Analysis of Multiuser Detectors and Performance improvement in DS-CDMA system using Multistage Multiuser Detection Techniques

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Abstract— Among the various interferences, the Multiple Access Interference (MAI) is a significant issue in Direct Sequence Code Division Multiple Access (DS-CDMA) system due to its users. When the number of users is increasing the MAI is likewise increments, subsequently the system performance progressively diminishes particularly in fading environment. In this paper, the system performance is improved by the proposed multistage multiuser detection technique called Multistage Multiuser Differencing Partial Parallel Interference Cancellation (DPPIC). This is the combination of Partial Parallel Interference Cancellation (PPIC) and Differencing Parallel Interference Cancellation (DPIC). Multistage Multiuser Parallel Interference Cancellation (PIC) and Multistage Multiuser PPIC techniques that exist gave improved system performance meaning as the number of stages increases the MAI decreases but at the cost of increased computational complexity. The computational complexity was reduced by utilizing Multistage Difference PIC (DPIC) technique but with no improvement in the performance. To improve the system performance as well as reduce the computational complexity Multistage Multiuser Partial Differencing Parallel Interference Cancellation (PDPIC) method can be used. The simulation results show that the proposed DPPIC technique performs better than PIC, PPIC and PDPIC in terms of Bit Error Rate (BER) versus normalized signal amplitude (i.e., E_b / N_0), but with a slight increase in computational complexity when compared to that of PDPIC in fading environment.

Keywords— Multiuser detection, MAI, PIC, PPIC, DPIC, PDPIC, DPPIC.

1 INTRODUCTION

Multiple Access Interference (MAI) is a significant issue in Direct Sequence Code Division Multiple Access (DS-CDMA) system because of its users. A promising method such as Multiuser Detection to accomplish improved performance for DS-CDMA system are reported [1-6]. The ideal multiuser identifier for information discovery in different access non-Gaussian stations has been determined in [7-8]. It has been shown that the performance gains afforded by optimum multiuser detection in impulsive noise can be substantial when compared to optimum multiuser detection based on a Gaussian noise assumption. Since the optimum strategy is computationally intensive, in [9], a lower complexity M-estimator-based multiuser detector has been proposed and analyzed. Specifically, the authors of [9] show that the proposed multiuser detector offers significant performance gain over the linear decorrelating detector when the ambient channel noise is Non-Gaussian. Moreover, an alternative M-estimator-based multiuser detector has been proposed in [10, 11] that assures a contained performance loss with respect to the optimum multiuser detector, particularly when the noise is moderately impulsive.

Since DS-CDMA transmissions are frequently made over channels that exhibit fading, it is of interest to design receivers that take into account this behavior of the channel.

The next section deals about CDMA Signal and channel model. In Section 3, conventional single user and multiuser detection methods are discussed. Interference and multi stage detection techniques are described in section 4. Section 5 provides simulation results on the performance comparison of different multistage multiuser detection techniques. The summary of the findings are given in conclusions in section 6.

2 CDMA SIGNAL AND CHANNEL MODEL

In low pass equivalent model for a K user synchronous DS-CDMA system, each user is assigned a signature sequence of duration T_b, where T_b is the symbol interval [12]. A signature sequence of k^{th} user may be expressed as

$$S_k(t) = \sum_{n=0}^{L-1} \alpha_n \, p(t-nT_c) \qquad 0 \le t \le T_b \qquad (1)$$

where

α_n, $0 \le n \le L-1$ is a pseudo random noise (PN) sequence consisting of L chips that can take values from the alphabet {+1,−1},

p(t) is a pulse of duration Tc, where Tc is the chip interval, and $T_b = LT_c$. Without loss of generality, one can assume that all K signature sequences have unit energy, i.e.

$$\int_0^{Tb} S_k^2(t)dt = 1$$

The cross correlation in two signature sequences is defined as

$$\rho_{jk} = \int_0^{Tb} S_j(t)S_k(t)\, dt \quad j \ne k \qquad (2)$$

For simplicity, we assume that binary antipodal signals are used to transmit the information from each user. As the transmission is synchronous, one needs to consider the interval and the signal corresponding to the transmission of only one bit.

The equivalent low-pass of the composite transmitted signal for K users may be expressed as

$$x(t) = \sum_{k=1}^{K} A_k b_k S_k(t) \qquad (3)$$

Where A_k, b_k and $S_k(t)$ are the transmitted amplitude, data bit and signature sequences, respectively, of k^{th} user.

The received signal from fading channel is given by

$$r(t) = h(t)x(t)+n(t) \qquad (4)$$

where

$n(t)$ is the noise with power spectral density $N_0/2$ and h(t) is complex fading coefficient. It is given by

$$h(t) = \alpha(t)e^{j\phi(t)} \qquad (5)$$

where

$\alpha(t)$ is Rayleigh distributed channel gain and

$\phi(t)$ is the phase shift uniformly distributed between 0 to 2π.

3. CONVENTIONAL AND MULTIUSER DETECTION SCHEMES

3.1 Conventional single user detection

The conventional single user detection system is shown in Figure1,

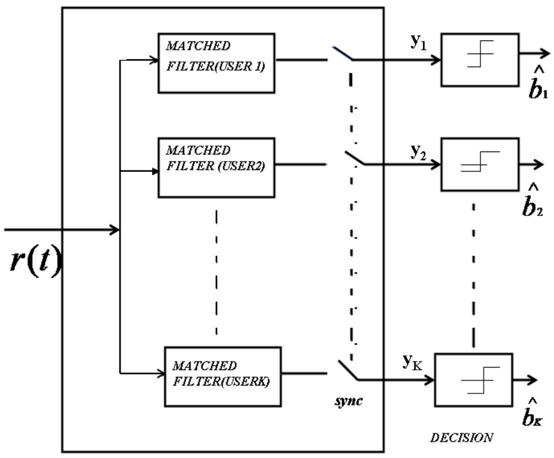

Figure 1: Matched filter bank

The detector is implemented as a K separate single-input (continuous time) single-output (discrete-time) filters without any joint processing. Each user is demodulated separately without taking into account the existence of other (K-1) active users in the system [13-14]. The sampled output of the k^{th} matched filter is given by,

$$y_K = \int_0^{T_b} r(t) s_K(t)\,dt \qquad (6)$$

The decision is made by

$$\hat{b}_K = \text{sgn}(y_k) \qquad (7)$$

3.2 Multiuser Detection Scheme

Multiuser detector detects the data of all users at a time. It is also known as joint detection. It deals with the demodulation of digitally modulated signals in the presence of MAI. Initially, optimal multiuser detector, or the maximum likelihood sequence detector was proposed by Verdu [15]. But using this detector is much too complex for practical applications like DS-CDMA systems. That's why one needs to go for suboptimal multiuser detectors.

The structure of multiuser detection system is shown in Figure 2. For detecting each user's transmitted symbols from the received signal, which consists of a matched filter bank that converts the received continuous time signal to the discrete-time sampled at chip rate without masking any transmitted information relevant to demodulation [8],[13-14].

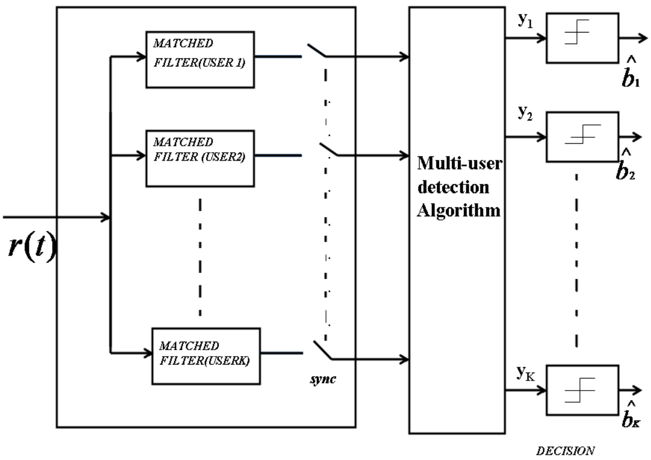

Figure 2: Multi-user detector

3.2.1 MMSE Method

The crosscorrelation matrix **R** of the spreading sequences is the only information required by decorrelating detector [1]. Recently, there has been considerable interest in multi-user detection based on Minimum Mean Square Error (MMSE) criterion [1]. The MMSE detector is shown in Figure 3. In the linear mapping that minimizes the mean-squared error between the actual data and the output of the conventional detector, the decision for the kth user is made based on

$$\hat{b}_k = \text{sgn}\left(((\mathbf{R} + \sigma^2 \mathbf{A}^{-2})^{-1} y_k)\right) \qquad (8)$$

where

σ^2 Normalised crosscorrelation
A Amplitude of the signal

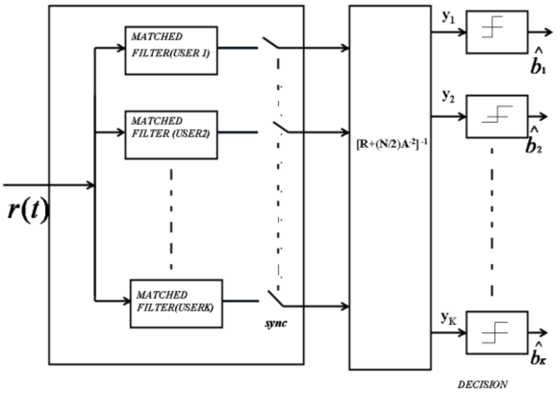

Figure 3: MMSE Detector

4 INTERFERENCE CANCELLATION SCHEMES

In general the interference cancellation can be classified into Successive Interference Cancellation (SIC), Parallel Interference (PIC) and Hybrid Interference cancellation (HIC) schemes. In SIC and PIC, PIC detector performance is found to be better [16]. In case of an efficient power control, all signal powers are of the same order. Therefore, there is no reason for one of these signals to be privileged. In such cases parallel interference cancellation (PIC) detector can be used. The PIC detector estimates the data bits and subtracts the MAI imposed by all interfering users from the signal of the desired user.

4.1 Multistage Multiuser Parallel interference cancellation

The PIC detector performs multiple iteration in detecting the data bits and canceling the interference. The MMSE is used in the first stage to estimate the data bits. The remaining stages perform for each user, signal reconstruction and subtraction of the estimated interference from all other users [1]. In the multistage multiuser PIC detector the interference is cancelled from the MMSE detector outputs or outputs of previous stages by using the estimates of the data bits as well as the known cross-correlations between users. The multi stage PIC is shown in Figure 4. In the S^{th} -stage of the PIC detector, the decision for the stage s+1 can be expressed as [1]:

$$\hat{b}_k^{(s+1)} = \operatorname{sgn}(z_k^{(s+1)}) \tag{9}$$

where

$$Z_k^{(s+1)} = y_k - \sum_{j \neq 1} A_j \rho_{kj} \hat{b}_j^{(s)} \tag{10}$$

and

$$z_k^{(1)} = y_k \tag{11}$$

The PIC detector requires knowing the amplitudes of the received signals of all the users. Since this information is not directly available at the receiver, the received amplitudes have to be estimated. If the amplitude of the signal is accurately estimated at the previous stage, then performance of the multistage PIC will be better. However, the PIC cannot guarantee the performance improvement in further stages [16].

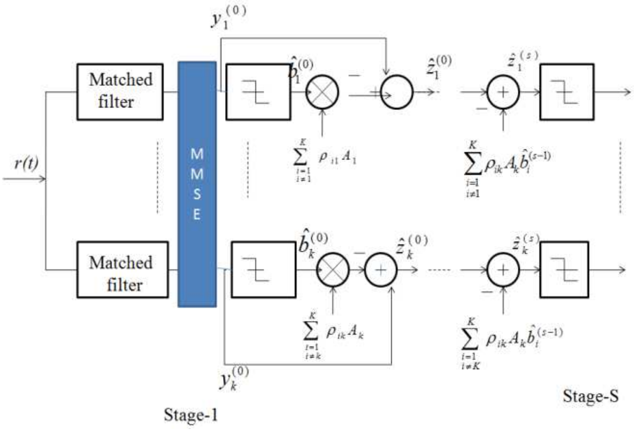

Figure 4: Multistage PIC detector

4.2 Multistage Multiuser Partial Parallel Interference Cancellation

The implementation of Multistage Multiuser PIC detector based on subtraction of the interference estimates results in a biased decision statistic. The bias has its strongest effect on the first stage of interference cancellation, in the subsequent stages its effect decreases. However if the bias leads to incorrect cancellation at the first stage the effects of these errors may be observed at later stages [1]. A simple method to avoid the effect of the biased decision statistic and improve the performance of multistage parallel interference cancellation is based on multiplying the amplitude estimates with a partial-cancellation factor (range between 0 to 1) that varies with the stage of cancellations and system load K. Multi stage PPIC is shown in Figure 5. In this method, the partial factors 0.3, 0.4 and 0.5 are used at first, second and third stage.

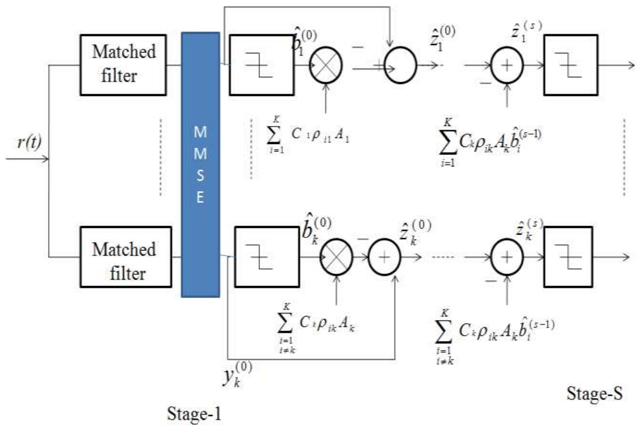

Figure 5: Partial PIC detector

This multiplication has to be performed before the amplitude estimates are used to subtract the interference. This can be interpreted as modifying the equation (10) to include a partial cancellation factor resulting [1], [13-14].

$$Z_k^{(s+1)} = y_k - \sum_{j \neq k} C_k^{(s)} A_j \rho_{kj} \hat{b}_j^{(s)} \tag{12}$$

where

$C_k^{(s)}$ is partial cancellation factor ranging from 0 to 1

4.3 Multi stage Difference PIC (DPIC)

In the Multistage PIC detection if one observes $b_k^{(s)} = b_k^{(s-1)}$, then it reflects the convergence of the iterative method. Instead of dealing with each estimated bit vector $b_k^{(s)}$, as in equation (10), one can calculate the differencing of the estimated bits in two consecutive stages. The input of each stage becomes $x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$, which is called the differencing technique [1] as shown in Figure 6.

$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \quad \ldots\ldots\ldots \quad (13)$$

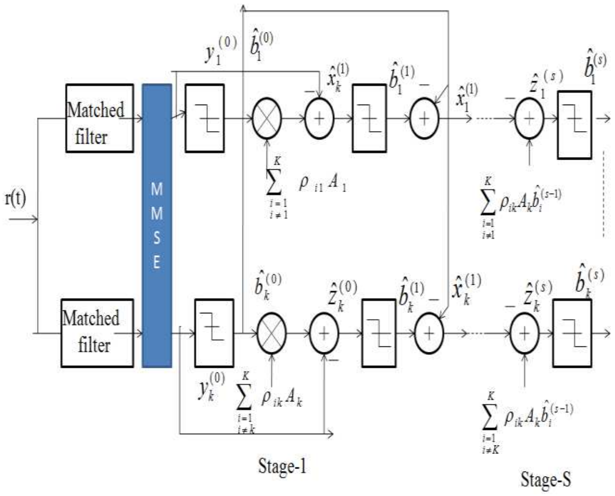

Figure 6: Difference PIC detector using MMSE

4.4 Proposed Multi stage Multiuser Difference Partial PIC technique (DPPIC)

The PIC method suffers from the biasing effect in decision statistic. But this problem can be reduced by using the partial parallel interference cancellation of the estimated multiple access interference especially at the first stage can be used to solve this problem. The most important interesting factor in difference PIC technique is the computational complexity reduction. The partial PIC offers a good improvement in performance. The combination of difference PIC (DPIC) and partial PIC (PPIC) will result in either difference partial PIC (DPPIC) or partial difference PIC (PDPIC). The DPPIC and PDPIC diagrams are shown in Figures 7 and 8. Both diagrams are almost the same except multiplication of partial factors is done before differencing (in DPPIC) and after differencing (in PDPIC). By using this technique, performance can be improved and also computational complexity can be reduced.

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^s \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \right) \quad (14)$$

where

$$x_j^{(s)} = \overset{\wedge(s)}{b_k} - \overset{\wedge(s-1)}{b_k}$$

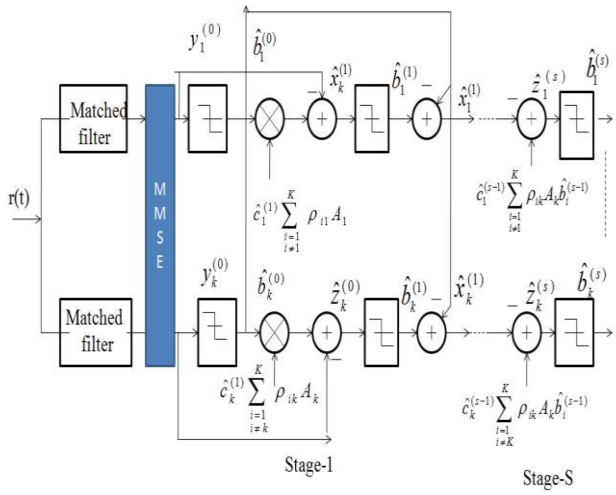

Figure 7: Multi stage PDPIC detector

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^s \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s)}{b_k} - C_k^s \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s-1)}{b_k} \right) \quad (15)$$

Algorithm for PDPIC

$$\overset{\wedge(1)}{b_1} = \mathrm{sgn}(y_{MMSE})$$

For s = 2 to S

For k = 1 to K

$$z_k^{(2)} = y_{MF} - \sum_{j=1}^{K} A_j (R_{ij} - diag(R_{ij})) b_j^{\wedge(1)}$$

End

$$\overset{\wedge(2)}{b_1} = \mathrm{sgn}(Z_1^{(2)})$$

$$x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$$

$$Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j\neq k} A_j R_{jk} \overset{\wedge(s)}{x_k}$$

End

$$\overset{\wedge}{b_k}^{(s+1)} = \mathrm{sgn}(Z_k^{(s+1)})$$

End

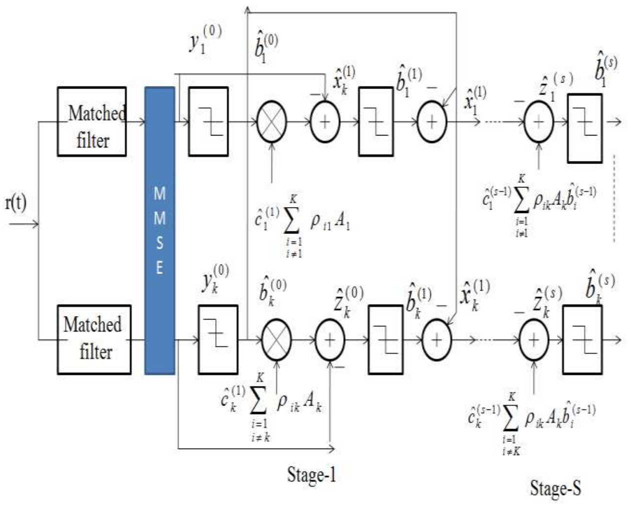

Figure 8: Multi stage DPPIC detector

Algorithm for DPPIC

$$\hat{b}_1^{(1)} = \mathrm{sgn}(y_{MMSE})$$

For s = 2 to S

For k = 1 to K

$$z_k^{(2)} = y_{MF} - \sum_{j=1}^{K} A_j (R_{ij} - diag(R_{ij}))\hat{b}_j^{(1)}$$

End

$$\hat{b}_1^{(2)} = \mathrm{sgn}(Z_1^{(2)})$$

$$x_k^{(s)} = b_k^{(s)} - b_k^{(s-1)}$$

$$Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j R_{jk} \hat{x}_k^{(s)}$$

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \hat{b}_k^{(s)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \hat{b}_k^{(s-1)} \right)$$

End

$$\hat{b}_k^{(s+1)} = \mathrm{sgn}(Z_k^{(s+1)})$$

End

5 Simulation Results

Multistage multiuser discrete time basic DS-CDMA model has been used. BPSK modulation, Kasami odd spreading sequence methods are used to spread the user information.

Figure 9 to 12 show the System performance of multistage PIC, PPIC, PDPIC and DPPIC with MMSE multiuser detector for different stages. For simplicity, only three stages are considered here. System performance at stage 3 is better than those at stage 1 and stage 2.

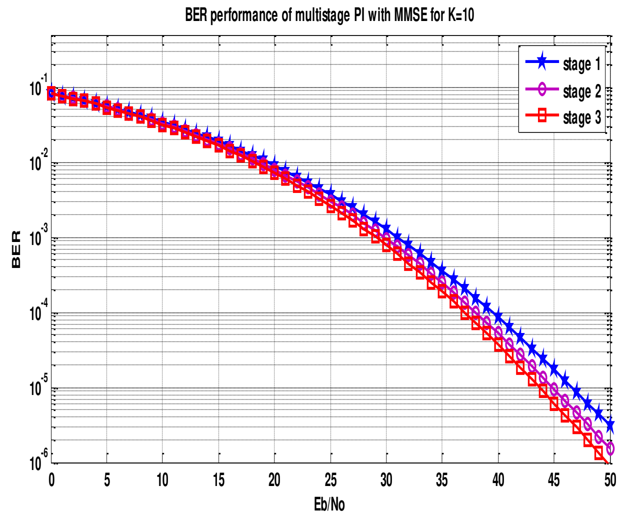

Figure 9: BER performance of multistage PIC with MMSE, K=10 for three different stages

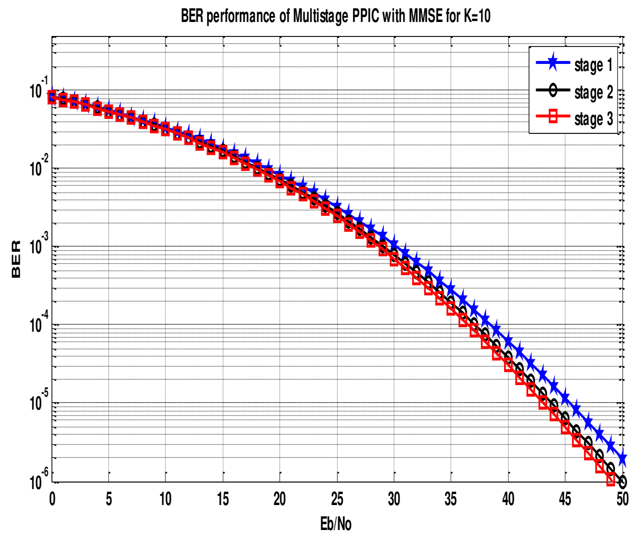

Figure 10: BER performance of multistage PPIC with MMSE, K=10 for three different stages

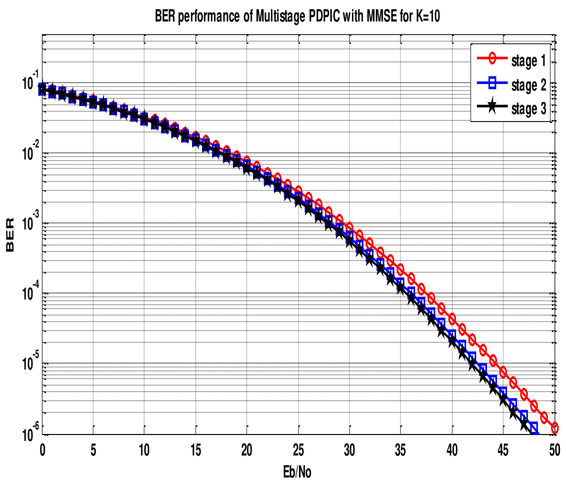

Figure 11: BER performance of PDPIC with MMSE K=10 for three different stages

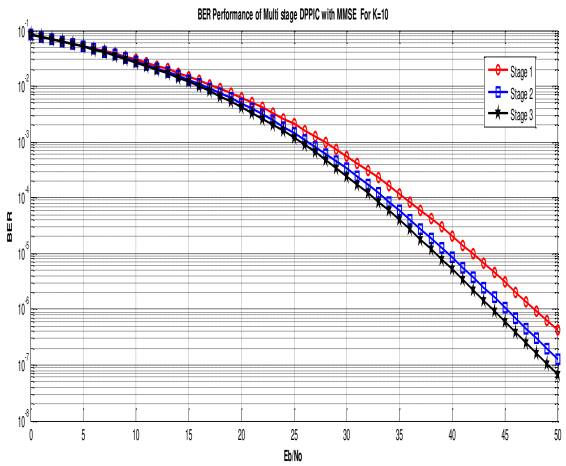

Figure 12 : BER performance of DPPIC with MMSE K=10 for three different stages

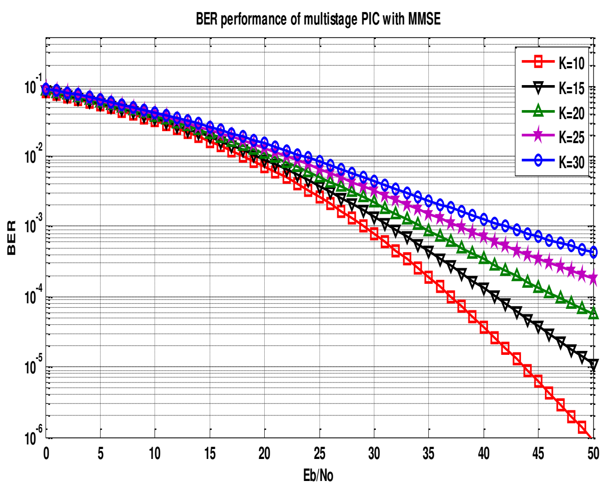

Figure 13: BER performance of 3rd stage PIC with MMSE for K= different users

In general as the no. of stages increases in the system, its performance is improved but the computational complexity also increased. When the no. of users increases the BER also increases, so the system performance gradually decreases as shown in Figures 13 to 16.

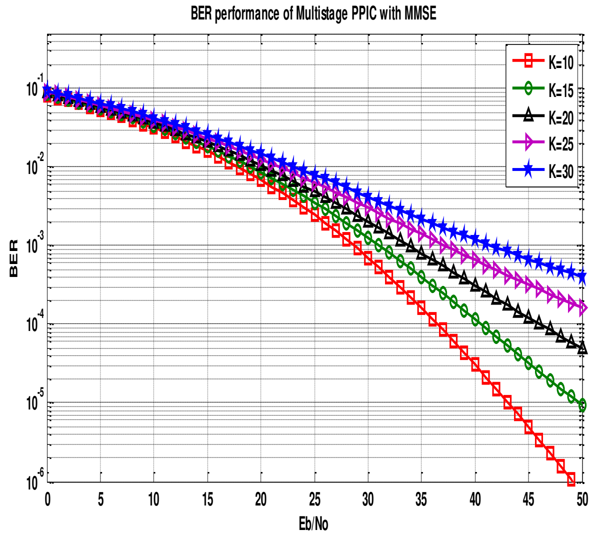

Figure 14: BER performance of 3rd stage PPIC with MMSE K= different users

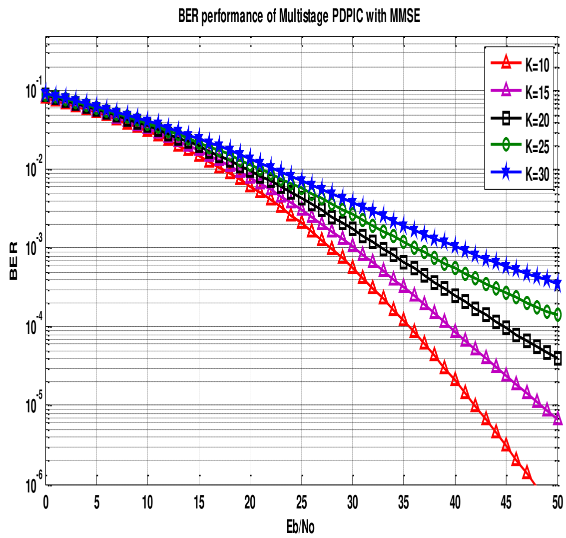

Figure 15: BER performance of 3rd stage PDPIC with MMSE K= different users

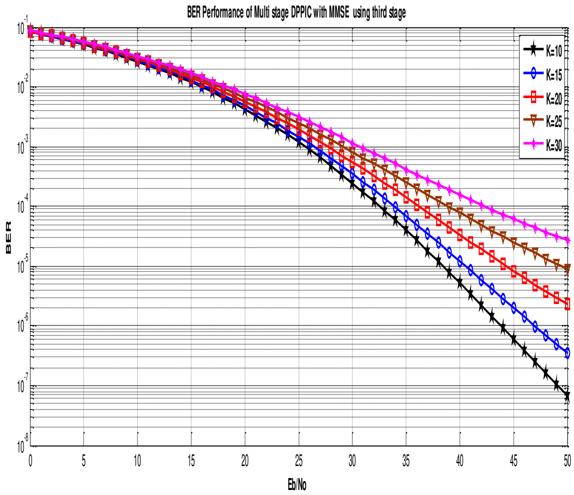

Figure 16: BER performance of 3rd stage DPPIC with MMSE K= different users

Comparison of the simulated system performance of PIC, PPIC, PDPIC and DPPIC at third stage is shown in Figure 17. From this figure it is evident that the proposed multi stage DPPIC performs better than the remaining ones. Figure 18 shows the comparison of computational complexity between PDPIC and DPPIC. In this figure the computational complexity of DPPIC slightly more than PDPIC.

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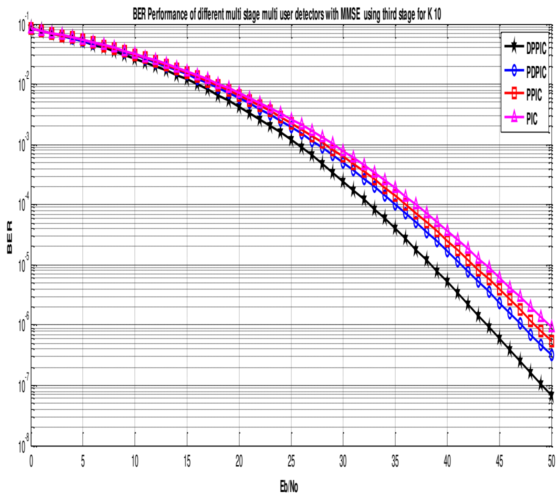

Figure 17: BER performance comparison of multi stage multi user detectors at third stage for K=10

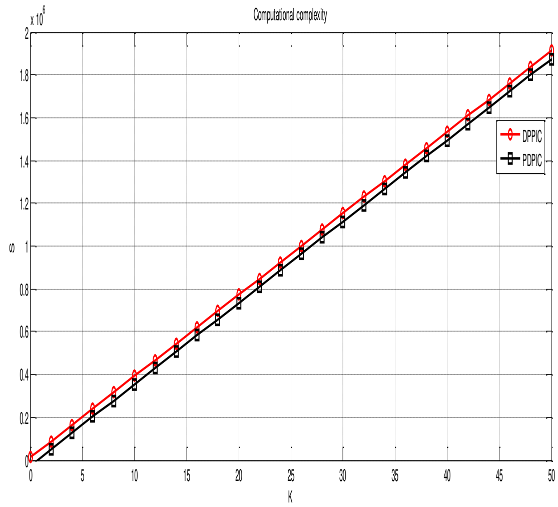

Figure 18: Computational complexity between DPPIC and PDPIC.

6 Conclusions

Multiple Access Interference as well as computational complexity can also be reduced in DS-CDMA system by using multistage multiuser techniques. In multistage PIC method, as the number of stages increase, the detection is more reliable and bit error rate (BER) also decreases. The PIC cannot guarantee that the performance improvement in further stages. The performance of Partial Parallel Interference Cancellation (PPIC) method is evaluated in DS-CDMA system. Performance improvement and computational complexity reduction at a time can be obtained by using multistage PDPIC and DPPIC methods. In conclusion one can find that DPPIC performs better than PIC, PPIC and PDPIC techniques, but with slight increase in computational complexity when compared to that of PDPIC.

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- Availability of data and material- Available
- Code availability- Available

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