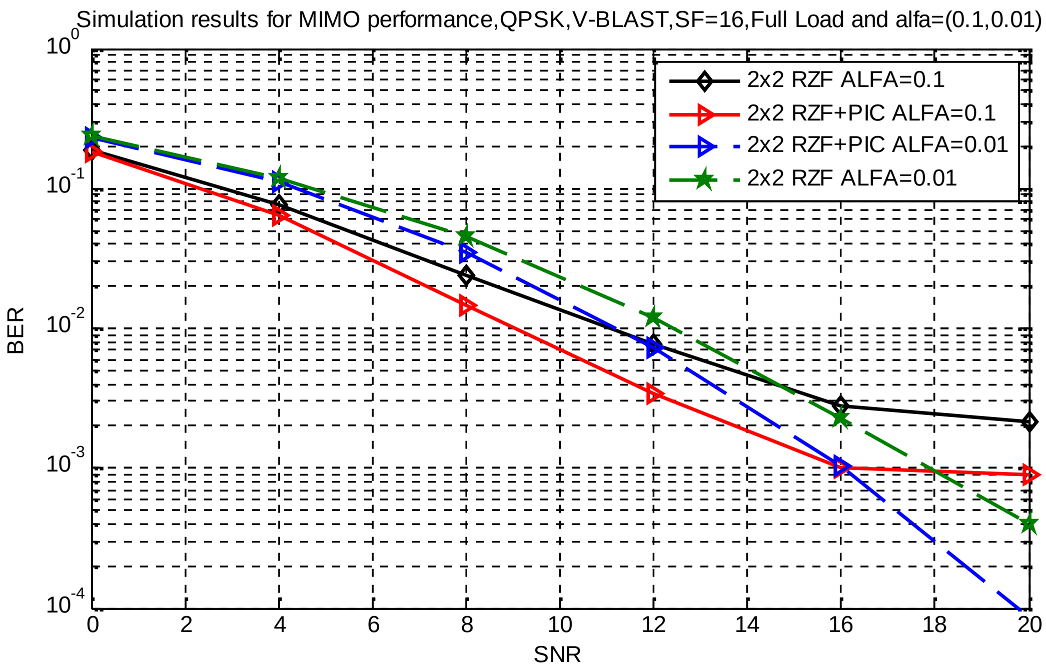


***Figure (13):** Performance of different reception schemes Vs the SNR for MIMO MC-CDMA and the RZF parameter ALFA=(0.1,0.01), and K = 16 (full load)*

5. Conclusions:

In this paper, we have proposed efficient receiver structure for downlink SIMO and MIMO MC-CDMA transmissions. The efficiency of the proposed structure is obtained by implementing all filters in the frequency domain through efficient FFT. The comparison studies show that the proposed receiver offers a large performance improvement with reasonable complexity relative to the rake receiver, SIMO Equalization, and SISO Equalization-PIC. The obtained results indicate that the performance of the proposed scheme is more efficient when the system load is high and a reliable communication is possible with the proposed scheme.

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