# Complexity Reduction and Performance Improvement of Multistage Detector with Parallel Interference Cancellation for DS-CDMA System

**Bayez K. Al-Sulaifanie** **Sedki. B. T. Younis**

Bayez_K@yahoo.com
sedkibakir@yahoo.com

**College of Electronics Engineering**

**Computer & Information Engineering Department**

**Mosul-Iraq**

**Abstract**

In this paper we propose a new method which combines the partial cancellation and differencing technique to achieve performance improvement and reduction in complexity, the proposed technique is named Multistage (DP-PIC) Detector. The simulation model for the proposed DP-PIC is implemented in floating and fixed point arithmetic. The simulation results illustrates that a partial cancellation factor of 0.7 and 0.8 in the first and second stage respectively gives a good performance for the proposed technique. A precision of 16-bit is enough to achieve a small performance degradation compared to floating point results. Finally the proposed fixed point DP-PIC is implemented on TMS320C6400 DSP simulator. The implementation results illustrate that 35% complexity reduction can be achieved compared with conventional PIC detection.

**Keywords:** DS-CDMA, PIC, Complexity reduction, performance improvement.

**تقليل التعقيد وتحسين الأداء لكاشف متعدد المراحل مع إلغاء التداخل المتوازي لأنظمة الوصول المتعدد بتقسيم الشفرة**

د. بايز خورشيد السليفاني صدقي بكر ذنون

كلية هندسة الالكترونيات-جامعة الموصل

**الخلاصة**

في هذا البحث تم اقتراح نموذج لكاشف متعدد المراحل يستخدم خوارزمية إزالة التداخل المتوازية المحسنة مع استخدام متجه الفرق وذلك للحصول على أداء جيد مع تقليل بتعقيد الخوارزمية، وقد تم بناء نموذج لهذه الخوارزمية يعمل بحسابات الفاصلة الثابتة. لقد أظهرت نتائج المحاكاة مدى التحسن الذي يطرأ على أداء النظام عند استخدام تقنيات الكشف بتعدد المستخدمين. إن تقييم الأداء للخوارزمية المقترحة اظهر أن عامل إزالة جزئية بمقدار 0.7 في المرحلة الأولى و0.8 في المرحلة الثانية أعطت أفضل نتائج لهذه الخوارزمية. وقد أظهرت نتائج المحاكاة بالفاصلة الثابتة إن دقة 16-bit تكون كافية لهذه الخوارزمية مقارنة مع حسابات الفاصلة العائمة.

Received 15 Oct. 2006 Accepted 8 Oct. 2007

## 1-Introduction

Wireless communications have become one of the hottest research areas in the world. The fast grows in this field requires complex signal processing techniques and sophisticated multiple access methods to meet these demands. Direct Sequence Code Division Multiple Access (DS-CDMA) has been recognized as one of the best multiple access schemes for wireless communication systems [1].

The DS-CDMA scheme have several advantages compared to other access schemes. It is also an access schemes for many future applications [2]. However, in DS-CDMA systems multiple access interference (MAI) arises because of the non-ideal cross correlation properties of the spreading codes. The detection of such CDMA signals using the conventional detection which consist of a bank of Matched Filter (M.F) leads to unacceptable performance degradation in terms of bit error rate (BER). This presents the need for more sophisticated detection strategies and signal processing, such as multi-user detection (MUD) to overcome this performance degradation. An overview of different MUD algorithms can be found in [3].

The Multistage Parallel Interference Cancellation (PIC) detection is one of the most interesting multiuser detection techniques. Its concept is to cancel the interference generated by the users. One of the most effective PICs comes from the iterative multistage method, where the inputs of one particular stage are the estimated bits of the previous stage. After interference cancellation, the new estimations, which should be closer to the transmitted bits, are fed into the next stage [4].

The literature review for the multistage PIC detector showed that many research focused on this type of multiuser detection due to its good performance compared to other multiuser detection technique. The biased decision statistic problem due to imperfect estimation of multiple access interference is introduced in [5], the partial cancellation technique is proposed to cancel the interference partially stage by stage to overcome this problem. The complexity reduction for PIC detection is introduced in [6], the method is based on the convergence nature of interference cancellation which is called the differencing PIC technique.

In this paper we combine the two technique illustrated in [5],[6] to propose a multistage detector based on PIC technique to achieve performance improvement and complexity reduction compared to conventional multistage PIC detector.

## 2- DS-CDMA Transmission Model

A synchronous *K*-user DS-CDMA model is shown in figure (1). In this model the bit streams of *K* synchronous users antipodally modulate *K* signature waveforms which are transmitted over an Additive White Gaussian Noise (AWGN) channel [7].

The received signal for one symbol period in such a system can be expressed as [8] [9]:

$$r(t) = \sum_{k=1}^{K} A_k b_k c_k(t) + n(t) \qquad \ldots\ldots\ldots\ldots (2)$$

Where

- $c_k(t)$ is the signature waveform assigned to the $k$th user.
- $A_k$ is the received amplitude of the $k$th user's signal.

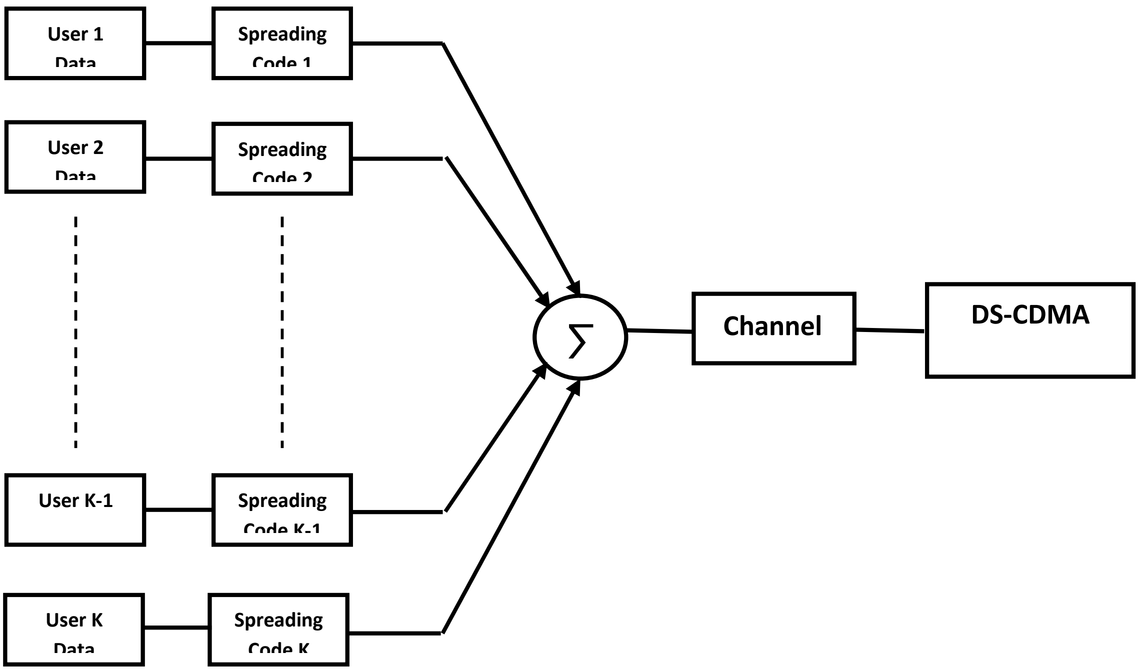


Figure (1) DS-CDMA Model

- $b_k \in \{-1,+1\}$ is a bit transmitted by the $k$th user.

- $n(t)$ is white Gaussian noise.

## 3- Conventional Detection of DS-CDMA Using Matched Filter Bank

DS-CDMA detectors commonly have a front-end consisting of Matched Filter (M.F) bank as shown in figure(2), each matched to the signature waveform of different user. The outputs of the matched filters are then sampled at the end of each bit period [7].

The output of the matched filter for a user $k$ in synchronous DS-CDMA can be expressed as [9]:

$$y_k = A_k b_k + \sum_{j \neq k} A_j b_j \rho_{jk} + n_k \qquad \text{............(2)}$$

Where

$\rho_{jk}$ is the cross correlation between the signature sequence of the desired user and the signature sequence of the other users.

$n_k$ is a Gaussian random variable with zero mean and variance equal to $\sigma^2$.

It can be seen that the output of a matched filter consists of a desired signal component, a MAI component (caused by the non-orthogonal signature sequences) and a noise component.

The decisions for the bits transmitted by user $k$ are based on the sign of the output of the matched filter bank for user $k$ at the end of each bit. The success of this detector depends on the properties of the cross correlation between the signature sequences, where the existence of MAI has a significant impact on the capacity and performance of DS-CDMA with conventional detector. As the number of active users in the system increases the amount of MAI increases which degrade system performance [3] [8].

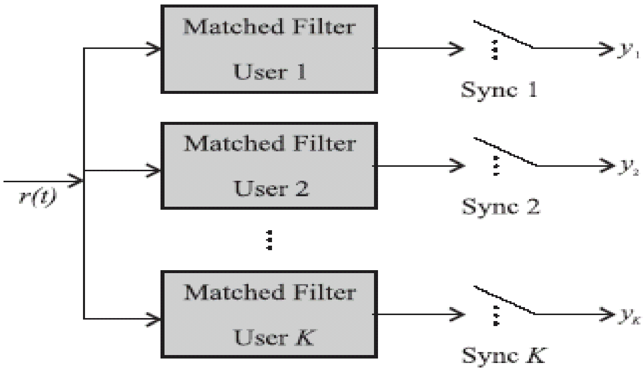


Figure (2) Matched Filter Bank

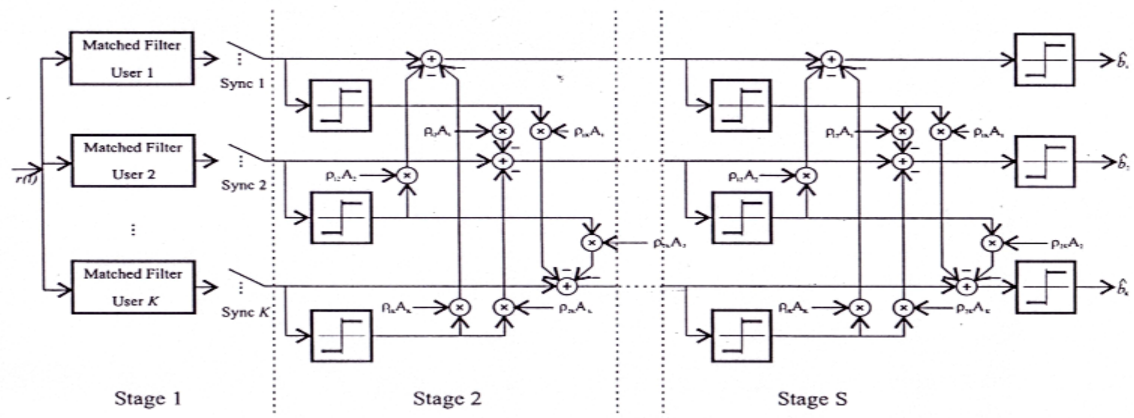


Figure (3) Multistage PIC Detector

## 4- Multistage Parallel Interference Cancellation Detector

The idea behind this types of detector is, if a decision has been made a bout the interfering user's bit, then the interfering signal caused by this user can be reconstructed and subtracted from the received signal [8].

The parallel interference cancellation (PIC) detector is based on a technique that employs multiple iteration in detecting the data bits and canceling the interference. PIC detectors have multiple stages for interference estimation and cancellation. The conventional detector is used in the first stage to estimate the data symbols. The other stages perform, for each user, signal reconstruction and subtraction of the estimated interference from all other users [5] [9].

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 symbols as well as the known cross-correlations between users as shown in figure(3). In the S-stage PIC detector, the decision for the stage s+1 can be expressed as [8]:

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

where

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

and

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

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. In this case the decision statistic of PIC detector could be rewritten as [9]:

$$Z_k^{(s+1)} = y_k - \sum_{j \neq k} Z_j^{(s)} \rho_{jk} \qquad \ldots\ldots\ldots\ldots\ldots\ (6)$$

The complete PIC algorithm is as follows [6]:

$\hat{d}^{(1)} = \text{sgn}(y)$ **/*hard decision for M.F output*/**

For s=2 to S **/* repeat cancellation S-1 stages*/**

For *k*=1 to K **/*subtract the interference from each user signal at each stage*/**

$$Z_k^{(s)} = y_k - \sum_{j=1}^{K} A_j (R_{kj} - diag(R_{kj}))\hat{d}_j^{(s-1)}$$

End

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

## 4-1 Multistage Partial Parallel Interference Cancellation (P-PIC)

The straightforward implementation of Multistage PIC detector based on complete 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 diminishes. 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 mitigate the effect of the biased decision statistic and improve the performance of parallel multistage 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:

$$Z_k^{(s+1)} = y_k - \sum_{j \neq k} C_K^{(s)} A_j \rho_{jk} \overset{\wedge}{b}_j^{(s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

## 4-2 Multistage Differencing PIC (D-PIC)

In the Multistage PIC detection after *s* iterations, it is more likely 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 (4), we can calculate the difference of the estimated bits in two consecutive stages. The input of each stage becomes $x_k^{(s)} = d_k^{(s)} - d_k^{(s-1)}$, which is called the differencing technique. Using this technique equation (4) can be re-written as [6]:

$$Z_k^{(s)} = Z_k^{(s-1)} - \sum_{j \neq k} A_j \rho_{jk} \overset{\wedge}{x}_j^{(s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Using this differencing algorithm, computations can be saved by computing equation (8) instead of equation (4). This is because more and more elements in the vector $x_k^{(s)}$ tend to be zero after several iterations. Moreover, all the non-zero terms in $x_k^{(s)}$ are equal to +2 or -2. The constant multiplication by 2 in equation (8) can be implemented by arithmetic shifts. Therefore, dedicated multipliers are not necessary for this algorithm. However, a two times (2x) speed up can be achieved by using the differencing technique. The total number of floating point operations (FLOPS) for he conventional PIC detector is $2L(NK)^2$, where L is the number of stages, K is the number of users and N is the window size. The total number of FLOPS can be reduced to $L(NK)^2$ when the differencing technique is used[10]. Finally, because this manipulation, which subtracts two consecutive stages, is a linear transformation, the bit error rate (BER) after each stage will not change, compared with the conventional multistage PIC detector implementation. Therefore, the final BER is exactly the same as the conventional multistage PIC detector.

The complete algorithm for Multistage D-PIC is shown below [9]:

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

For *k*=1 to K **/* first stage conventional multistage detection*/**

$$Z_k^{(2)} = y_k - \sum_{j=1}^{K} A_j (R_{kj} - diag(R_{kj}))\hat{d}_j^{(1)}$$

End

$$\hat{d}^{(2)} = \operatorname{sgn}(Z^{(2)})$$

For *s*=2 to S **/* second and later stages: differencing multistage detection*/**

$$\hat{x}^{(s)} = \hat{\mathrm{d}}^{(s)} - \hat{\mathrm{d}}^{(s-1)}$$ **/* differencing vector generation*/**

For *k*=1 to K

$K$ $\hat{}^{(s)}$

## 4-3 Proposed Multistage Combined Differencing Partial PIC (DP-PIC)

It is explained previously that the differencing PIC offer a good reduction in computational complexity of the algorithm compared to conventional PIC algorithm. Also it is noted that PIC algorithm suffers from the biasing effect in decision statistic. So, the partial cancellation of the estimated MAI especially in the first stage is used to solve this problem. The main interesting factor in differencing PIC technique is the computational complexity reduction. On the other hand the partial PIC offers a good improvement in performance. According to these two criteria the DP-PIC detector which combines the above two approach is proposed to improve the performance and reduces the computational complexity. This approach is performed by replacing equation (8) by:

$$Z_k^{(s)} = Z_k^{(s-1)} - C_K^{(s)} \sum_{j \neq k} A_j \rho_{ij} \hat{x}_j^{(s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Thus the proposed algorithm will use the partial cancellation to mitigate the effect of biased decision statistic, and the differencing technique to provide a reduction in complexity.

## 5- Simulation Results

In this section the performance evaluation for the previously explained detection technique is illustrated. The simulation parameter for the DS-CDMA system is as follows:

No. of active users in the system: 15 Spreading Factor (SF): 31

Code type: Gold Code

The performance of the M.F Bank Compared with the Multistage PIC detection technique is shown in figure (4). It is noted that Multistage PIC detection provides a significant improvement in performance when compared with the conventional detection. Also it is shown that increasing the number of PIC stages will improve the detection performance. But increasing the number of PIC stages will increase the complexity of the receiver, thus using 3-stage of PIC will be a good compromise between the performance and complexity [5].

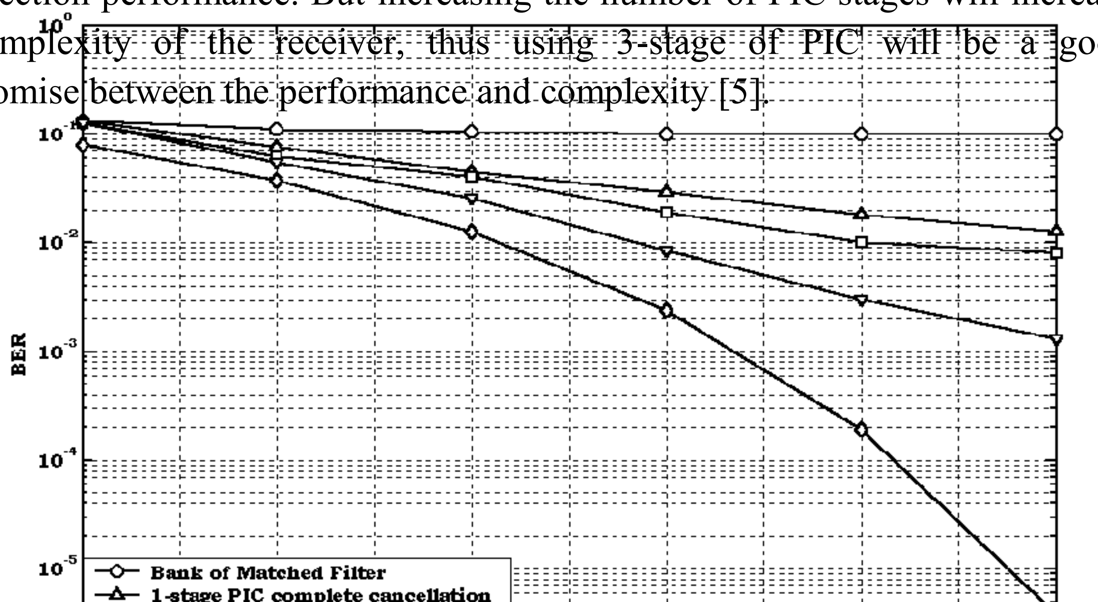

Figure (4) BER Vs. $E_b/N_o$ for the Matched Filter bank and Multistage PIC Detection

The Multistage D-PIC technique is used to reduce the complexity of the detection due to convergence of iterative PIC stages. The performance of Multistage D-PIC technique is the same as conventional Multistage PIC as shown in fig.(4). The simulations results are compared with the single user performance to show the effectiveness of the detection technique to combat the interference caused by the other users in the system.

The Multistage PIC Detection suffers from the biased decision statistic due to imperfect estimation of MAI. The Multistage P-PIC detection is used to combat the biased decision statistic by multiplying the estimated MAI by a partial cancellation factor. The effect of biased decision statistic is a raised in the first stage of PIC. In this paper the partial cancellation factor used is 0.5 in the first stage [5] [9].

The performance of Multistage P-PIC is shown in fig.(5). Here it is noted that the performance of the Multistage P-PIC detection provides a significant improvement over the conventional Multistage PIC detection. For example if $E_b/N_o$=10 dB the Multistage P-PIC offers a BER of 0.0001 while the Conventional Multistage PIC offers a BER of 0.0013. In fig.(5) the simulation results for the Multistage P-PIC is compared with the analytical performance of Multistage PIC with perfect estimation of MAI (i.e. no biased decision statistic problem). It is noted that there is still difference between the analytical and simulated performance because there is still imperfect estimation of MAI in the latest stages. In fig. (6) the performance of Multistage P-PIC compared with the conventional detection is illustrated, it is noticeable the significant performance improvement of 3-stage D-PIC over the conventional detector.

The performance of the proposed Multistage DP-PIC is shown in figure (7). It shows that when partial cancellation factor of 0.5 is used in the first stage, the performance is degraded compared with the 3-stage P-PIC detection. Thus the partial cancellation factor is regulated to 0.7 in the first stage and 0.8 in the second stage to get approximately the same performance as 3-stage P-PIC detection.

The proposed DP-PIC detection is also implemented in fixed point arithmetic, and compared with the algorithm performance behavior when implemented in floating point arithmetic. It is shown that a 16-bit fixed implementation gives satisfactory performance degradation compared with the floating point implementation. The fixed point arithmetic tool provided in matlab 6.5 is used.

Finally the proposed 3-stage DP-PIC detection (fixed point version) is implemented on TMS320C6400 DSP simulator with Code Composer Studio (CSS) provided by Texas Instrument. The number of clocks needed to implement the Conventional 3-stage PIC detection compared with the proposed 3-stage DP-PIC detection is shown in table (1). It is noticeable that the number of clocks needed to implement the proposed DP-PIC detection is about 35% less than that of conventional PIC detection. So the proposed DP-PIC detection provides a computational complexity reduction compared with the conventional PIC due to the use of differencing technique [9].

Table (1)

Number of clocks needed to implement the conventional PIC and the proposed DP-PIC

| **No. of Users (K)** | **8** | **10** | **12** | **14** | **16** |
|---|---|---|---|---|---|
| **3-stage PIC (cycles)** | **1226** | **1582** | **1974** | **2402** | **2866** |
| **3-stage DP-PIC (cycles)** | **803** | **1021** | **1257** | **1512** | **1783** |
| **Percentage Reduction** | **34.5** | **35.46** | **36.32** | **37.05** | **37.78** |

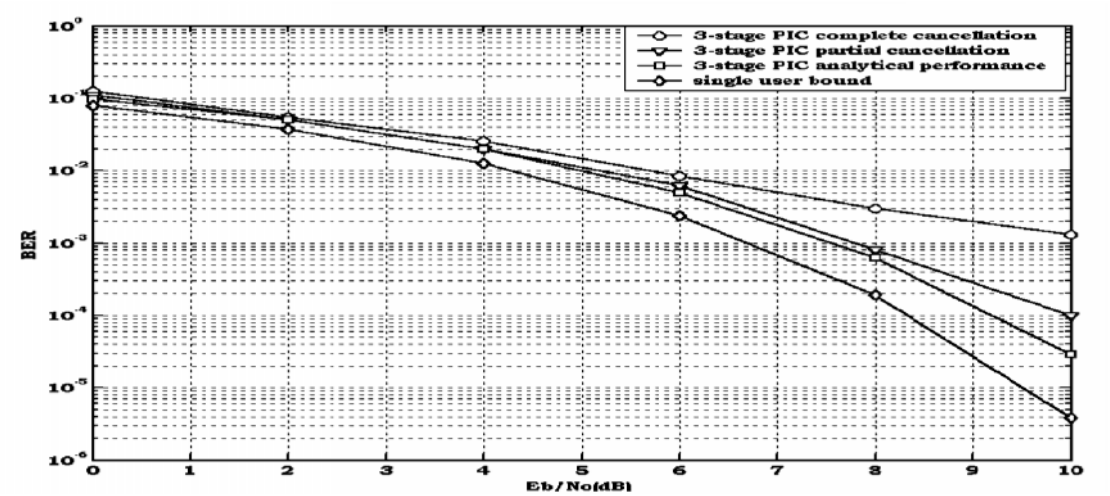


Figure (5) BER vs. $E_b/N_o$ of 3-stage complete and partial PIC Detector compared with analytical performance

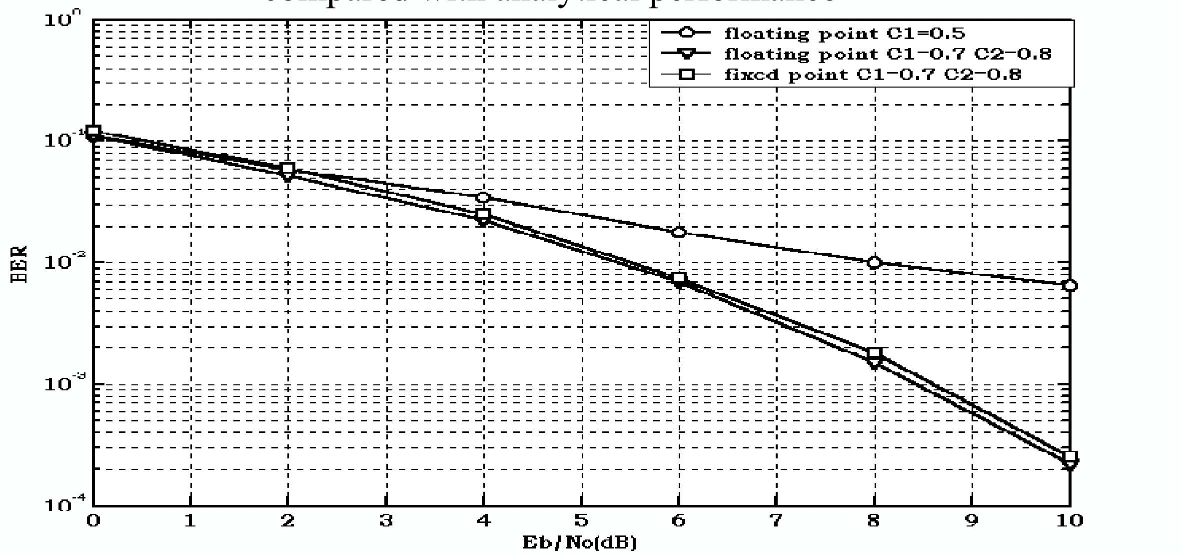

Figure (6) BER vs. $E_b/N_o$ of M.F Bank and 3-stage partial PIC Detection

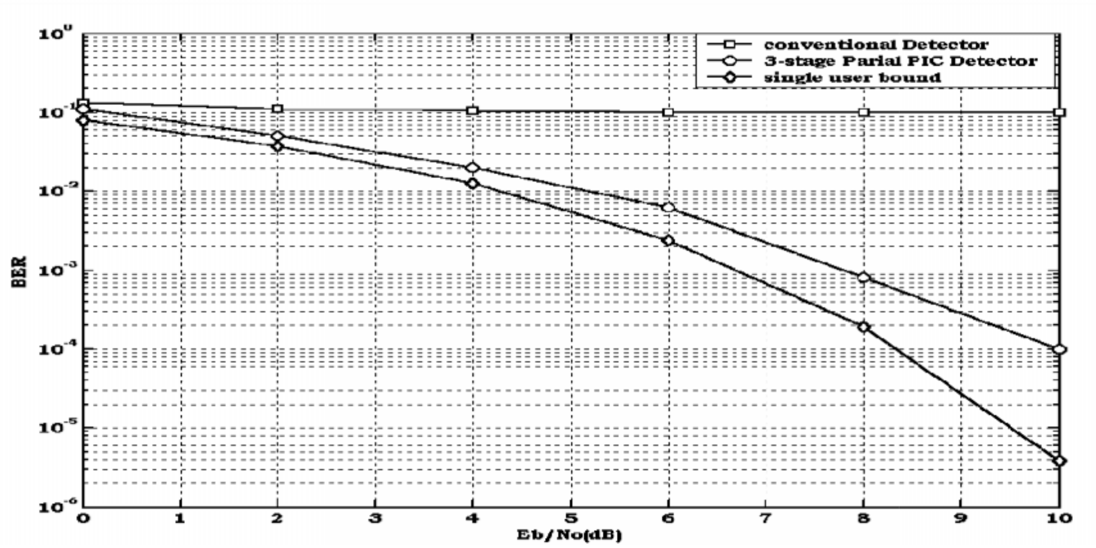


Figure (7) BER vs. $E_b/N_o$ for the proposed DP-PIC Detection with floating and fixed point implementation

## 6. Conclusion

In this paper a detection technique called Multistage Differencing Partial Parallel Interference Cancellation (DP-PIC) is proposed. It cancels efficiently MAI and has reduced computational complexity.

When it is compared with conventional detection technique it has superior performance. Also when it is implemented in 16-bit fixed point arithmetic it is showed little degradation in performance compared to floating point implementation. When the proposed DP-PIC is implemented on DSP, the number of clocks needed is much less than the Conventional PIC detection, thus the proposed DP-PIC has complexity reduction.

It is interesting to note that the partial cancellation factor used for the proposed DP-PIC is 0.7 in the first stage and 0.8 in the second stage. Also the complexity reduction is about 35% less than the conventional PIC.

## 7. References

**1.** G.Proakis, ***"Digital Communications"***, McGraw-Hill, 1995.

**2.** D.Schilling, R.Pickholtz, and L.Milstein ***"Theory of Spread Spectrum Communications, a tutorial"***, IEEE transactions on communications,Vol. COM 30 – No. 5, May 1982.

**3.** A.Duel-Hallen, J.Holtzman, and Z.Zvonar **"Modifying present systems could yield significant capacity increases: Multiuser detection CDMA systems"** IEEE Personal Comm., April 1995.

**4.** 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.

**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.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.

**7.** V.Chandrasekhar, F.Livingston and J.Cavallaro **"Reducing dynamic power consumption in next generation DS-CDMA mobile communication receivers"** IEEE proceedings in the Application Specific Systems, Architectures, and Processors, 2003**.**

**8.** J. Potman **" Development of a Multiuser detection Testbed"** Master's thesis, university of Twente, May 2002.

**9.** S.Bakir **"DSP Based Spread Spectrum Receiver"**, Master's thesis, university of Mosul, Feb. 2004.

**10.** X. Gang, **"Implemntation Issues of Multiuser Detection in CDMA Communication Systems",** Master's thesis, Rice university, May 1999.

**The work was carried out at the college of Engg. University of Mosul**