Interference Reduction in fading environment using Multistage Multiuser Detection Techniques

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Abstract— Direct Sequence Code Division Multiple Access (DS-CDMA) system is one of the multiple access technique. Multiple Access Interference (MAI) is a major problem in DS-CDMA system caused by its users. When the number of users increases the MAI is also increases, hence the system performance gradually decreases especially in fading environment. In this paper, the interference is reduced in fading environment by using multiuser detection methods were introduced to detect the users data in presence of MAI. Multistage Multiuser Parallel Interference Cancellation (PIC) and Partial Parallel Interference Cancellation (PPIC) methods are introduced, which gives good system performance that means no.of stages increases the MAI gradually decreases but computational complexity is raised. The computational complexity is minimized by using Multistage Difference PIC (DPIC) detection method is introduced based on the convergence nature of interference cancellation, but system performance cannot be improved. Finally, Multistage Multiuser Partial Differencing Parallel Interference Cancellation (PDPIC) method is proposed in fading environment (combination of Difference PIC and Partial PIC). By using method, system performance is improved and computational complexity is minimized both are performed at a time. Simulation results shows that the PDPIC better performed (in terms of Bit Error Rate (BER)) than PIC and PPIC in fading environment.

Keywords— Multiuser detection, MAI, PIC, PPIC, DPIC, PDPIC, fading channel.

1 Introduction

In wireless communication systems, Direct Sequence Code Division Multiple Access (DS-CDMA) system performance is limited. A promising technique such as Multistage Multiuser Detection to achieve improved performance for DS-CDMA system [1]. In many physical channels, such as indoor and urban [2-3], radio channels and underwater acoustic channels [4], the ambient noise is known through experimental results to be decidedly non-gaussian, due to the impulsive nature of man-made electromagnetic interference and of a great deal of natural noise as well. Thus, the development of demodulation techniques for non-gaussian multiple access channels is of significant interest. An early study of error rates in non-gaussian DS-CDMA channels is found in [5-6].

The optimum multiuser detector for data detection in multiple access non-Gaussian channels has been derived in [7], and its performance has been analyzed in [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 in [9] show that the proposed multiuser detector offers significant performance gain over the linear decorrelating detector when the ambient channel noise is non-gaussian, with little attendant increase in the algorithmic complexity. Moreover, an alternative M-estimator-based multiuser detector has been proposed in [10] 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.

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

2 CDMA Signal and Channel Model

Low pass equivalent model for a K user synchronous DS-CDMA system is depicted in figure 1. Each user is assigned a signature waveform of duration T_b, where T_b is the symbol interval [11]. A signature waveform of k^{th} user may be expressed as

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

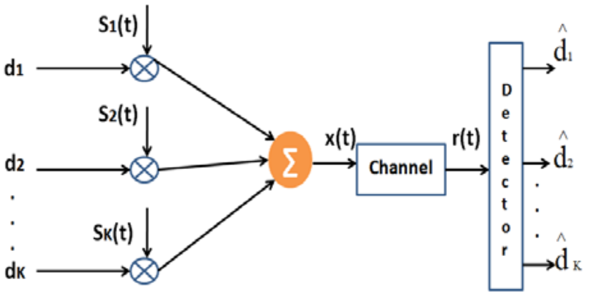

Figure 1: DS-CDMA system Model

Where $a_n, \; 0 \le n \le L-1$ is a pseudo-noise (PN) code 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, we assume that all K signature waveforms have unit energy, i.e.

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

The cross correlation in two signature waveforms 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, we 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, d_k and $S_k(t)$ are the transmitted amplitude, data bit and signature waveform, respectively, of k^{th} user.

The received signal from fading channel is given as

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

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

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

Where $\alpha(t)$ is Rayleigh distributed channel gain and $\phi(t)$ is the phase shift uniformly distributed between 0 to 2π.

The term fading means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. Actually in wireless communication systems there are two types of fading

- Large scale fading and
- Small scale fading

Large scale fading represents the path loss of a signal affected by large objects, like hills, forests, buildings, etc. between a transmitter and receiver. It occurs when a mobile transmitter and/or receiver moves over long a distance, resulting in rapid fluctuations in the received signal's envelope.

Small scale fading refers to large changes in the amplitude and phase of a signal caused by a small change in the position of the transmitter or receiver.

In this paper we considered Rayleigh fading channel model is used.

- All the signals are NLOS signals and there is no dominant direct path.
- Signals from all paths have comparable signal strengths.
- If there is no line of sight path among the multiple paths between a transmitter and receiver, a Rayleigh fading model is used as shown in figure 2.

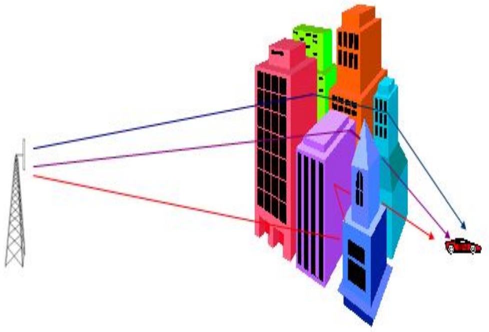

Figure 2: Rayleigh Fading

3 Conventional and Multiuser Detection Schemes

3.1 Conventional single user detection

In conventional single user communication system as shown in Figure 3, the matched filter is used to generate sufficient statistics for signal detection. The detector is implemented as a K separate single-input (continuous time) single-output (discrete-time) filters with no joint processing at all. Each user is demodulated separately without taking into account to the existence of other (K-1) active users in the system [13], [14]. The sampled output of the kth matched filter is given by,

$$y_k = \int_0^T r(t)s_k(t)dt \qquad (5)$$

The decision is made by

$$\hat{b} = \mathrm{sgn}(y_k) \qquad (6)$$

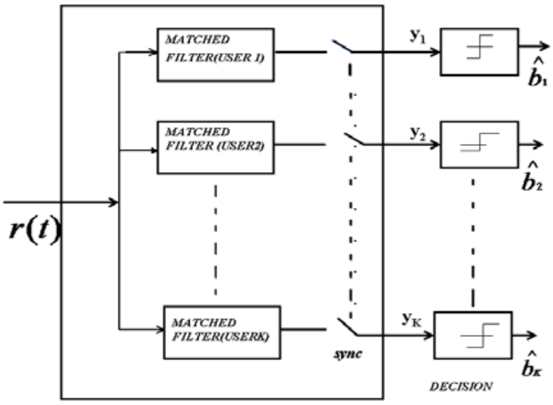

Figure 3: Matched filter bank

3.2 Multiuser Detection schemes

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 estimation detector was proposed by Verdu [15], this detector is much too complex for practical applications like DS-CDMA systems. That’s why we are going to suboptimal multiuser detectos.

General structure of multiuser detection system as shown in figure 4. 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 statistics sampled at chip rate without masking any transmitted information relevant to demodulation. This is followed by applying multiuser detection algorithm for optimality conditions to produce the soft output statistics [8].
The soft outputs are passed to the single user decoders. With the statistic {y_1, y_2, , , ,y_k], at the output of the matched filter, an estimate for the transmitted bits {b_1, b_2, , , ,b_k], that minimizes the probability of error can be found [13].

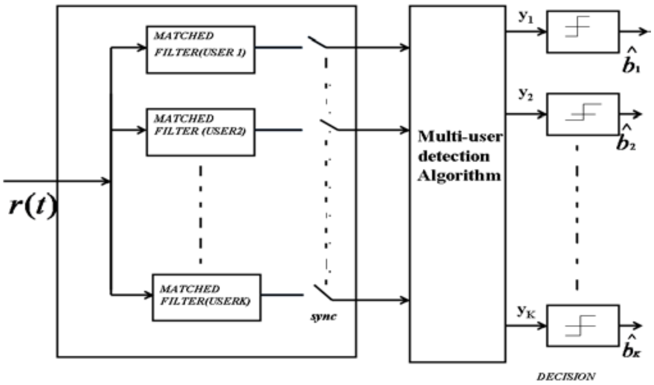

Figure 4: A typical multi-user detector

Generally, there are two types of multiuser detectors such as decorrelating detector and Minimum Mean Squared Error detector (MMSE). MMSE is better performed than Decorrelator generally [14].

3.2.1 MMSE

In decorrelating detector, the only information required by the detector is the crosscorrelation matrix **R** of the spreading sequences. Recently, there has been considerable interest in multi-user detection based on Minimum Mean Square Error (MMSE) criterion [13].

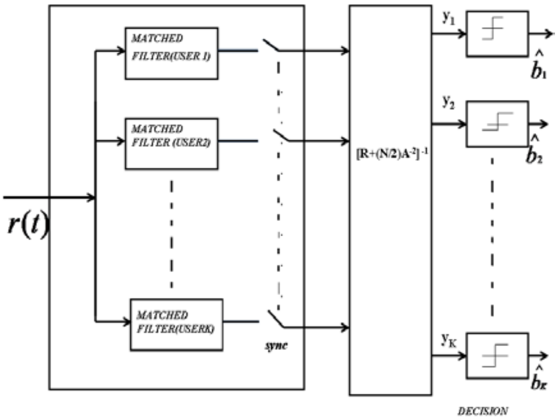

Figure 5: MMSE linear detector

The MMSE receiver is another kind of multi-user detector. It is shown in Figure 5, implements the linear mapping which minimizes the mean-squared error between the actual data and the output of the conventional detector, so the decision for the kth user is made based on

$$\hat{b}_k = \mathrm{sgn}\left(((\mathbf{R}+\sigma^2\mathbf{A}^{-2})^{-1}y)_k\right) \qquad (7)$$

4 Interference Cancellation Schemes

For practical implementation the interference cancellation schemes have been subject of most attention. These schemes rely on simple processing elements constructed around the matched filter. The detector selects in each stage the most likely transmitted symbol for each user in parallel assuming that the decisions made for all the other users in the previous stage are correct. That is why it is termed as parallel interference cancellation (PIC) in the literature [14].

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 this case parallel interference cancellation (PIC) detector can be applied. The PIC detector estimates and subtracts the MAI imposed by all interfering users from the signal of the desired user in parallel.

4.1 Multistage Multiuser Parallel interference cancellation

The parallel interference cancellation (PIC) detector employs 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 other 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 as shown in Figure 6. In the S-stage PIC detector, the decision for the stage s+1 can be expressed as [8]:

$$\hat{b}_k^{(s+1)} = \mathrm{sgn}(z_k^{(s+1)}) \qquad (8)$$

Where

$$Z_k^{(s+1)} = y_k - \sum_{j \neq 1} A_j \rho_{kj} \hat{b}_j^{(s)} \qquad (9)$$

and

$$z_k^{(1)} = y_k \qquad (10)$$

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. As a result, when the estimate of the previous stage becomes more accurate, the performance of the multistage PIC will be better. However, the PIC cannot guarantee the performance that improves in later stages.

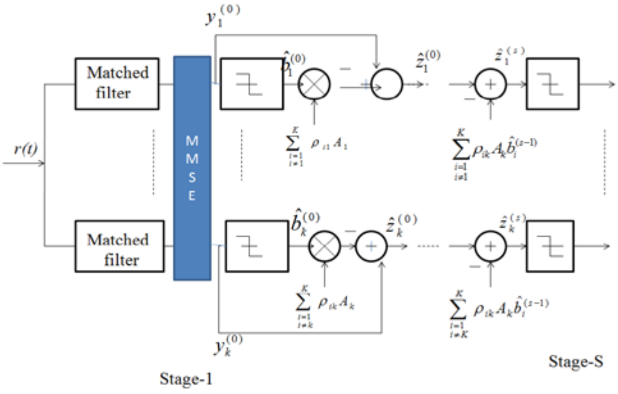

Figure 6: Multistage PIC detector

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 the next 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* as shown in Figure 7. In this paper the partial factors 0.3, 0.4 and 0.5 are used at first, second and third stage.

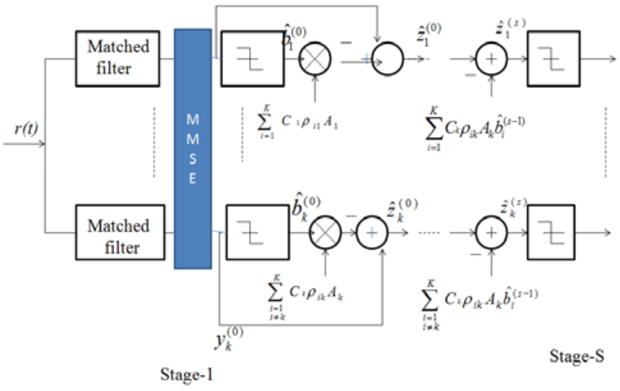

Figure 7: Partial PIC detector

This multiplication has to be performed before the amplitude estimates are used to subtract the interference. This can be interpreted as modifying the equation (9) to include a partial cancellation factor resulting [1], [14].

$$Z_k^{(s+1)} = y_k - \sum_{j\neq k} C_k^{(s)} A_j \rho_{kj} \overset{\wedge(s)}{b_j} \tag{11}$$

4.3 Multi stage Difference PIC (DPIC)

In the Multistage PIC detection to observe $b_k^{(s)} = b_k^{(s-1)}$.This reflects the convergence of the iterative method. We observe that instead of dealing with each estimated bit vector $b_k^{(s)}$, as in equation (10), we 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 [18] as shown in figure 8.

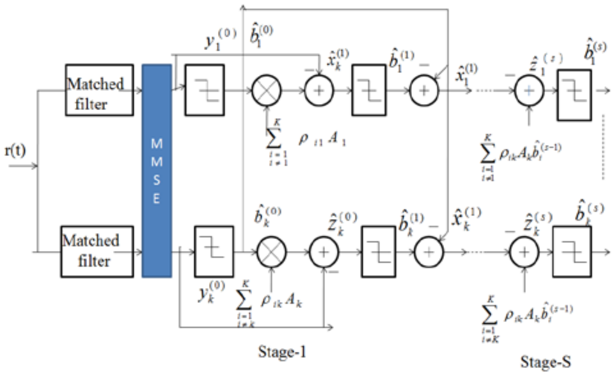

Figure 8: Difference PIC detector using MMSE

By using this technique computational complexity can be reduced than PPIC [8]. Equation (10) can be rewritten as

$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{12}$$

4.4 Multi stage Multiuser Difference Partial PIC technique

The PIC scheme suffers from the biasing effect in decision statistic. So, this problem is reduced by using the partial parallel cancellation of the estimated multiple access interference especially in the first stage is 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 and partial PIC is called difference partial PIC is shown in Figure 9. By using this technique, performance can be improved and also complexity can be reduced.

$$Z_k^{(s)} = \left(Z_k^{(s-1)} - C_k^{s} \sum_{j\neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \right) \tag{13}$$

Where

$$x_j^{(s)} = \hat{d}_k^{(s)} - \hat{d}_k^{(s-1)}$$

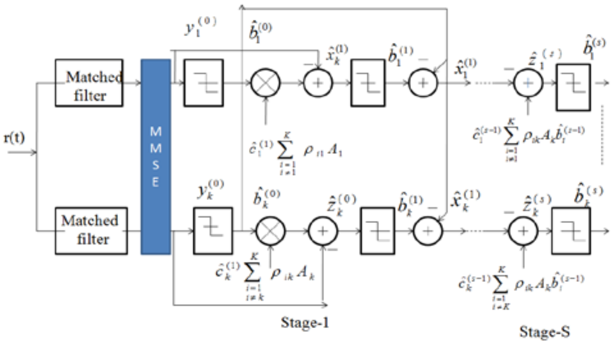

Figure 9: Multi stage PDPIC detector

5 Simulation Results

In this section a description of the multistage and multiuser discrete time basic synchronous DS-CDMA model has been used. BPSK modulation technique is used to spread the user information and kasami odd spreading sequence is used in fading environment.

Now, we provide a comparison of multistage multi user detectors in Rayleigh fading channel.

Figure 10 & 12 shows that the BER performance of multistage PIC and PPIC with MMSE multiuser detector for different stages. For simplicity, only three stages are considered here. Stage 3 is better performed than stage 1 and 2. Generally, no. of stages increases in the system the performance is improved, but computational complexity is also increased. Now 3rd stage is considered for calculate the BER with different users. When the no. of users increases the BER is also increases so the system performance gradually decreases as shown in figure 11 and 13. Now, computational complexity is reduced approximately 50% by using Differencing PIC compared with conventional PIC as shown in figure 14. Performance improved and computational complexity is reduced at time by using multi stage multiuser partial differencing PIC detection method is the combination of difference and partial PIC. The BER performance is simulated from partial differencing PIC as shown in figure 15 & 16. Finally, the multi stage PDPIC is better performed than PIC and PPIC detector as shown in figure 17.

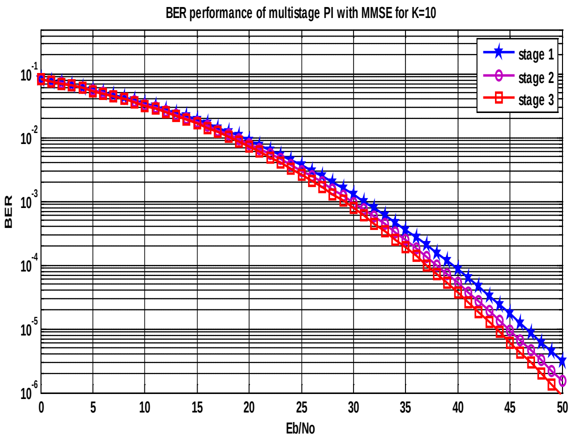

Figure 10: BER performance of multistage PIC with MMSE, K=10 for three different stages

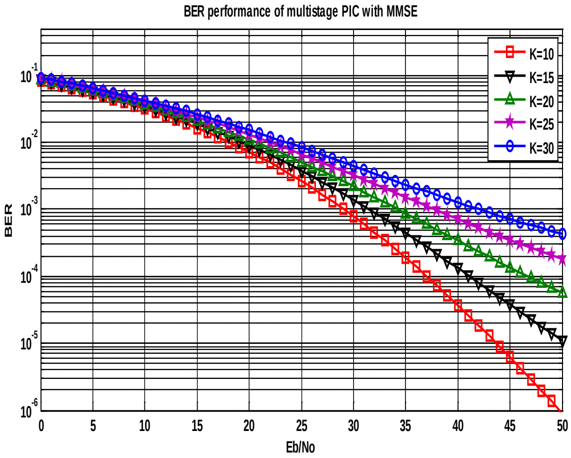

Figure 11: BER performance of 3rd stage PIC with MMSE for K= different users

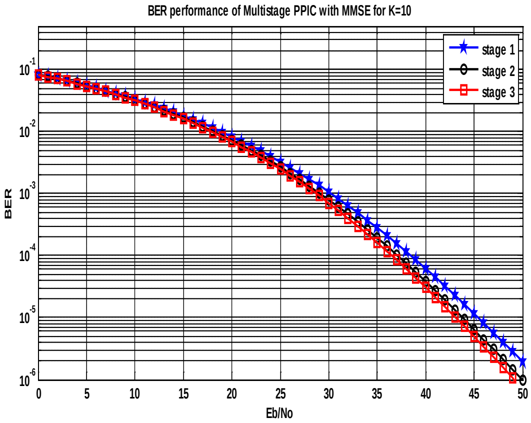

Figure 12: BER performance of multistage PPIC with MMSE, K=10 for three different stages

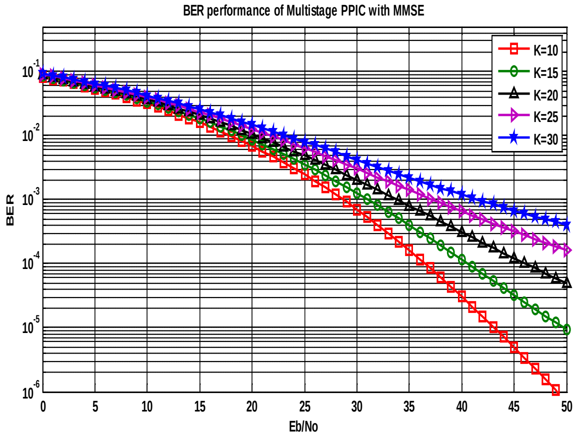

Figure 13: BER performance of 3rd stage PPIC with MMSE K= different users

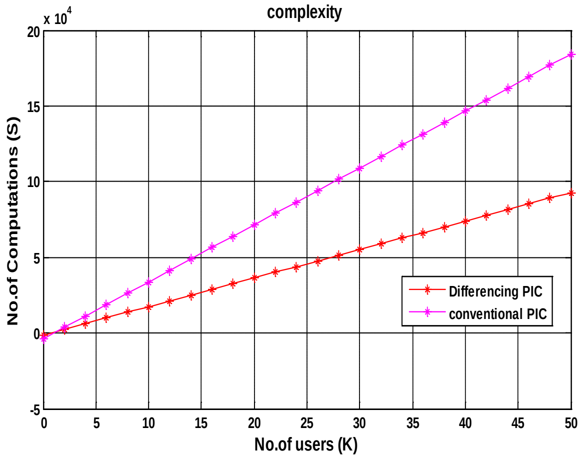

Figure 14 : Comparison of Computational complexity between PIC and DPIC.

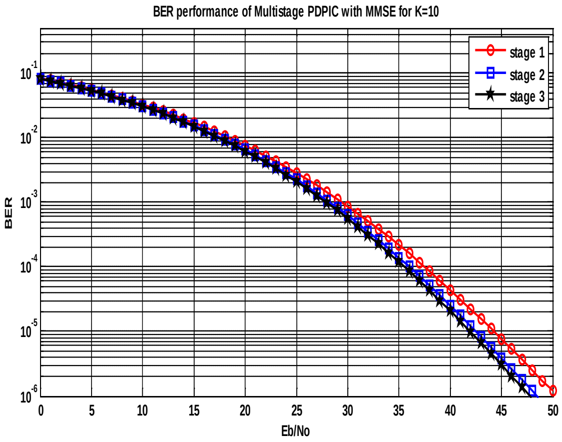

Figure 15: BER performance of PDPIC with MMSE K=10 for three different stages

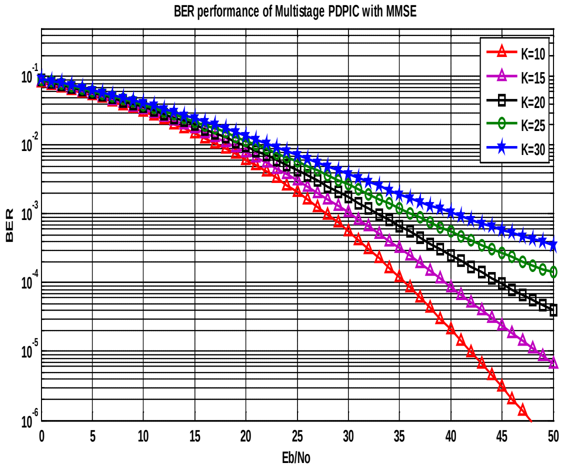

Figure 16: BER performance of 3rd stage PDPIC with MMSE K= different users

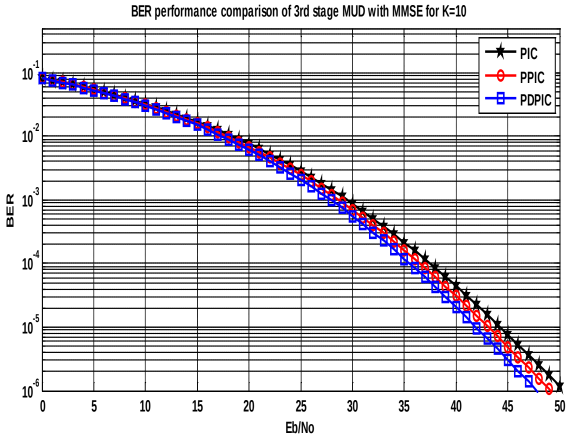

Figure 17 : BER performance comparison between PIC, PPIC and PDPIC with MMSE K=10 for stage 3

6 Conclusions

Multiple Access Interference is reduced in multistage multiuser DS-CDMA systems in fading environment. In multistage PIC detector, 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 improves in later stages. The performance of Partial Parallel Interference Cancellation (PPIC) detector is evaluated in DS-CDMA system. The philosophy behind it is that the certain knowledge about the MAI to enhance the performance of interference cancellation is available at the cost of additional complexity; it is desirable to keep this additional computational complexity as low as possible. Computational complexity is obtained from differencing parallel interference cancellation and parallel interference cancellation methods are compared for their complexity performance. Computational complexity of differencing parallel interference cancellation method is superior to parallel interference cancellation scheme. Performance improvement and computational complexity reduction at a time can be obtained by using multistage PDPIC method. It is the combination of partial parallel interference cancellation and differencing parallel interference cancellation schemes.

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