Performance Analysis, improvement and complexity reduction in Multi stage Multi-User Detector with parallel interference cancellation for DS-CDMA System Using odd kasami sequence

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Abstract— Direct Sequence Code Division Multiple Access (DS-CDMA) system is well known wireless technology. This system suffers from MAI (Multiple Access Interference) caused by Direct Sequence users. Multi-User Detection schemes were introduced to detect the users' data in presence of MAI. In Multi stage Partial parallel interference cancellation (MP-PIC) method complexity is more than multi stage conventional PIC (MC-PIC), but performance is better than MC- PIC. In This paper we proposed multi stage subtractive PIC (MS-PIC). In this method the complexity is less than MP-PIC and performance is slightly less than MP-PIC. Now we proposed one more method that is the combination of partial and subtracting parallel interference cancellation (PS-PIC) in multi stage. This method gives to achieve performance improvement and complexity reduction compared to conventional multistage PIC detector.

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

1 Introduction

The great demand for wireless systems has caused a search for techniques to improve the performance and capacity of current digital wireless communication. One of the most popular wireless technologies is direct sequence code division multiple access (DS-CDMA) in last few years [1]. In CDMA, users are multiplexed by distinct codes rather than by orthogonal frequency band as in frequency-division multiple accesses (FDMA), or by orthogonal time slots as in time division multiple access (TDMA). In CDMA, all users can transmit at the same time. Also, each user is allocated the entire frequency spectrum for transmission; hence, CDMA is also known as spread spectrum communications [2]. Multiple access interference (MAI) is the major factor limiting the performance In DS-CDMA system. The interference from other users is known as multiple access interference (MAI). There are two basics approaches to solve this problem. The first approach is based on the concept of single user detection. The single user detector detects the data of one user at a time where as multi-user detectors jointly detects several users' information. The aim of the detector is to restore the signal, which is corrupted by the channel back to its original form. 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].

The paper is organized as follows. In the next section we presented about the system model. In Section 3 proposed   interference cancellation techniques are described. Section 4 gives information about odd kasami sequence and Section 5 provides some simulation results on the

performance comparison of different interference cancellation methods with conventional matched filter detector. A summary of the findings is given in the conclusion in section 6.

2 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 K 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].
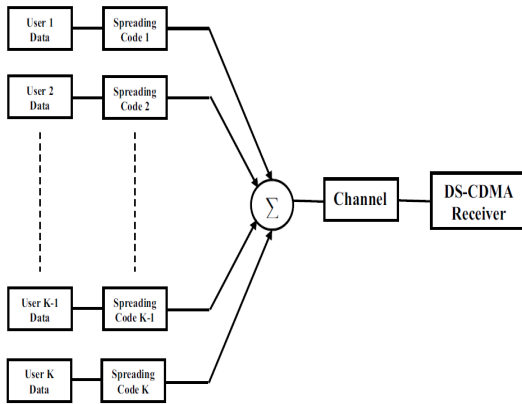

Figure 1: DS-CDMA Model

2.1 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 [6]. 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

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

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

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

Where

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

ρ_{kj} is the crosscorrelation of the spreading sequence between the kth and j^{th} user.

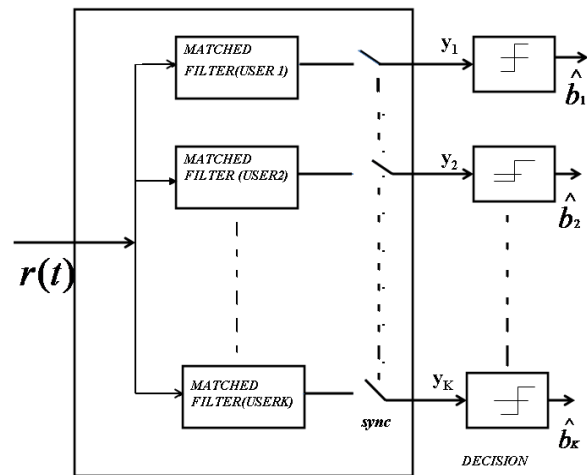The decision is made by

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

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$\{A_1,\ldots\ldots,A_k\}$, $\mathbf{y}$ =$[y_1,\ldots\ldots.y_k]^T$, $\mathbf{b}$= $[b_1,\ldots\ldots.b_k]^T$ and n is a Gaussian random vector with zero mean and covariance matrix $\sigma^2\mathbf{R}$ [7].

2.2 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 [7]. 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 [6]. 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 [6-7].
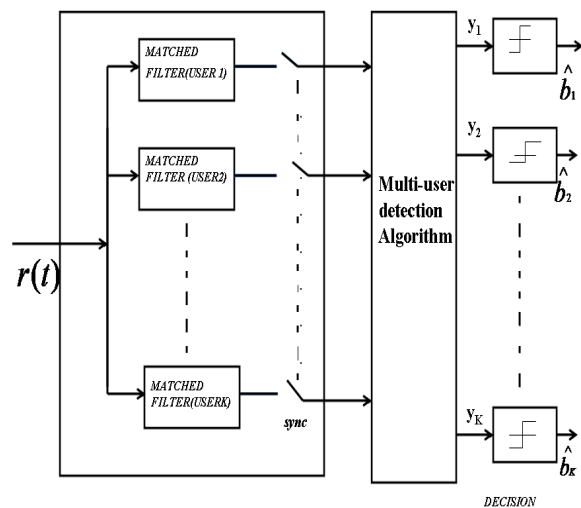
and subtraction of the estimated interference from all other users . In the Multistage PIC detector the interference is cancelled from the matched filter outputs or outputs of previous stages by using the estimates of the data bits as well as the known cross-correlations between users as shown in figure 5a & b. In the S-stage PIC detector, the decision for the stage s+1 can be expressed as [8]:
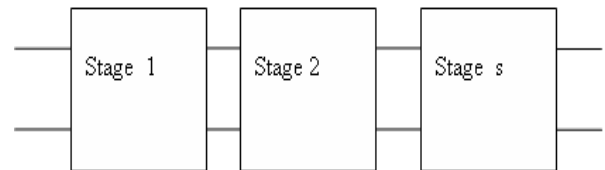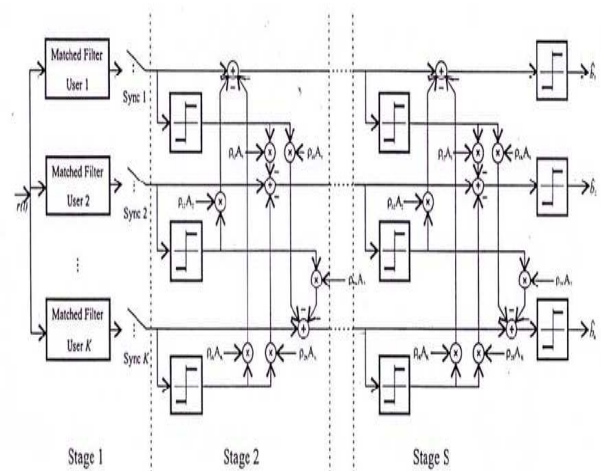

Figure 4 : The concept of multistage detector
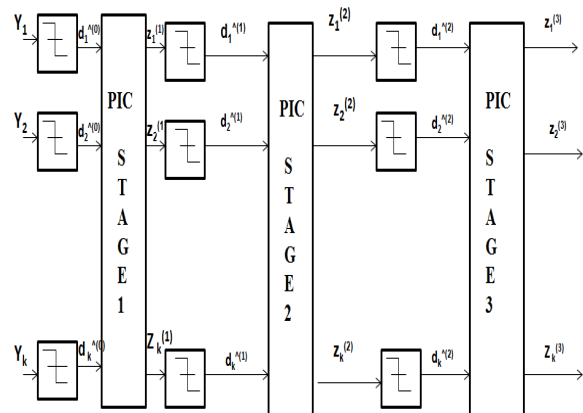

Figure 5a: Multistage PIC detector for S stage

Figure.3 A typical multi-user detector

2.3 Multi stage Parallel Interference Cancellation (M-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. The conventional detector is used in the first stage to estimate the data bits. The other stages perform for each user, signal reconstruction

Figure 5b: Multistage PIC detector for 3 stage

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

Where

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

and

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

The PIC detector requires to know 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. A common way to do this is to use the matched filter outputs or outputs of a previous stage, which are both referred to as soft decisions, as a joint estimation of the detected bits and the received signal amplitudes [9].

Multistage PIC algorithm

/ Matched filter output (stage 1)/

$$\hat{d}^{(1)} = \text{sgn}(y)$$

/ Interference cancellation s-1 stages /

for s=2 to S

/ subtract the interference from each user at each stage /

for k=1 to K

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

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

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

end

/ Decision /

$$\hat{d}^{(s)} = \text{sgn}(z^{(s)})$$

end

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

2.4 Multistage Partial Parallel Interference Cancellation (MP-PIC)

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 [10]. 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 cancellation*s* 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 [10-11]:

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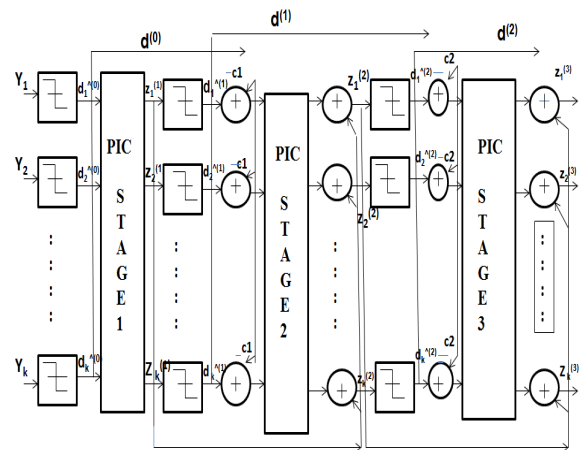

Figure 6: partial PIC detector

Multistage P-PIC Algorithm

/ Matched filter output (stage 1)/

$$\hat{d}^{(1)} = \text{sgn}(y)$$

/ Interference cancellation s-1 stages /

for s=2 to S

/ subtract the interference from each user at each stage /

for k=1 to K

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

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

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

     end

/ Decision /

$$\overset{\wedge(s)}{d} = sgn(z^{(s+1)})$$
     end

3 proposed Multistage Subtracting PIC (MS- PIC)

In the Multistage PIC detection to observe $d_k^{(s)} = d_k^{(s-1)}$. This reflects the convergence of the iterative method. We observe that instead of dealing with each estimated bit vector $d_k^{(s)}$, as in equation (4), we can calculate the subtraction of the estimated bits in two consecutive stages. The input of each stage becomes $e_k^{(s)} = d_k^{(s)} - d_k^{(s-1)}$, which is called the subtracting technique. Using this technique equation (4) can be rewritten as

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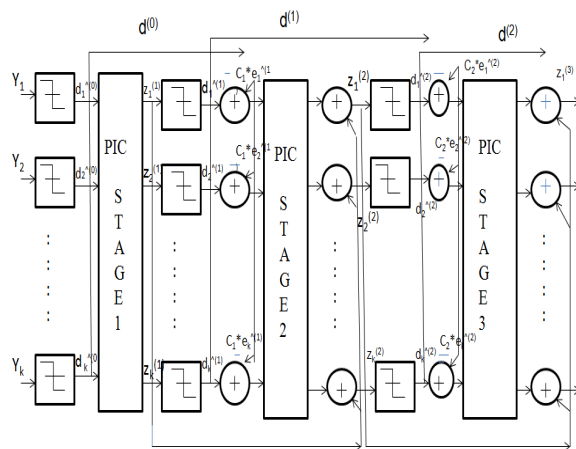

Figure 7: subtractive PIC detector

Multistage S-PIC Algorithm

/ Matched filter output (stage 1)/

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

/subtract the interference from each user at each stage /

    for k=1 to K

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

    end

/second and next stages:

Subtracting multistage detection/

$$\overset{\wedge(2)}{d} = sgn(Z^{(2)})$$

    for s=2 to S

$$e_k^{(s)} = d_k^{(s)} - d_k^{(s-1)}$$

     for k = 1 to K

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

end

/decision/

$$\overset{\wedge(s+1)}{d} = sgn(Z^{(s+1)})$$

end

3.1 proposed Multistage Subtracting and partial PIC (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 M-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. Considered these two techniques we proposed SP-PIC detector which combines the subtracting PIC and partial PIC. This proposed technique to improve the performance and reduces the computational complexity. This approach is performed by replacing equation (7) by:

$$Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \, \hat{e}_j^{(s)} \qquad (8)$$

Multistage SP-PIC Algorithm

*Subtracting PIC

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

*Partial PIC

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

*Combination of subtracting and partial

(SP-PIC)

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

4. Odd Kasami 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 [12]. 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

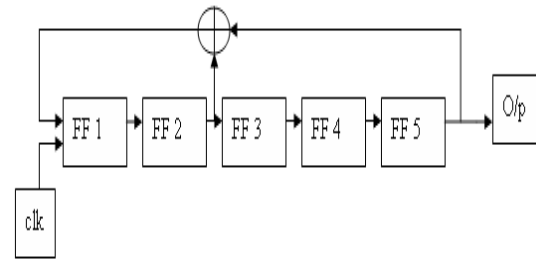shows the kasami Sequence generator for m=5 (odd).

Figure-8: Generation of proposed odd kasami Sequence of length 32

$a = [1\ 0\ 1\ 0\ 0\ 1\ 0\ 0 \quad 0\ 0\ 1\ 1\ 1\ 0\ 1\ 0$

$\quad 0\ 1\ 0\ 0\ 0\ 0\ 1\ 1 \quad 1\ 0\ 1\ 0\ 0\ 1\ 0\ 0]$

$a' = 1\ 0\ 0\ 1$

$b = [1\ 0\ 0\ 1\ 1\ 0\ 0\ 1\ 1\ 0\ 0\ 1\ 1\ 0\ 0\ 1$

$\quad 1\ 0\ 0\ 1\ 1\ 0\ 0\ 1\ 1\ 0\ 0\ 1\ 1\ 0\ 0\ 1]$

a xor $b = [0\ 0\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 0\ 1\ 0\ 0\ 0\ 1\ 1$

$\quad 1\ 1\ 0\ 1\ 1\ 0\ 1\ 0\ 0\ 0\ 1\ 1\ 1\ 1\ 0\ 1]$

5. Simulation Results

Conventional single user Matched Filter (MF), conventional parallel interference cancellation and partial parallel interference cancelletion methods are investigated. In this section a description of the multi stage and K-user discrete time basic synchronous DS-CDMA model has been used. Odd kasami spreading sequence is used.

The multistage multiuser detection schemes for DS-CDMA communication described in section 2 and 3 were simulated in MATLAB.

Multistage PIC performance compared with the Matched filter is shown in figure 9. The Multistage PIC detection provides a better improvement in performance compared with the conventional Matched filter. Also it is shown that number of PIC stages increases the detection performance will be improved. When number of PIC stages increases will 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.

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. In this paper partial cancellation factor 0.1 in the first stage, v0.2 and 0.3 in the second and third stages. The performance of Multistage Partial-PIC is shown in Figure 10. The simulation results for the Multistage P-PIC provide good performance compared with the performance of conventional matched filter.

The multi stage P-PIC suffers from computational complexity. To mitigate this problem by using proposed subtractive PIC technique but system performance approximately equal to conventional PIC. The simulation results as shown in figure 11. The computational complexity and performance both can be significantly improved by using one more proposed technique that is called the combination of subtractive and partial parallel interference cancellation technique. The simulation results as shown in figure 12.

Now we considered stage 3 for multi user detection, because the performance is good than stage 2 and stage 1. From figure 13 to 16 shows that the number of users increases the system performance gradually decreases for using different PIC detection schemes.
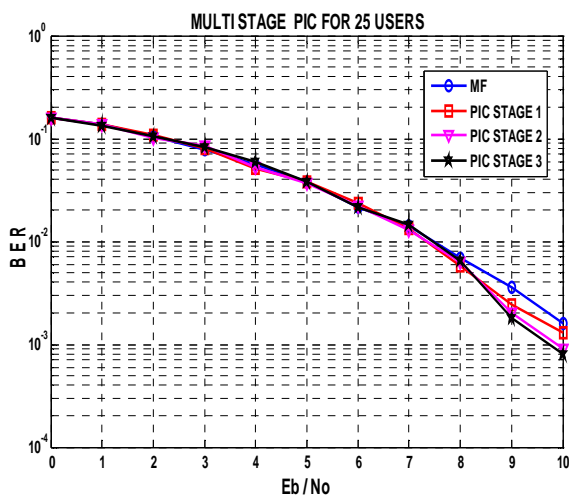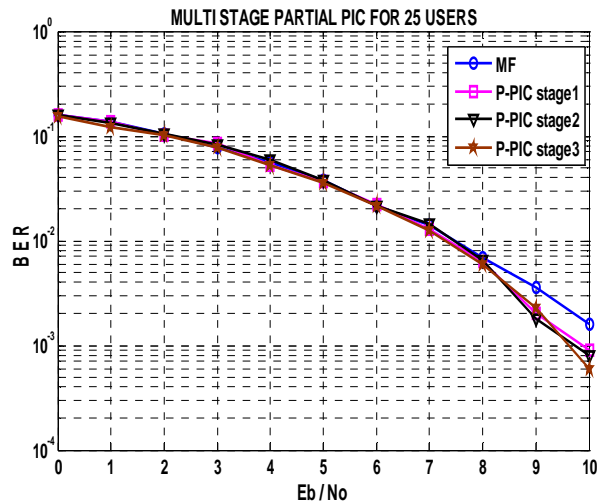
Figure 10: BER Vs. Eb/No for the Matched Filter and Multistage P-PIC Detection

Figure 11: BER Vs. Eb/No for the Matched Filter and Multistage S-PIC Detection

Figure 9: BER Vs. Eb/No for the Matched Filter and Multistage PIC Detection

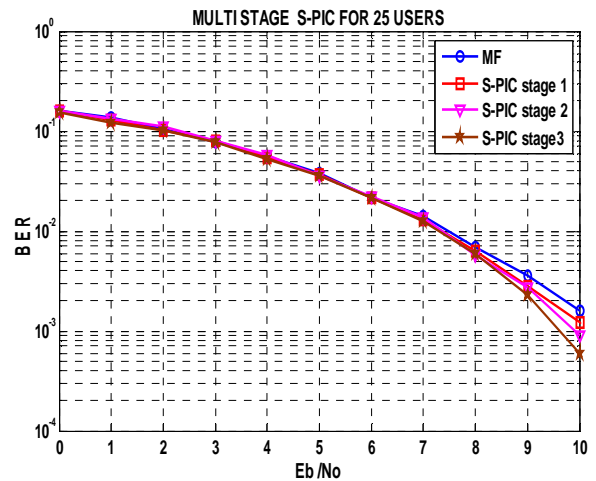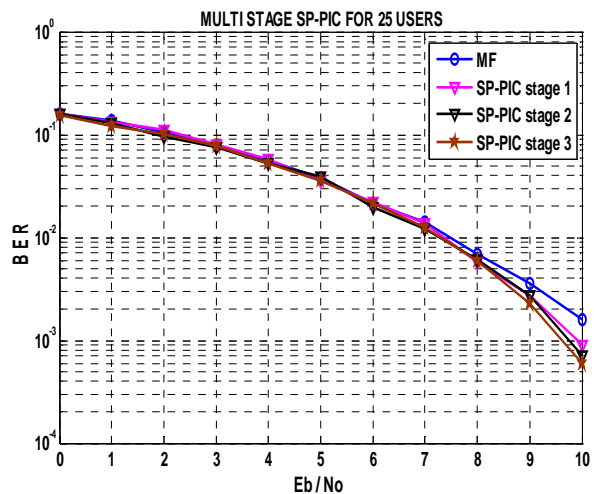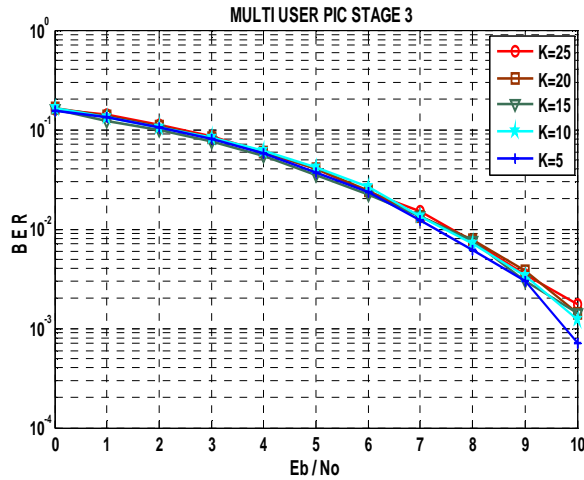Figure 12: BER Vs. Eb/No for the Matched Filter and Multistage SP-PIC Detection
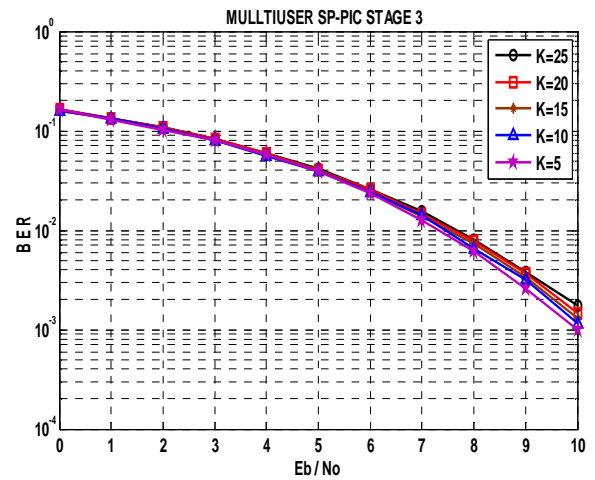
Figure 13: BER Vs. Eb/No for PIC Detection
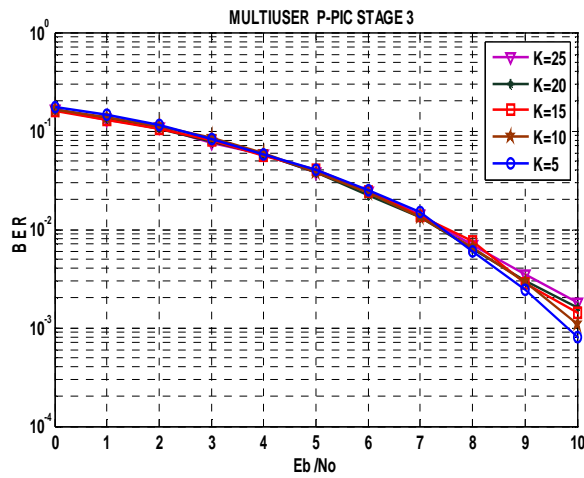

Figure 14: BER Vs. Eb/No for P-PIC Detection

Figure 15: BER Vs. Eb/No for S-PIC Detection

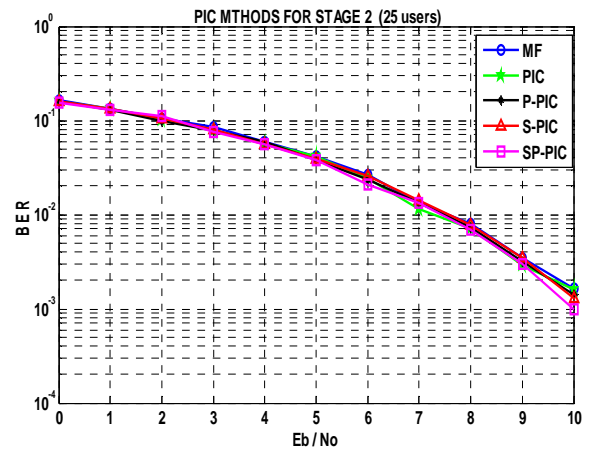
Figure 16: BER Vs. Eb/No for SP-PIC Detection

Figure 17: BER Vs. Eb/No for the Comparison of Matched Filter and different Multistage PIC Detection methods for stage 2
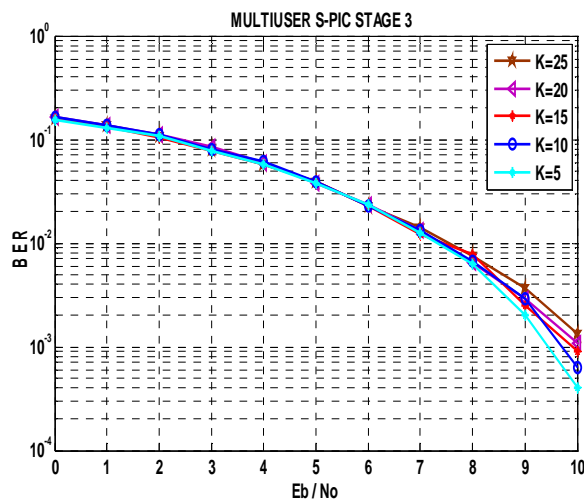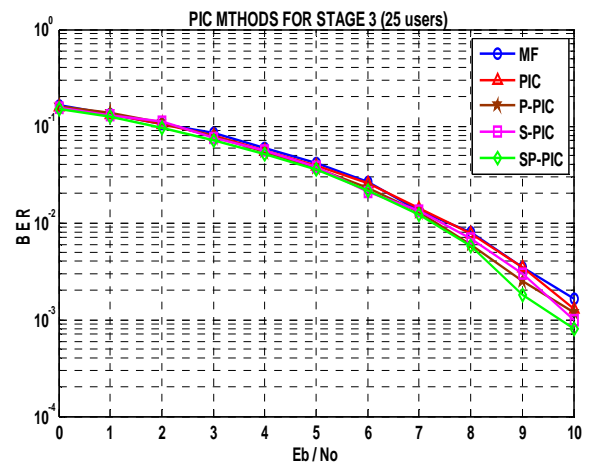

Figure 18: BER Vs. Eb/No for the Comparison of Matched Filter and different Multistage PIC Detection methods for stage 3

Finally, we compared with different types of PIC techniques. Here considered stage 2 & 3 because the system performance is improved when number of stages increased. The SP-PIC provides significant improvement in performance compared with the PIC, P-PIC and S-PIC schemes. Simulation results as shown in figure 17 for stage 2 & 18 for stage 3.

6. Conclusions

In this paper we introduced different interference cancellation methods. subtracting and partial & subtractive detection techniques are proposed in multistage parallel interference cancellation. Conventional PIC suffered from computational complexity and performance. This problem is reduced by using the partial PIC method. Partial cancellation factors are 0.1 in first stage and 0.2, 0.3 are the next stages. In this method performance can be improved but complexity can not be improved. Now we proposed subtractive PIC, by using this method complexity can be reduced but performance is slightly less compared to the P-PIC. Both these problems can be rectified by using one more proposed method that is the combination of d Subtractive and partial PIC is called SP-PIC. It cancels efficiently multiple access interference and has reduced computational complexity, when it is compared with conventional detection technique it has superior performance.

References:

[1] Lokesh Tharani and Dr. R.P.Yadav, "Performance evaluation of multistage multiuser detector for asynchronous DS-CDMA system" *IEEE Proceeding of International Conference on Computational Intelligence and Multimedia Applications* 2007 (ICCIMA-07), Volume IV, page No. 316-321, Sivakasi, Tamilnadu, India, Dec 2007

[2] Alexandra Duel-Hallen, Jack Holtzman, and Zoran Zvonar. "Multi-user Detection for CDMA systems". *IEEE Personal Communications*, April 1995.

[3] S.Moshavi "multiuser detection for DS-CDMA communications" *IEEE communication. Mag*., vol.34,pp.132-136,oct,1996.

[4] Kavitha Khairnar and Shikha Nema. "Comparison of multi-user detectors of DS-CDMA system" *Proceedings of World Academy of Science, Engineering and Technology*, vol.10 december 2005.

[5] S. Correal, R.buehrer, and D.Woerner "A DSP-Based DS-CDMA Multiuser Receiver Employing Partial Parallel Interference Cancellation", *IEEE Journal on Selected Areas in Communications*, Vol.17, No.4, April 1999.

[6] S.Verdu, "*Multiuser Detection*", Cambridge University Press. 1998.

[7] J.Ravidrababu and E.V.Krishna Rao. "Performance Analysis and comparison of Linear Multi-User Detectors in DS-CDMA system" *International journal of electronics and communication engineering & technology*. Vol-3, issue 1,.pp.229-243. January-june 2012.

[8] S.Rajagopal, S.Bhashyam, R.Cavallaro and B.Aazhang″ Real-Time Algorithms and Architectures for Multiuser Channel Estimation and Detection in Wireless Base-Station Receivers", *IEEE Transactions on Wireless Communications*, Vol.1, No.3, July 2002.

[9] Louis G.F. Trichard, "Optimal Multistage Linear Multiuser Receivers",*IEEE Transaction on Wireless Communication,* Vol. 4,NO. 3, May 2005.

[10] A.Nahler, R.Irmer, and G.Fettweis "Reduced and Differential Parallel Interference Cancellation for CDMA Systems", *IEEE Journal on Selected Areas in Communications*, Vol.20, No.2, February 2002.

[11] Lokesh Tharani, R.P.Yadav "Interference Reduction Technique in Multistage Multiuser Detector for DS-CDMA System″ *International Journal of Electronics, Circuits and Systems* 2;4 © www.waset.org Fall 2008.

[12] J.Ravidrababu and E.V.Krishna Rao. "Performance Analysis and comparison of spreading codes in Linear Multi-User Detectors for DS-CDMA system" *world Scientific and Engineering Academic and Society* transactions on communications. 2012 (process in publication).

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