Interference cancellation and complexity reduction in multi stage multi-user detection

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Abstract— Multi stage Parallel Interference Cancellation (PIC) technique gives good performance compared to Successive Interference Cancellation (SIC) method, but biased decision statistic and complexity problems are raised due to imperfect estimation of Multiple Access Interference (MAI) as number of stages increases. Partial Parallel Interference Cancellation (PPIC) technique is proposed to cancel the interference partially stage by stage to overcome biased problem. The complexity reduction for PIC detection is based on the convergence nature of interference cancellation which is called the Difference PIC (D-PIC) detection technique. In this paper we combine (PPIC and DPIC) these two techniques and propose a Multi stage multiuser Hybrid or PD-PIC using MMSE detector for performance improvement and complexity reduction compared to conventional PIC detector. The performance is degraded as the number of users' increases in each technique. Here considering MMSE for first stage instead of matched filter.

Keywords— Multi-user detection, MMSE, MAI, SIC, PIC, PPIC, DPIC and PDPIC.

1 Introduction

The tremendous increase in demand for wireless services has caused a search for techniques to improve the capacity of current digital communication systems. To bring this vision for future, the current state of wireless technology is necessary for major improvements.

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 bit error rate (BER). Hence, there is a 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. Optimal solutions with best possible performance in Gaussian noise channels have been already investigated and developed. Unfortunately when the number of users increases the complexity of these schemes increase exponentially, hence this type of detector is not suitable for practical applications. 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 suboptimal 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 [6–11].

In the next section, we present about the system model. In Section 3, proposed Interference cancellation schemes are described. Section 4 provides some simulation results on the performance comparison of different interference cancellation methods. The summary of the findings is given in conclusions in section 5.

2 System Model

For K direct sequence users in the synchronous single path BPSK real channel, the baseband received signal [6-7] is expressed as

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

where

$A_k(t)$ = Amplitude of the kth user

$s_k(t)$ = Signature code waveform of the kth user

$b_k(t)$ = 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.

2.1 Conventional single user detector

The current CDMA receivers are based on conventional single user detector, also known as matched filter. In conventional single user digital communication system as shown in Figure 1, 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. In other words, other users are considered as interference or noise [12], [13].

The sampled output of the kth matched filter is given [13] by

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

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

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

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 jth user [13].

The decision is made by

$$\hat{b} = \operatorname{sgn}(y_k) \qquad (2)$$

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

$$\mathbf{y} = \mathbf{RAb} + \mathbf{n} \qquad (3)$$

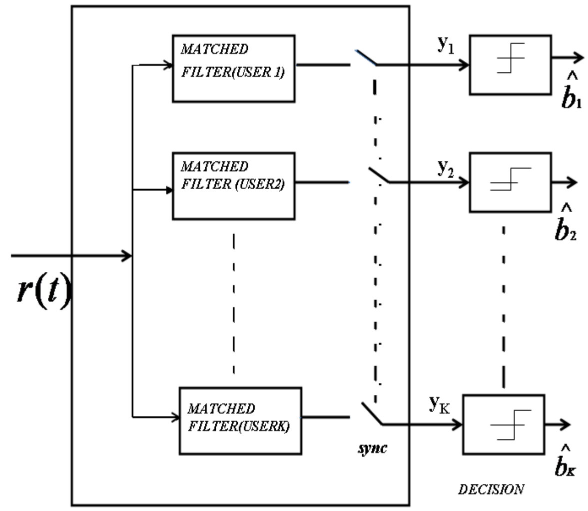

Figure:1 Matched filter bank

where **R** is the normalized crosscorrelation matrix whose diagonal elements are equal to 1 and whose (i,j) elements are equal to the crosscorrelation, $\rho_{i,j}$, **A**=diag{A_1,……,A_k},
y =[y_1,……..y_k]^T ,
b= [b_1,……..b_k]^T and
n is a Gaussian random vector with zero mean and covariance matrix σ^2**R** [13].

2.2 Multi-User Detection

Spread spectrum has been very successfully used by the military for decades. DS-CDMA has a significant role in cellular and personal communications. Comparing to other multiple access schemes, DS-CDMA has been found to be attractive because of potential capacity increases over competing methods, robustness to multipath, soft capacity and soft handoff. There has been great interest in improving DS-CDMA detection through the use of multiuser detectors [14-18]. Multiuser detection refers to the problem of detecting transmitted signals by considering all users. Initially, optimal multiuser detector, or the maximum likelihood sequence estimation detector was proposed by Verdu [15], this detector is much too complex for practical DS-CDMA systems.

There are two categories of the most proposed detectors: linear multiuser detectors and non-linear multiuser detectors. In linear multiuser detection, a linear mapping (transformation) is applied to the soft outputs of the conventional detector to produce a new set of outputs, which hopefully provide better performance. In non-linear detection, estimates of the interference are generated and subtracted out [8-9].

Figure-2 shows the general structure of multiuser detection systems. 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. This is followed by applying multiuser detection algorithm for optimality conditions to produce the soft output statistics [15].

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 [15-16].

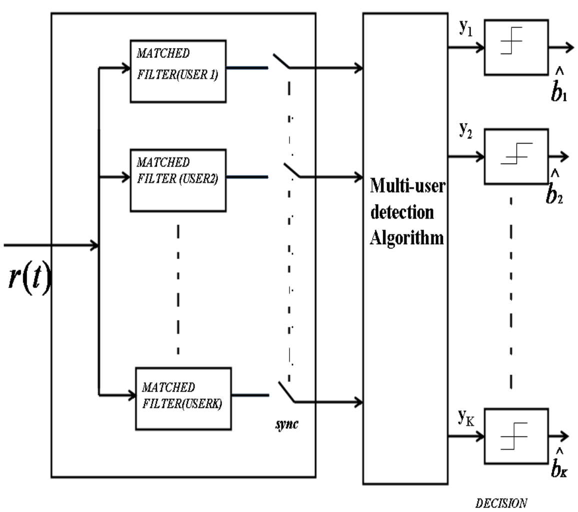

Figure.2 A typical multi-user detector

2.3 The Conventional Detector as a Front End of MUD's

The front end of any MUD has a section to convert the continuous-time received signal to a discrete-time process. This is usually done by sampling or it can also be done using the matched filter bank. As shown earlier, the conventional detector takes the received signal r(t) and outputs the statistic y = [y_1 …..y_k] . It has been proved [17] that the matched filter bank sacrifices no information relevant to demodulation. Hence r(t) can be replaced by y without any loss in system performance.

Most MUDs therefore have the matched filter as the front end. With the matched filter front end, the objective of MUD can be stated as follows: Given the statistic {y_1, y_2, , , ,y_k], at the output of the matched filter, find an estimate for the transmitted bits {bl, b2, ... , bk } that minimizes the probability of error [17].

2.4 Minimum Mean-Squared Error (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 linear multi-user detection based on Minimum Mean Square Error (MMSE) criterion [13].

The MMSE receiver is another kind of linear multi-user receiver. It is shown in Figure 3, implements the linear mapping which minimizes the mean-squared error between the actual data and the soft output of the conventional detector, so the decision for the k^{th} user is made based on

$$\hat{b}_k = \mathrm{sgn}\left(((\mathbf{R}+\sigma^2\mathbf{A}^{-2})^{-1}y)_k\right) \qquad (4)$$

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

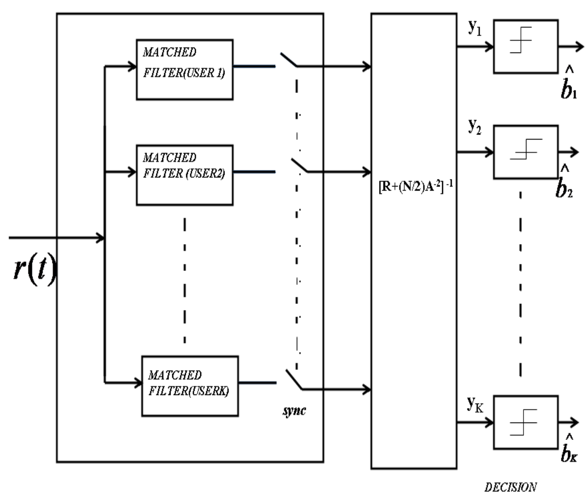

Figure 3 MMSE linear detector

3 Interference Cancellation methods

3.1 Parallel interference cancellation

The parallel interference cancellation (PIC) detector employs multiple iteration in detecting the data bits and canceling the interference. PIC detector requires the number of stages as shown in Figure 4. 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 [7-8]. In the multistage 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 5. In the S-stage PIC detector, the decision for the stage s+1 can be expressed as [18]:

$$\hat{b}_k^{(s+1)} = \text{sgn}(z_k^{(s+1)}) \quad (5)$$

Where

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

and

$$z_k^{(1)} = y_k \quad (7)$$

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 MMSE 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. 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.

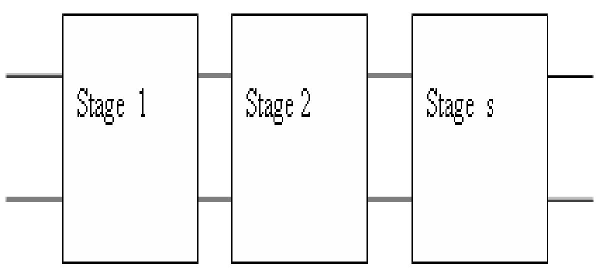

Figure 4: The concept of multistage detector

3.1.1 Computational complexity

The complexity can be represented by the number of multiplications and the number of additions needed to accomplish the multi-user detection. Usually, to accomplish the multiplication of a (M×N) matrix with a (N×P) matrix we need to do MNP times of multiplications and MNP times of additions. Assuming in our case there are a total of K users in the system where the transmission is in burst.

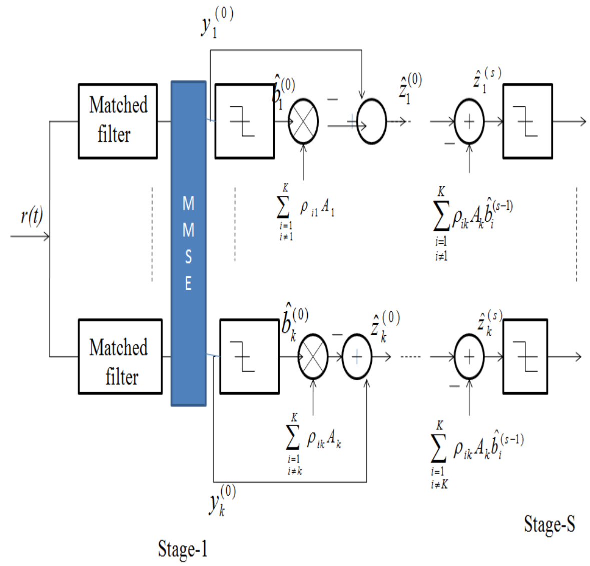

Figure 5: Multistage PIC detector

Each user transmits Q data symbols per burst. N represents the length of the spreading sequence for each user, and W is the complex matrix which contains the elements describe the channel impulse response. Then for each user, it will need NQ times of multiplications and NQ times of additions for every path ((N×Q) × (Q×1)). Multiplying with which represents the multi-path components, the receiver will require QNL times of additions and multiplications. To combine the Q symbols transmitted from the dispersive paths, it will need other QL times of multiplications and additions. Therefore, to get the data estimates from the receiver, QNL+QL times of multiplications and additions are required. At the signal reconstruction part, the detected data should be multiplied with the spreading sequence first, which results in QN times of multiplications, and then convolves with the corresponding channel impulse response, which leads to QNL times of multiplications and (QN+W−1) times of additions. To get the estimate for each user, all the other users influences should be subtracted.To cancel one user's MAI, it will need (QN+W−1) times of subtraction. Therefore, for each user, (K−1) (QN+W−1) times of subtractions are needed. For a system supporting K users, the total number of mathematic operations is

S_{PIC}=k* [QNL+QL+QNL+QL+QN+QNL+QN+W-1+(K-1)(QN+W-1)]

= K*[3QNL+2QL+QN+K(QN+W-1)] for first stage

= 2* K*[3QNL+2QL+QN+K(QN+W-1)] for second stage

Therefore, the number of operations needed by the PIC detector for every symbol is $S_{PIC\ /symbol} = S_{PIC} / KQ$ for one stage. The number of stages are increases the number of operations also increases.
Example: L=1 and supporting K = 9 users, Q=20symbols and N = 31chips for a system, the number of operations needed for PIC detector is

S_{PIC}= K*[3QNL+2QL+QN+K(QN+W-1)]
= K[(K+4)NQ+2Q]
= 9*[(9+4)31*20+2*20
= 72900

And the number of operations needed by the PIC detector for every symbol is

$S_{PIC\ /symbol} = S_{PIC} / KQ$
= 72900 / 9*20 = 405

This is only for single stage.
Example: Number of stages = 2, the number of operations needed for PIC detector is 72900 * 2 = 145800.
The number of operations needed by the PIC detector for every symbol is

$S_{PIC\ /symbol} = S_{PIC} / KQ$
= 145800 / 9*20 = 810

The number of stages is increases the number of operations also increases.

3.2 Partial Parallel Interference Cancellation

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 [5]. 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 6. This multiplication has to be performed before the amplitude estimates are used to subtract the interference. This can be interpreted as modifying the equation (6) to include a partial cancellation factor resulting [18].

$$Z_k^{(s+1)} = y_k - \sum_{j\neq k} C_k^{(s)} A_j \rho_{kj} \overset{\wedge(s)}{b_j} \quad (8)$$

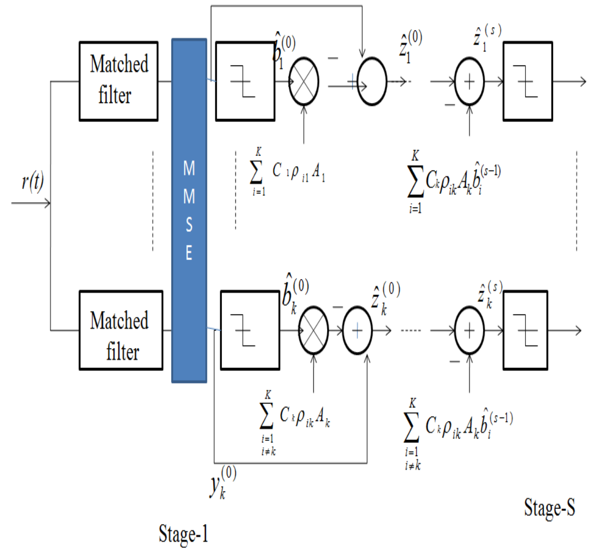

Figure 6: Partial PIC detector

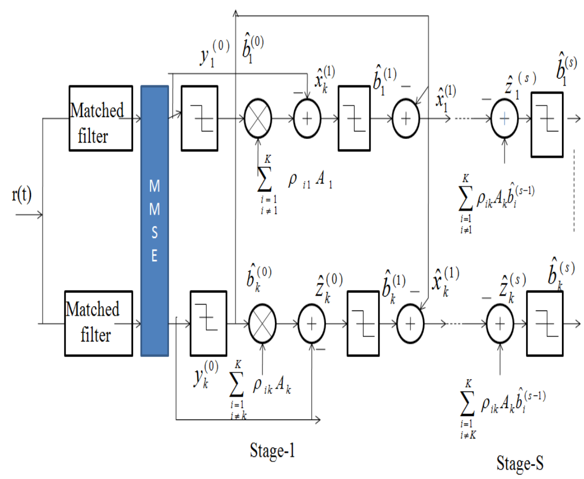

Figure 7: Difference PIC detector using MMSE

3.3 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 (6), 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]. By using this technique computational complexity can be reduced than PPIC. Equation (6) can be rewritten as

$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

3.3.1 Computational complexity

As the complexity calculation discussed in the Section 3 a), in this section, discuss the complexity of the Differencing PIC receiver based on the number of multiplications and additions. Using the parameters given in the Section 3 a), that is, K, the users; Q, data symbols per user; N, the length of the spreading codes; L is the number of paths and W represents the channel impulse response. The procedure is similar to PIC up to first stage. But in second stage, only NQ times additions are required in differencing PIC.For a system supporting K users, the total number of mathematic operations is S_{DPIC}=k*[QNL+QL+QNL+QL+QN+QNL+QN+W-1+(K-1)(QN+W-1)]

= K*[3QNL+2QL+QN+K(QN+W-1)] for first stage. This is similar to conventional PIC. But for second stage

S_{DPIC} = K*[3QNL+2QL+QN+K(QN+W-1)] + QN. second stage

S_{PIC}= K*[3QNL+2QL+QN+K(QN+W-1)]
= K[(K+4)NQ+2Q] + NQ
= 9*[(9+4)31*20+2*20 + 31*20
= 72900 + 620
= 73520

the number of operations needed by the PIC detector for every symbol is

$S_{PIC /symbol}$ = S_{PIC} / KQ
= 73520 / 9*20 = 408

In this method the computations are less compared to the conventional PIC.

3.4 PD-PIC technique

It is explained before that the multi stage difference 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 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 PD-PIC or Hybrid PIC and is shown in Figure 8. By using this technique, performance can be improved and also complexity can be reduced [18].

$$Z_k^{(s)} = Z_k^{(s-1)} - C_k^s \sum_{j \neq k} A_j \rho_{kj} \overset{\wedge(s)}{x_j} \qquad (10)$$

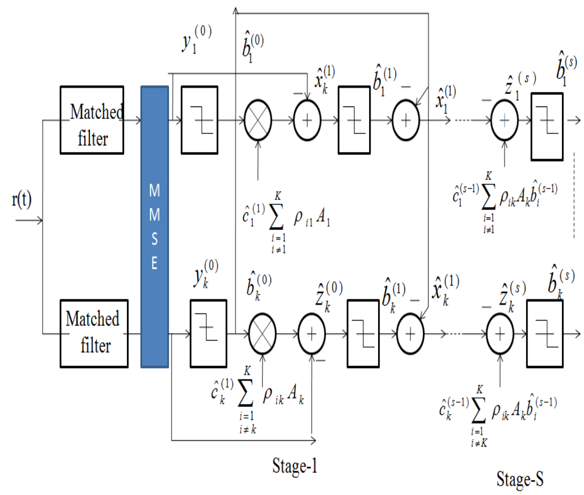

Figure 8: PD-PIC detector

4 Simulation Results

MF, MMSE, conventional Parallel Interference Cancellation (PIC) and Partial Parallel Interference Cancellation (PPIC) methods are investigated. Difference PIC and Partial Differential PIC (PDPIC) Techniques are proposed using MMSE. In this section a description of the multi stage and K-user 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.

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

Multistage conventional PIC, partial PIC, difference PIC and partial difference PIC or hybrid PIC BER performance compared with different stages using MMSE detector is shown in Figure 9 to 12. It is seen that as the number of stages increases the detection performance is improved. But, when number of stages increases the complexity also increased. Thus we are using only 3-stages of PIC will be a good compromise between the performance and complexity. Now, we have considered 3rd stage for comparison with the different PIC's. Here the PD-PIC provides better performance compared to the other PIC's as shown in Figure 13.

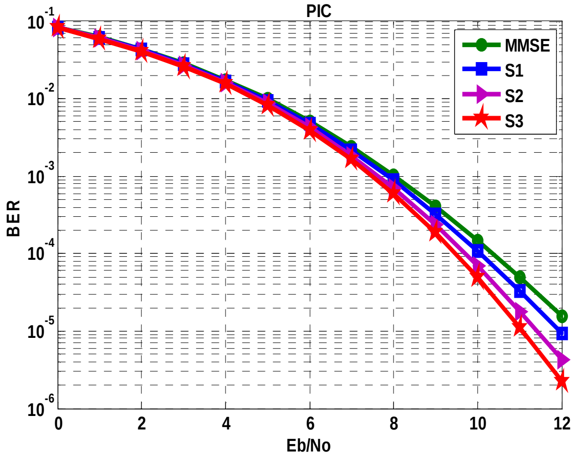

Figure 9: BER Performance of Multistage PIC (K=5)

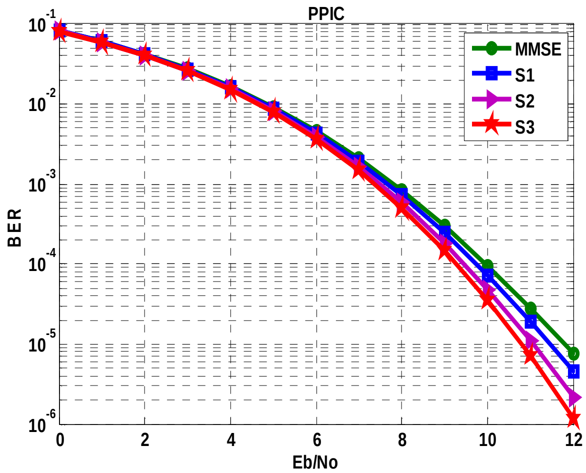

Figure 10: BER Performance of Multistage PPIC (K=5)

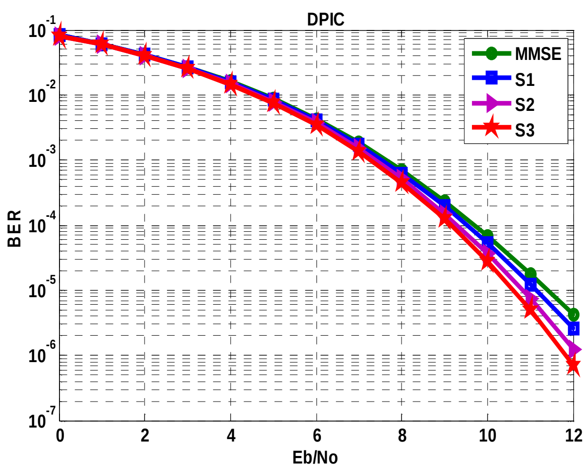

Figure11 : BER Performance of Multistage DPIC (K=5)

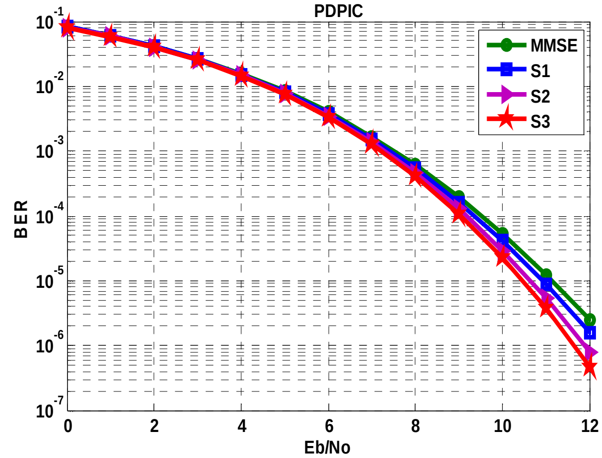

Figure 12 : BER Performance of Multistage DPIC (K=5)

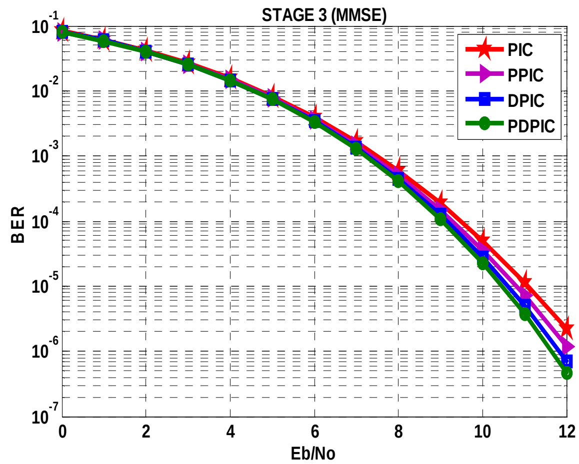

Figure 13: BER Performance of multiuser PD-PIC for third stage (K=5)

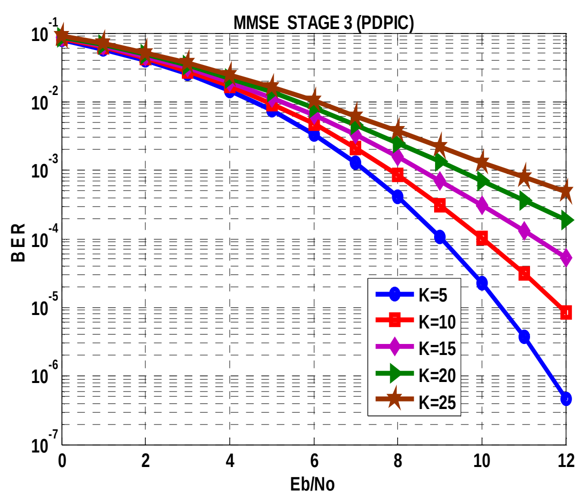

Figure 14: BER Performance of PDPIC for different users.

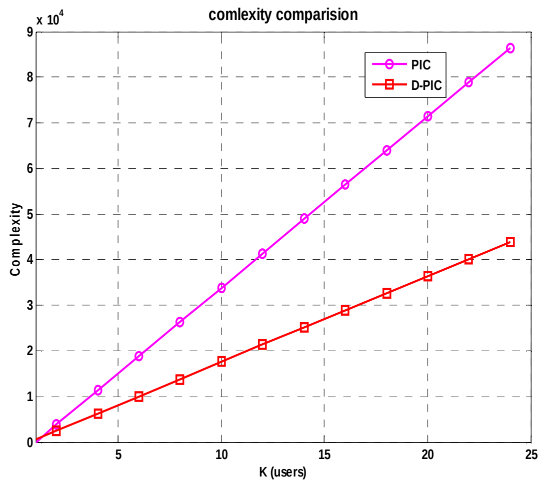

Figure 15: computational complexity between PIC and DPIC.

The number of users increases the system performance gradually decreases as shown in Figure 14. The computational complexity of the DPIC is better than conventional PIC detector as shown in figure 15.

5 Conclusions

Different interference cancellation techniques are studied. Conventional PIC suffered from statistical biased and computational complexity. The biasing problem is reduced by using the multi stage partial PIC (PPIC) method. By using multi stage difference PIC (DPIC), complexity can be reduced. The combination of PPIC and DPIC is called PD-PIC or H-PIC. By using this method, performance can be improved and also complexity can be reduced compared to the conventional PIC method. When number of stages increases, the performance can be improved. But, when the number of users increases the performance degrades.

Acknowledgments:

I would like to thank the following professors for their support and advice during the research work: Dr.M.Madhavi Latha, Dr.P.Chandrasekar Reddy, Dr.M.Asha Rani, Dr. P.V.D.Somasekara Rao, Dr.L. Pratap Reddy and Dr.D Srinivasa Rao.

References

[1] R. Pickholtz, D. Schilling, and L. Milstein, Theory of spread-spectrum communications A tutorial," *IEEE Trans. Commun.*, vol. 30, May 1982, pp.855-884.

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

[3] 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.

[4] M.Varanasi and B. Aazhang, "Multistage detection in asynchronous code division multiple access communications," *IEEE Trans.Commun.*, vol. 38, , Apr. 1990, pp. 509–519.

[5] S. Correal, R.buehrer, and D.Woerner "A DSP-Based DS-CDMA Multiuser Receiver Employing Partial Parallel Interference Cancellation", *IEEE Journalon 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, January-June 2012, pp.229-243.

[8] D.Divsalar, M. K. Simon, and D. Raphaeli, "Improved parallel interference cancellation for CDMA," IEEE Trans. Commun., vol. 46, Feb. 1998, pp.258–268.

[9] R.Fantacci,"Proposal of an interference cance llation receiver with low complexity for DS/CDMA mobile communications systems," *IEEE Trans. Veh. Technol.*, vol. 48, July 1999, pp. 1039–1046,

[10] J. F. Weng, Q. Xue, T. Legoc, and S.Tahar "Multistage interference cancellation with diversity reception for asynchronous QPSK DS/CDMA systems over multipath fading channels," *IEEE J. Select.Areas Commun.*, vol. 17, Dec. 1999, pp 2162–2180,

[11] D.Guo, L. Rasmussen, S. Sun, and T. Lim, "A matrix-algebraic approach to linear parallel interference cancellation," *IEEE J. Select. Areas Commun.*, vol. 48, Jan. 2000, pp. 152–161.

[12] L.Rasmussen, "On ping pong effects in linear-interference cancellation for CDMA," in Proc. *IEEE ISSSTA*, 2000, pp. 348–352.

[13] Rajagopal, S.Bhashyam ,R.Cavallaro and B.A azhang "Real Time Algorithms and Architectu res for Multiuser Channel Estimation and Detection in Wireless Base- Station Receivers", *IEEE Transactions on Wireless Comm.*, Vol.1, No.3, July 2002.

[14] Louis G.F.Trichard, "Optimal Multi stage linear Multiuser Receivers", *IEEE Transaction on Wireless Communication*, Vol.4, no.3, May 2005.

[15] J.Ravidrababu and E.V.Krishna Rao. "Perform ance Analysis and comparison of spreading codes in Linear Multi-User Detectors for DS-CDMA system" *WSEAS transactions on communications.* Issue 11, vol 11, November-2012.

[16] AM. Zoubir and AT. Lane-Glover (2001), Multiuser Detection in Impulsive Noise, In Proceedings of the 11th *IEEE Workshop on Statistical Signal Processing*, 26-29.

[17] S. Moshavi, E. G. Kanterakis, and D. L. Schilling, Multistage Linear Receivers for DS-CDMA Systems, *Int'1. J, Wireless Info. Networks*, vol. 3, no. 1, 1996, pp.1-17.

[18] J.Ravidrababu and E.V.Krishna Rao. "Perform ance Analysis and Performance Analysis, impro vement and complexity reduction in Multi-stage Multi user detector with parallel interfere nce cancellation for DS-CDMA System Using odd kasami sequence *WSEAS transactions on co mmunications,* Issue 4, vol-12, April 2013.

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