Interference cancellation in multi stage multi-user detection in DS-CDMA System using Hybrid technique

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Abstract— Direct Sequence Code Division Multiple Access (DS-CDMA) system is suffers from Multiple Access Interference (MAI). Multi-User Detection schemes were introduced to detect the users' data in presence of MAI. In this paper, we proposed a novel method is called Hybrid Interference cancellation (HIC) scheme. It consists of the combination of subtracting and partial parallel interference cancellation schemes. Here considering decorrelator for first stage instead of matched filter. Partial PIC is based on multiplying the amplitude estimates with a partial cancellation factor. Subtracting PIC exploits the multi stage character of PIC to avoid unnecessary double calculations of certain terms in consecutive stages. The hybrid PIC scheme to achieve performance improvement and complexity reduction compared to conventional PIC in multistage multiuser environment.

Keywords— Multi-user detection, MAI, Matched filter, Decorrelator, DS-CDMA, PIC. kasami odd sequence.

I Introduction

Because of its many advantages compared to other multiple access schemes like Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) is an access scheme for many future applications [1]. However, in CDMA systems multiple access interference (MAI) arises because of the non-ideal cross correlation properties of the spreading signals and multipath propagation. The detection of such CDMA signals using the conventional single user receiver leads to unacceptable performance degradations in terms of the bit error rate (BER). This presents the need for more sophisticated detection strategies, such as Multi User Detection (MUD) to overcome these performance degradations. An overview of different MUD schemes can be found in [2].

Multi-user detectors have the potential to significantly improve the performance and capacity of a DS-CDMA system. The multi user detectors classified as optimal and suboptimal detectors.

Optimal solutions with best possible performance in Gaussian noise channels have been investigated and developed. Unfortunately, when the number of users increases the complexity of these

schemes increases exponentially, this type of detector is not suitable for a practical application. This problem can be reduced by using suboptimal multi-user detection algorithms such as linear detectors and interference cancellation detectors [3-5].

Parallel Interference Cancellation (PIC) scheme is one of the suboptimum interference cancellation techniques introduced in [5] that can be repeated in multiple stages. The concept of one such stage is to regenerate the transmitted signals based on the tentative estimated data from the previous stage, emulate the distortions occurring from the multipath channels and, finally, subtract all regenerated interfering signals from the received signal to obtain more reliable estimated data for the user of interest[6–10].

The paper is organized as follows. In the next section we presented about the system model. In Section III proposed Interference cancelletion schemes are described. Section IV Section gives information about kasami odd sequence and Section V provides some simulation results on the performance comparison of different interference cancellation methods with decorrelator. A summary of the findings is given in the conclusion in section VI.

II System Model

A synchronous K user DS-CDMA model is shown in figure 1. From this model the bit streams of K synchronous users antipodally modulate with signature sequences which are transmitted through an Additive White Gaussian Noise (AWGN) Channel.

The baseband received signal is given by

$$r(t) = \sum_{k=1}^{K} A_k(t) s_k(t) b_k(t) + n(t) \qquad (1)$$

Where $A_k(t)$, $s_k(t)$ and $b_k(t)$ are the amplitude, signature code waveform and modulated data of the kth user respectively and $n(t)$ is Additive White Gaussian Noise (AWGN), with a two sided power spectral density of $N_o/2$ W/Hz [6].
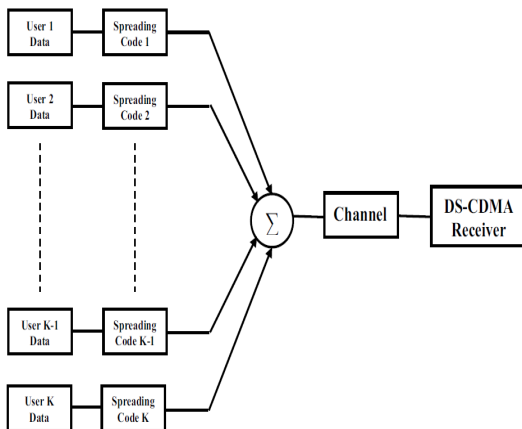

Figure 1: DS-CDMA Model

i) Conventional single user detector

The Matched filter is a conventional single user detector. This detector is the simplest suboptimum detector used in DS-CDMA [3]. It follows a single user detection strategy in which each user is treated separately as a signal, while the other users are considered as either interference or noise [11]. It is shown in Figure 2; the matched filter is used to generate sufficient statistics for signal

detection. The sampled output of the kth matched filter is given by

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

$$y_k = \int_0^T \left[\sum_{j=1}^{k} A_j b_j s_j(t) + n(t) \right] s_k(t) dt$$

$$y_k = A_k b_k + \sum_{\substack{j=1 \\ j \neq k}}^{k} A_j b_j \int_0^T s_k(t) s_j(t) dt + \int_0^T s_k(t) n(t) dt$$

Where

$$\rho_{kj} = \int_0^T s_k(t) s_j(t) dt$$

ρ_{kj} is the cross correlation of the spreading sequence between the kth and j^{th} user.
The decision is made by
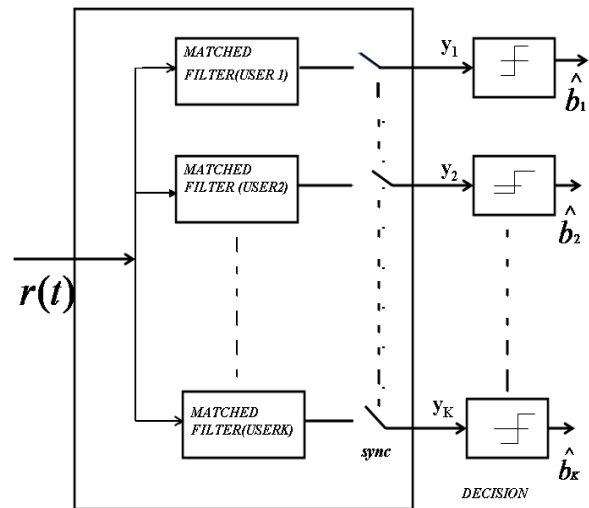
$$\hat{b} = \text{sgn}(y_k)$$

Figure:2 Matched filter bank

The single user matched filter detector takes the MAI as noise and cannot suppress it. In matrix form, the outputs of the matched filter as

$$\mathbf{y} = \mathbf{RAb} + \mathbf{n} \qquad (2)$$

Where $\mathbf{R}$ is the normalized crosscorrelation matrix whose diagonal elements are equal to 1 and whose (i,j) elements is equal to the crosscorrelation, $\rho_{i,j}$, $\mathbf{A}$=diag$\{A_1,\ldots,A_k\}$, $\mathbf{y}$ =$[y_1,\ldots\ldots y_k]^T$, $\mathbf{b}$= $[b_1,\ldots\ldots b_k]^T$ and n is a Gaussian random vector with zero mean and covariance matrix $\sigma^2 \mathbf{R}$ [12].

ii) Multi-User Detection

Multi-User detection deals with the demodulation of digitally modulated signals in the presence of MAI.

A major technological hurdle of CDMA systems is the near / far problem: the bit error rate of the conventional receiver is so sensitive to differences between the received energies of the desired user and interfering users that reliable demodulation is impossible unless stringent power control is exercised [12]. In the early stages, optimal solutions with best possible performance in Gaussian noise channels have been investigated and developed. Unfortunately, the complexity of these schemes increases exponentially with the number of users, which is not suitable for a practical application. This problem has been tackled subsequently and resulted in less complex suboptimal multi-user detection algorithms such as interference cancellation detectors [11]. Multi-user detectors assumed that the receiver has the knowledge of the codes of all users. These detectors can be used only for the uplink transmission. For downlink transmission, a detection scheme is required that needs only the code of desired user. Multi-user detectors have the potential to significantly improve the performance and capacity of a DS-CDMA system [1].

Figure 3, shows the general structure of multi user detection system for detecting each K 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 [11-12].
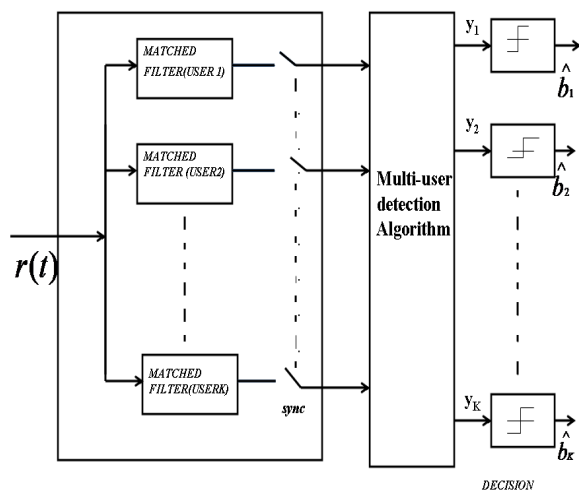

Figure.3 A typical multi-user detector

iii) Decorrelating Detector:

Decorrelator is a kind of linear multi-user receiver. The decorrelator has several desirable features. It does not require the knowledge of the users' power, and its performance is independent of the powers of the interfering users. The only requirement is the knowledge of timing which is anyway necessary for the code dispreading at the centralized receiver [6]. The decision for the kth user is made based on

$$\hat{b} = \text{sgn}((\mathbf{R}^{-1}y)_k)$$

$$\hat{b} = \text{sgn}(\mathbf{R}^{-1}(\mathbf{RAb}+n)_k)$$

$$\hat{b} = \text{sgn}((\mathbf{Ab}+\mathbf{R}^{-1}n)_k) \qquad (3)$$

When the background noise is zero,
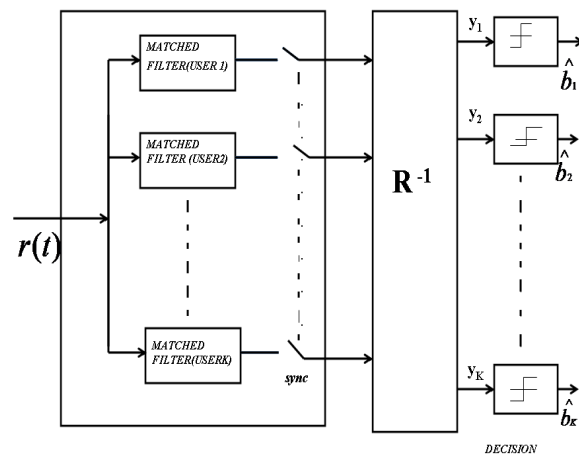
$$\hat{b} = \text{sgn}(\mathbf{Ab})$$

Figure 4. Decorrelating Detector

Hence, in the absence of background noise the decorrelating detector achieves perfect demodulation unlike the matched filter. It is shown in figure 3. Decorrelating detector can achieve any given performance level in the multi-user environment regardless of the multi-user interference, provided that the desired user is supplied enough power. Thus, it provides a substantial performance or capacity gains over the conventional detector [13].

III Parallel Interference Cancellation (PIC)

The parallel interference cancellation (PIC) detector employs multiple iteration in detecting the data bits and canceling the interference. PIC detectors have number of stages for interference estimation and cancellation as shown in figure 4. The decorrelator 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 [13-15]. In the multistage PIC detector the interference is cancelled from the decorrelator 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 5. In the S-stage PIC detector, the decision for the stage s+1 can be expressed as:

$$\hat{b}_k^{(s+1)} = \mathrm{sgn}(z_k^{(s+1)}) \qquad (3)$$

Where

$$Z_k^{(s+1)} = y_k - \sum_{j \neq 1} A_j \rho_{kj} \hat{b}_j^{(s)} \qquad (4)$$

and

$$z_k^{(1)} = y_k \qquad (5)$$

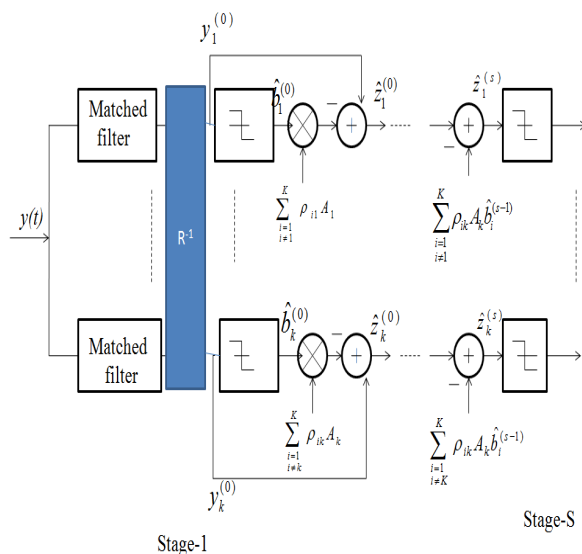Figure 5 : The concept of multistage detector

Figure 6: Proposed multistage PIC detector

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.

Multistage PIC algorithm

/ Decorrelator output (stage 1)/

$$\hat{b}^{(1)} = \mathrm{sgn}(y)$$

/ Interference cancellation s-1 stages /

for s=2 to S

/ subtract the interference from each user at each stage /

for k=1 to K

$$z_k^{(s)} = y_k - \sum_{j=1}^{K} A_j \rho_{kj} \hat{b}_j^{(s-1)}$$

Where $\rho_{kj} = R_{ij} - diag(R_{ij})$

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

End

/ Decision /

$$\hat{b}^{(s)} = \mathrm{sgn}(z^{(s)})$$

End

Where R is the cross correlation matrix between the signature sequences of the users.

i) Partial Parallel Interference Cancellation (PPIC)

The implementation of Multistage 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 . 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 that varies with the stage of cancellations and system load K. This multiplication has to be performed before the amplitude estimates are used to subtract the interference. This can be interpreted as modifying equation (4) to include a partial cancellation factor resulting.

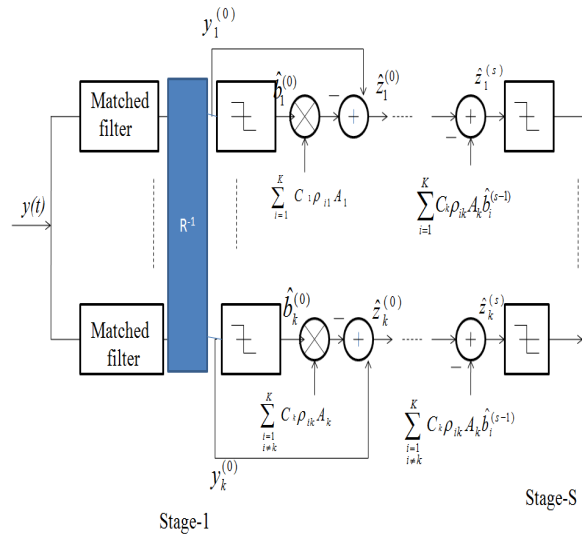$$Z_k^{(s+1)} = y_k - \sum_{j \neq k} C_k^{(s)} A_j \rho_{kj} \overset{\wedge(s)}{b}_j \qquad (6)$$

Figure 7: Proposed partial PIC detector

Multistage PPIC Algorithm

/ Decorrelator output (stage 1)/

$$\overset{\wedge(1)}{b} = \mathrm{sgn}(y)$$

/ Interference cancellation s-1 stages /

for s=2 to S

/ subtract the interference from each user at each stage /

for k=1 to K

$$z_k^{(s)} = y_k - \sum_{j \neq k} c_k^{(s)} A_j \rho_{kj} b_j^{\wedge(s-1)}$$

Where $\rho_{kj} = R_{ij} - diag(R_{ij})$

$$z_k^{(s)} = y_k - \sum_{j \neq k} c_k^{(s)} A_j (R_{ij} - diag(R_{ij})) b_j^{\wedge(s-1)}$$

End
/ Decision /
$$\overset{\wedge(s)}{b} = \mathrm{sgn}(z^{(s+1)})$$
End

ii) Subtracting PIC (SPIC)

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 (4), we can calculate the subtraction 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 subtracting technique. Using this technique equation (4) can be rewritten as

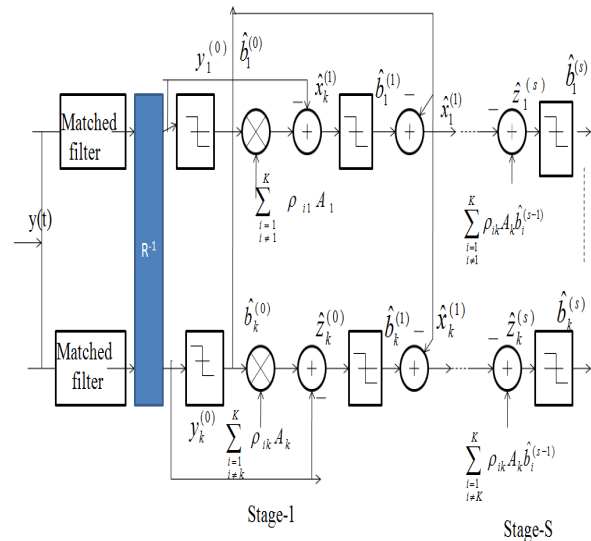$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{x}_j \qquad \ldots\ldots\ldots\ldots\ldots(7)$$

Figure 8: Proposed subtractive PIC detector

Multistage S-PIC Algorithm

/ Decorrelator output (stage 1)/

$$\overset{\wedge(1)}{b} = \mathrm{sgn}(y)$$

/subtract the interference from each user at each stage /

for k=1 to K

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

end

/second and next stages:

Subtracting multistage detection/

$$b^{\wedge(2)} = \text{sgn}(Z^{(2)})$$

for s=2 to S

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

for k = 1 to K

$$z_k^{(s+1)} = z_k^{(s)} - \sum_{j=1}^{K} A_j (R_{kj} - diag(R_{kj})) x_j^{\wedge(s)}$$

End

/decision/

$$b^{\wedge(s+1)} = \text{sgn}(Z^{(s+1)})$$

End

iii) Hybrid PIC (H-PIC or SP-PIC)

It is explained before that the multi stage subtracting PIC offer a better reduction in computational complexity of the algorithm compared to multi stage conventional PIC algorithm. The PIC algorithm 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 subtracting PIC technique is the computational complexity reduction. But the partial PIC offers a good improvement in performance. The combination of subtracting PIC and partial PIC is called SP-PIC. This technique, improve the performance and reduces the computational complexity. This approach is performed by replacing equation (7) by:

$$Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} x_j^{\wedge(s)} \tag{8}$$
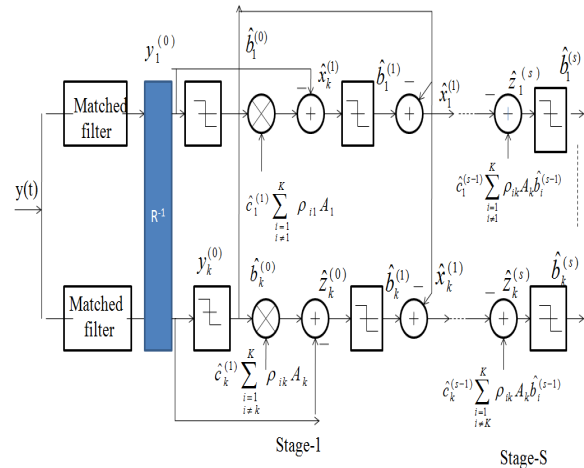

Figure 9: Proposed SP-PIC or H-PIC detector

Multistage SP-PIC Algorithm

*Subtracting PIC

$$z_k^{(s+1)} = z_k^{(s)} - \sum_{j=1}^{K} A_j (R_{kj} - diag(R_{kj})) x_j^{\wedge(s)}$$

*Partial PIC

$$z_k^{(s+1)} = y_k - \sum_{j=1}^{K} c_k^{(s)} A_j (R_{ij} - diag(R_{ij})) b_j^{\wedge(s)}$$

*Combination of subtracting and partial

(HPIC)

$$z_k^{(s)} = z_k^{(s-1)} - C_k^{(s)} \sum_{j=1}^{K} A_j (R_{kj} - diag(R_{kj})) x_j^{\wedge(s)}$$

IV. Kasami odd sequence

The Kasami sequence sets are one of the important types of binary sequence sets because of their very low cross-correlation. Kasami codes are based on PN codes of length of $L = 2^m$ including initial bit. where m is a nonnegative, odd integer. To generate a kasami sequence , first of all the sequence a' is found by selecting every $2^{(m+1)/2}$ bit of an m-sequence a. the first kasami sequence can be found

by adding (modulo-2 addition) the sequences *a* and *a*'. By including the sequence *a* in the set, a set of $2^{(m-1)/2}$ Sequences can be found [16]. For example, for the case of m=5, the length of sequence is L= 2^5 = 32. we take 32 length PN code and take it's every 8th bit and keep repeating it to find the sequence *a*'. The first member of the set is found by adding *a*' with the PN code *a* that is shown below. The primitive polynomial used here is $1+x^2+x^5$. Figure 4 shows the kasami Sequence generator for m=5 (odd).

Figure 10: Generation of proposed odd kasami Sequence .

a = [1 0 1 0 0 1 0 0   0 0 1 1 1 0 1 0

0 1 0 0 0 0 1 1   1 0 1 0 0 1 0 0]

a' = 1 0 0 1

b = [1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1

1 0 0 1 1 0 0 1 1 0 0 1 1 0 0 1]

a xor b = [0 0 1 1 1 1 0 1 1 0 1 0 0 0 1 1

1 1 0 1 1 0 1 0 0 0 1 1 1 1 0 1]

V. Simulation Results

Decorrelator, conventional parallel interference cancellation and partial parallel interference cancellation methods are investigated. In this section a description of the multi stage and K-user discrete time basic synchronous DS-CDMA model and kasami odd spreading sequence is used.

Multistage PIC performance compared with the decorrelator is shown in figure 11. The Multistage PIC detection provides a better improvement in performance compared with the decorrelator. Also it is shown that number of PIC stages increases the detection performance will be

improved but increase the complexity of the receiver, thus we are using only 3-stages of PIC will be a good compromise between the performance and complexity.
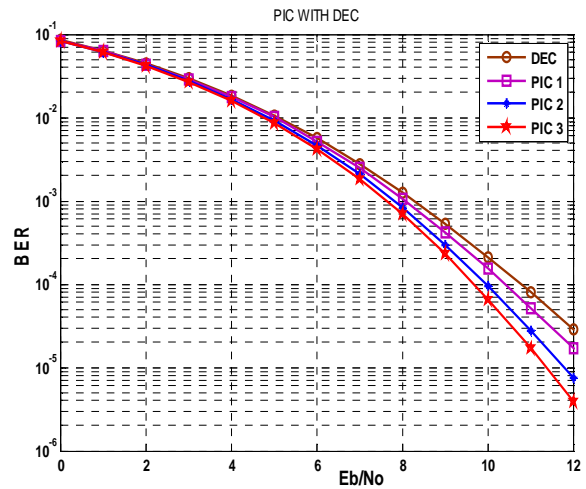

Figure 11: BER Performance of Multistage PIC

The Multistage PIC Detection suffers from estimated MAI. The Multistage Partial-PIC detection is used to reduce the estimated MAI by multiplying the partial cancellation factor. The performance of Multistage Partial-PIC is shown in Figure 12. Here also number of stages increases the performance is also improved. The simulation results for the Multistage P-PIC provide good performance compared with the performance of decorrelator.
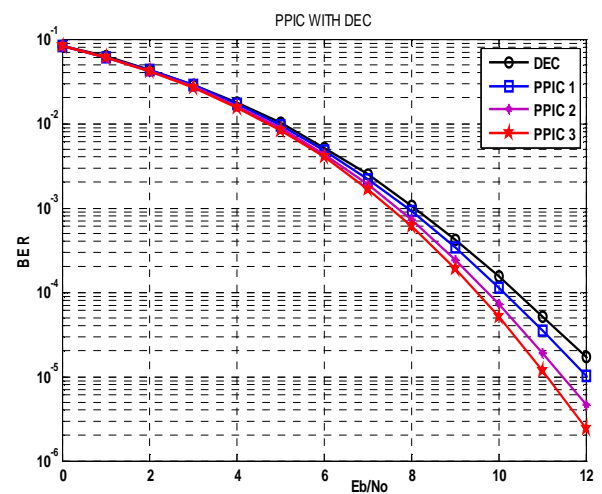

Figure 12: BER Performance of Multistage PPIC

Figure 13 & 14 shows the performance comparison between decorrelator and different PICs. The Subtractive PIC and Hybrid PIC provide well performance compared with the performance of decorrelator. It is observed that from these results stage 3 performances are well compared to stage 1 and 2.

Now, we are considered stage 3 for compared with the different PIC's. Here the SP-PIC provides better performance compared to the other PIC,s shown in figure 15.
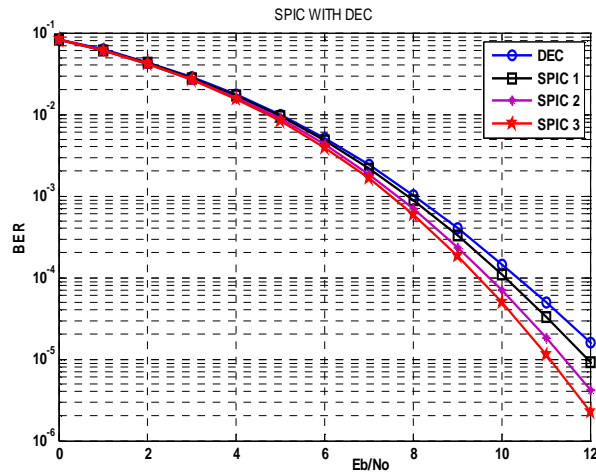

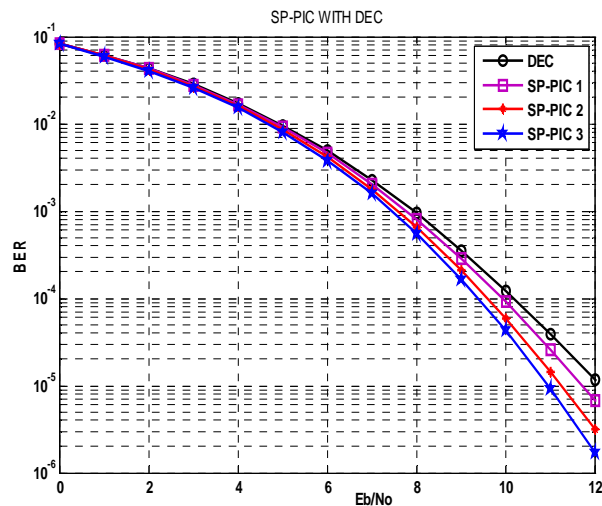Figure13 : BER Performance of Multistage SPIC

Figure 14: BER Performance of Multistage SP-PIC
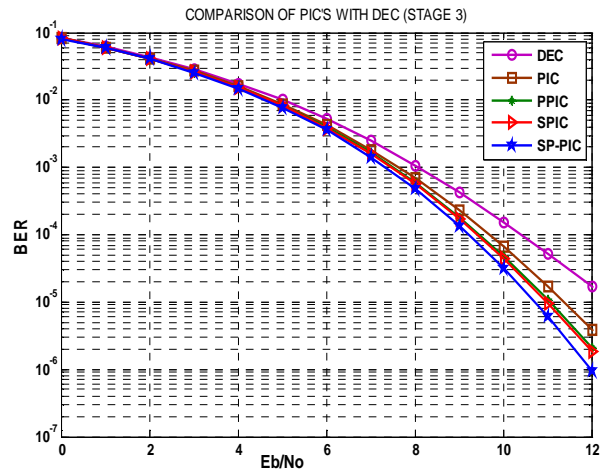

Figure 15: BER Performance of different PIC's for third stage
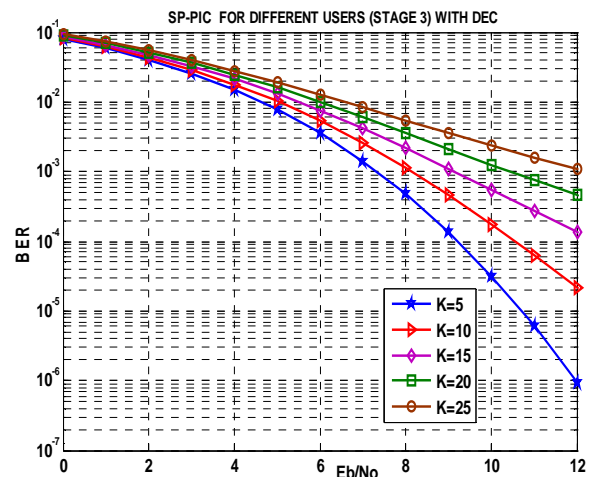

Figure 16 BER Performance of multiuser SP-PIC for third stage

It shows that the number of users increases the system performance gradually decreases for using different SP-PIC detection schemes as shown in figure 16.

VII. Conclusions

In this paper we introduced different interference cancellation schemes. Conventional PIC suffered from computational complexity and performance. This problem is reduced by using the partial PIC method, but in this method performance can be improved but complexity exists. Complexity can be reduced by using subtractive interference cancellation scheme, but performance is similar to the partial PIC. These two problems are solved by

using SP-PIC or H-PIC. By using this scheme provides superior performance and complexity reduced compared with the decorrelator.

Acknowledgment

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