A Performance Analysis of Novel Approach for Limited Multiuser Detection Technique using Multisub of Correlation Factor for DS- CDMA System

Lokesh Tharani†, Dr. R.P.Yadav††

†Department of ECE, JaganNath Gupta Institute of Engineering & Technology (JNIT), Jaipur, India
††Department of ECE, Malaviya National Institute of Technology (MNIT), Jaipur, India

Summary
This paper presents the performance analysis of the novel concept of limited multiuser detection (MUD) for direct sequence code division multiple accesses (DS- CDMA). The novel concept uses the correlation properties and bit streaming for reduced complexity architecture to meet real time requirement for asynchronous multiuser detection in wireless communication. To mitigate the effect of multiple access interference (MAI), this paper proposes a novel technique of multiplication and subtraction (Multisub) of cross correlation factor with receiving signal at output of matched filter, which is the first stage of parallel interference cancellation (PIC) multistage multiuser detector. Typically, asynchronous multiuser detector uses multishot detection, which involves block based computations and matrix inversions. Hence, Multisub correlation based suboptimal scheme have been evaluated to decrease the computational complexity and eliminate the need for matrix inversion. Moreover, such novel scheme can have added advantage to avoiding multishot detection if they start from a matched filter outputs. The paper compares the results of the novel scheme with the traditional single user matched filter and PIC multistage multiuser detector at different number of users. The result of the paper shows that bit error rate (BER) is minimize for 15-user and the performance of the limited parallel interference cancellation (PIC) multistage multiuser detector improves in that of other schemes.

Key words:
Multiuser detection (MUD), parallel interference cancellation (PIC), multiplication & subtraction (Multisub), correlation factor and matched filter.

1. Introduction

The code division multiple access (CDMA) is promising technology for future generation and the advent of third generation (3G) cellular systems based mainly on code division multiple access technology and the technological advancement in mobile computing hardware over the last decade have led to a renewal interest in multiuser detection [1] as a effective method to improve the throughput and quality of mobile cellular communication systems. It is known that the capacity of direct sequence code division multiple access (DS-CDMA) system is limited by multiple access interference (MAI) if traditional matched filter detectors are used. To mitigate this problem, multiuser detection [2] was proposed, which jointly uses the information of interfering users to improve the detection performance of desired signal. Multiuser detections cancel the interference from other users to detect desired signal, compared to conventional single user detection using only a matched filter. The desired user's bits mainly receive interference from the past and future overlapping signals of different users along with their current signal because they are asynchronous. The detection problem [3] in an asynchronous channel is more complicated than in a synchronous channel. The bits of each user are aligned in time for synchronous channel. Assume there are k direct sequence users in a synchronous single path BPSK real channel; the baseband received signal can be expressed as

$$r(t) = \sum_{k=1}^{K} A_k(t)\, g_k(t)\, d_k(t) + n(t) \qquad (1)$$

Where $A_k(t)$, $g_k(t)$ and $d_k(t)$ are the amplitude, signature code waveform and modulation of the k^{th} user respectively and n(t) is additive white gaussian noise(AWGN) with a two sided power spectral density of $N_0/2$ Watt/Hz. The power of the k^{th} signal is equal to the square of its amplitude, which is assumed to be constant over a bit interval. The modulation consist of rectangular pulses of duration T_b (bit interval) which take a $d_k = \pm 1$ values corresponding to the transmitted data.

2. Conventional DS-CDMA System Model

We assume a synchronous CDMA multiuser communication [4] system with binary signaling, non-orthogonal transmission and an additive white gaussian noise channel. The communication system model is identical to the basic synchronous CDMA model described in introduction. The number of users in this system model is denoted by k and multiuser detector considered in this paper operate on the k-dimensional matched filter bank or

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conventional detector for the received signal described in equation (1) is a bank of matched filter as shown in Fig.1

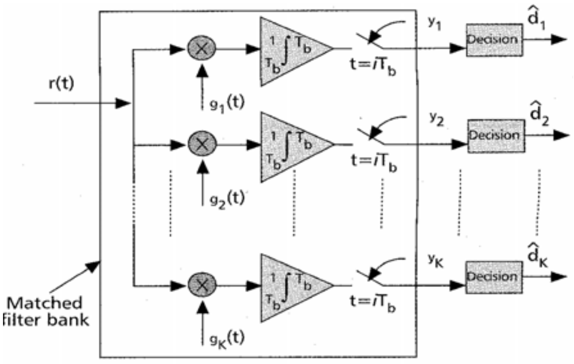

Fig.1 The conventional DS-CDMA detector using matched filters

The outputs of the matched filters are sampled at the bit times, which yield "soft" estimates of the transmitted data. The final decisions are made according to the signs of the soft outputs by Sgn (.) operator. The operator defined as

$$\text{Sgn}(d) = -1 \text{ if } d < 0, \quad = +1 \text{ if } d > 0 \tag{2}$$

We have seen from Fig.1 that the conventional detector [5] follows a single user detector strategy, each branch detects one user without regarded to the existence of the other users. Thus, there is no sharing of multiuser information or joint signal processing (i.e., multiuser detection). The success of this detector depends on the properties of the correlation between codes. We desire the auto-correlations (correlation between same code waveforms) to be much larger than cross- correlations (correlation between different code waveforms). The correlation value is defined as

$$\rho_{i,k} = \frac{1}{T_b} \int^{T_b} g_i(t)\, g_k(t)\, dt \tag{3}$$

Here, if i = k, $\rho_{i,i} = 1$, (i.e., the integral must equal one since $g_i(t) = \pm 1$) and if $i \neq k$, then $\rho_{i,k}$ between 0 to 1. The output of the k[th] user's correlation for a particular bit interval is

$$y_k = \frac{1}{T_b} \int^{T_b} r(t)\, g_k(t)\, dt$$

$$= A_k d_k + \sum_{\substack{i=1 \\ i \neq k}}^{k} \rho_{i,k} A_i d_i + \frac{1}{T_b} \int^{T_b} n(t)\, g_k(t)\, dt \tag{4}$$

$$= A_k d_k + MAI_k + Z_k$$

In other words, correlation with the k[th] user itself gives rise to the recovered data term, correlation [6, 7] with all other users gives rise to multiple access interference (MAI), and correlation with the thermal noise yields the noise term z_k. The codes are generally designed to have very low cross-correlation relative to the auto-correlation (i.e., $\rho_{i,k} \ll 1$). It is convenient to represent the matrix-vector system model to describe the output of the conventional detector. For sake of simplicity, assume a three user system, from equation (4) the output for each of the users for one bit is

$$y_1 = A_1 d_1 + \rho_{2,1} A_2 d_2 + \rho_{3,1} A_3 d_3 + z_1$$
$$y_2 = \rho_{1,2} A_1 d_1 + A_2 d_2 + \rho_{3,2} A_3 d_3 + z_2$$
$$y_3 = \rho_{1,3} A_1 d_1 + \rho_{2,3} A_2 d_2 + A_3 d_3 + z_3 \tag{5, 6, 7}$$

This can be written in the matrix-vector form

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} 1 & \rho_{2,1} & \rho_{3,1} \\ \rho_{1,2} & 1 & \rho_{3,2} \\ \rho_{1,3} & \rho_{2,3} & 1 \end{bmatrix} \begin{bmatrix} A_1 & 0 & 0 \\ 0 & A_2 & 0 \\ 0 & 0 & A_3 \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} \tag{8}$$

Or $$y = RAd + z \tag{9}$$

For a k-user system, the vector d, z and y are k-vector that holds the data, noise and matched filter outputs of all k-users, respectively; matrix A is a diagonal matrix containing the corresponding received amplitudes; the matrix R is a k x k correlation matrix [8, 9], whose entries contain the values of the correlation between every pair of codes. It is more effective to breakup matrix R into two matrices; one representing the auto-correlations, the other is cross-correlations. Therefore, parallel to equation (4), the conventional matched filter detector [10, 11] output can be expressed as three terms;

$$y = Ad + QAd + z \tag{10}$$

The first term Ad is simply the decoupled data weighted by the received amplitudes. The second term QAd represent the MAI interference where Q contains the cross-correlation dates of R in off-diagonal elements, i.e., R = I + Q, where I is identity matrix.

3. PIC Multiuser Detector using Multisub Correlation Technique

Based on the approach of the prior section that suggest that multiple access interference is often the dominant source of poor quality of signal as well as the limit the capacity of the system. This section proposes a new approach of multisub of correlation factor for improving the performance of the multistage multiuser PIC detector [12, 13]. The signal of any user is more affected from previous user's signal and just after user's signal. The equation (5, 6 &7) gives the output of the matched filter; our proposed multisub idea uses these equations. First of all we multiply the equation (5) and (7) with cross-correlation factors $\rho_{1,2}$ and $\rho_{3,2}$ respectively, now the equations are;

$$\rho_{1,2}\, y_1 = \rho_{1,2} A_1 d_1 + \rho_{1,2}\, \rho_{2,1} A_2 d_2 + \rho_{1,2}\, \rho_{3,1} A_3 d_3 + \rho_{1,2}\, z_1$$

$$\rho_{3,2}\, y_3 = \rho_{3,2} \rho_{1,3} A_1 d_1 + \rho_{3,2}\, \rho_{2,3} A_2 d_2 + \rho_{3,2} A_3 d_3 + \rho_{3,2}\, z_3 \qquad (11, 12)$$

Now both these equations (11) & (12) are subtracted from the equation (6) to eliminate the MAI interference

$$y_2 - \rho_{1,2}\, y_1 - \rho_{3,2}\, y_3 = \rho_{1,2} A_1 d_1 + A_2 d_2 + \rho_{3,2} A_3 d_3 + z_2 - \rho_{1,2} A_1 d_1 - \rho_{1,2}\, \rho_{2,1} A_2 d_2 - \rho_{1,2}\, \rho_{3,1} A_3 d_3 - \rho_{1,2}\, z_1 - \rho_{3,2} \rho_{1,3} A_1 d_1 - \rho_{3,2}\, \rho_{2,3} A_2 d_2 - \rho_{3,2} A_3 d_3 - \rho_{3,2}\, z_3 \qquad (13)$$

Due to the small values of cross-correlation factors obtained during the design of spreading codes for multiuser system, we assume $\rho_{1,2} = \rho_{2,1}$ and $\rho_{3,2} = \rho_{2,3}$, now output of matched filter 2 is

$$y_2 = A_2 d_2 - \rho_{1,2}^2 A_2 d_2 - \rho_{2,3}^2 A_2 d_2 - \rho_{1,2}\, \rho_{3,1} A_3 d_3 - \rho_{3,2} \rho_{1,3} A_1 d_1 - \rho_{1,2}\, z_1 - \rho_{3,2}\, z_3 + z_2 \qquad (14)$$

As shown in equation (14) that term 2 & 3 gives the values of infected signal due to user 1 and user 3 cross-correlations factors, terms 4 & 5 are multiple access interferences and term 7 & 8 are MAI noise.

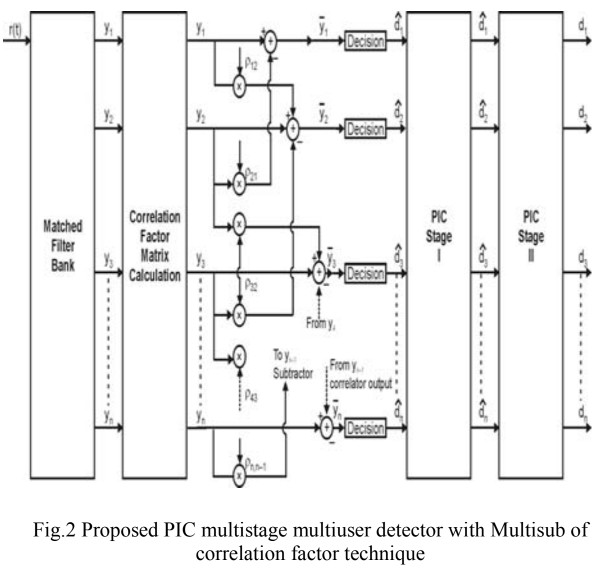

Fig.2 Proposed PIC multistage multiuser detector with Multisub of correlation factor technique

The study of equation (14) suggest that proposed multisub technique reduced the multiple access interference signal from the output of matched filter and this improves the quality of signal as well as capacity of system. This process is continuous for the N users output of matched filter. The block diagram of proposed multisub technique is shown in Fig.2. This rectified output of matched filter now process for multistage multiuser PIC detector [14, 15 & 16] for detection process.

4. Simulation and performance criteria

The Proposed PIC multistage multiuser detector with multisub of correlation factor technique and without multisub of correlation factor technique for CDMA communication described in section 2 and 3 was simulated in MATLAB [17, 18]. In simulation process two parameters were varied. First the number of users and second the signal to noise ratio (SNR) for calculating the bit error rate (BER) of different mentioned detector. The reduced bit error rate shows marginal reduction in multiple access interference leading to improvement in the capacity of the system. The parameters were used for simulation as follows.

Table 1: Simulation Parameters

Parameter	***Value***
Window length (L)	128
Spreading gain (N)	32
Signal to interference noise ratio (SINR)	0 dB
Number of paths (P)	3
Signal to noise ratio (SNR)	3,5,7,8,9,10,12,14 & 16 dB
Number of users	10, 15, 20, 25 & 30
Number of PIC stages	2

5. Simulation Results

The conventional single user matched filter detector and proposed parallel interference cancellation (PIC) multistage multiuser detector with multisub of correlation factor technique described in section 3 was implemented. Bit error rate (BER) at different signal to noise ratio (SNR) was observed and compare these results with PIC multistage multiuser detector without multisub of correlation factor technique for different number of users. The Tables 2, 3, 4, 5 & 6 gives the value of bit error rate of matched filter, PIC multistage multiuser detector without multisub of correlation factor technique and proposed parallel interference cancellation (PIC) multistage multiuser detector with multisub of correlation factor technique for 10,15,20,25 and 30 users respectively for 2-stage detector.

Table 2: BER for 10 users

SNR (dB)	***Matched Filter (BER)***	***PIC Detector (BER)***	***PIC Multisub (BER)***
3	0.1485	0.1435	0.1423
5	0.1028	0.0896	0.0883
7	0.0674	0.0478	0.0464
8	0.0540	0.0344	0.0327
9	0.0439	0.0229	0.0214
10	0.0362	0.0143	0.0142
12	0.0243	0.0042	0.0034
14	0.0166	0.0006	0.0004
16	0.0126	0.0003	0.0002

Table 3: BER for 15 users

SNR (dB)	***Matched Filter (BER)***	***PIC Detector (BER)***	***PIC Multisub (BER)***
3	0.1303	0.1227	0.1157
5	0.0911	0.0709	0.0657
7	0.0669	0.0377	0.0326
8	0.0585	0.0251	0.0214
9	0.0524	0.0172	0.0141
10	0.0467	0.0119	0.0087
12	0.0407	0.0059	0.0042
14	0.0371	0.0042	0.0024
16	0.0347	0.0019	0.0014

Table 4: BER for 20 users

SNR (dB)	***Matched Filter (BER)***	***PIC Detector (BER)***	***PIC Multisub (BER)***
3	0.1580	0.1462	0.1457
5	0.1211	0.0892	0.0887
7	0.0912	0.0489	0.0481
8	0.0806	0.0349	0.0340
9	0.0721	0.0226	0.0232
10	0.0645	0.0155	0.0159
12	0.0505	0.0067	0.0063
14	0.0425	0.0029	0.0022
16	0.0381	0.0014	0.0008

Table 5: BER for 25 users

SNR (dB)	***Matched Filter (BER)***	***PIC Detector (BER)***	***PIC Multisub (BER)***
3	0.1684	0.1758	0.1665
5	0.1325	0.1233	0.1105
7	0.1098	0.0767	0.0663
8	0.1011	0.0610	0.0504
9	0.0944	0.0476	0.0377
10	0.0889	0.0370	0.0276
12	0.0797	0.0232	0.0150
14	0.0736	0.0167	0.0090
16	0.0704	0.0126	0.0067

Table 6: BER for 30 users

SNR (dB)	***Matched Filter (BER)***	***PIC Detector (BER)***	***PIC Multisub (BER)***
3	0.1779	0.1870	0.1672
5	0.1460	0.1378	0.1209
7	0.1233	0.0988	0.0854
8	0.1135	0.0823	0.0683
9	0.1054	0.0693	0.0580
10	0.0980	0.0586	0.0469
12	0.0888	0.0422	0.0331
14	0.0826	0.0335	0.0257
16	0.0785	0.0297	0.0229

Now Fig.3 to 7 has shown below plot the graph between bit error rate and signal to noise ratio for users 10,15,20,25 and 30 respectively for 2-stage detector.

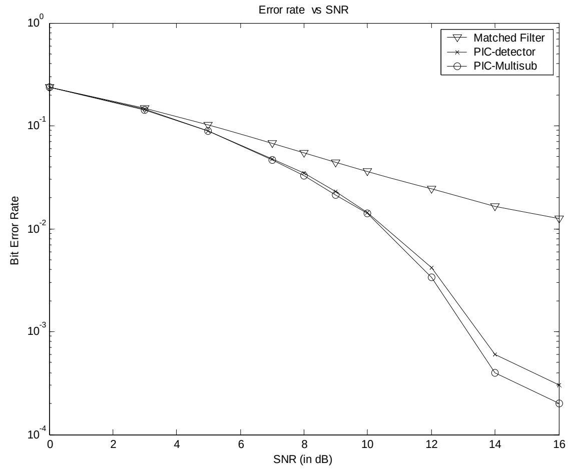

Fig.3 SNR Vs BER for 10 users

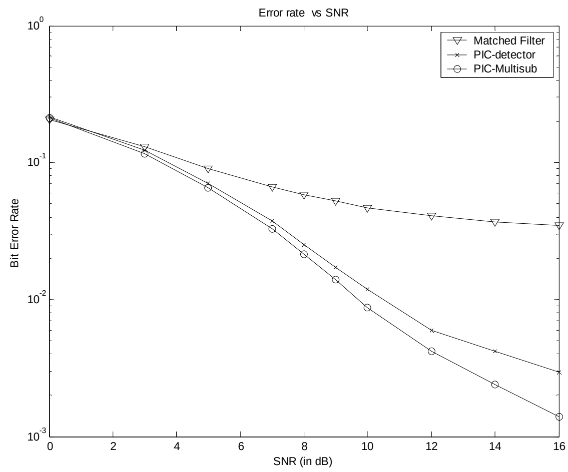

Fig.4 SNR Vs BER for 15 users

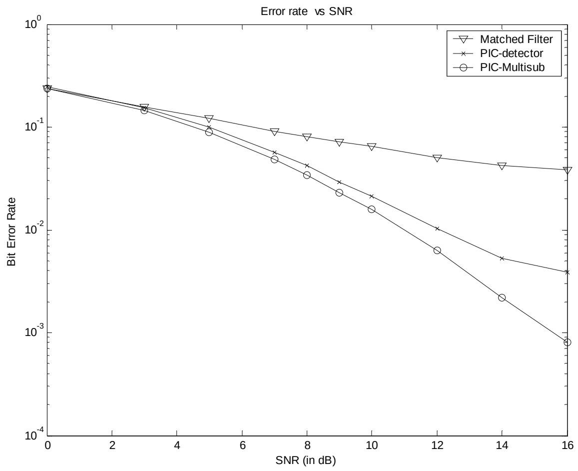

Fig.5 SNR Vs BER for 20 users

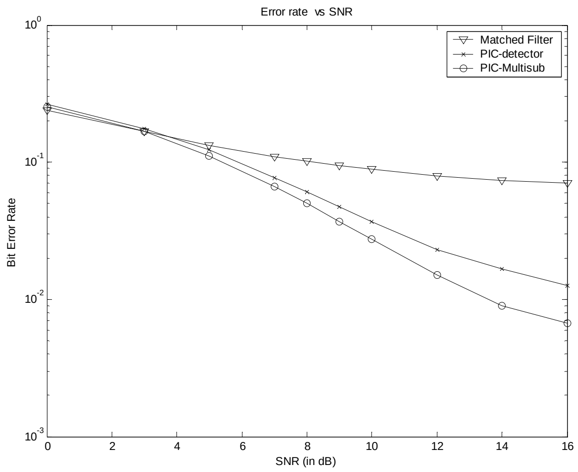

Fig.6 SNR Vs BER for 25 users

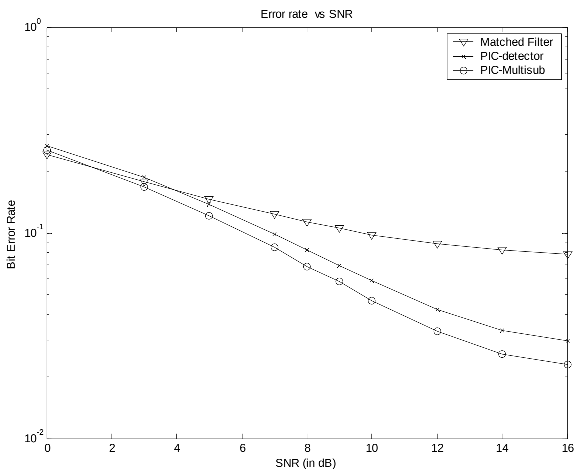

Fig.7 SNR Vs BER for 30 users

The comparisons of Tables 2 to 6 results indicate the bit error rate for 15 users is minimum in all cases. At PIC stage-2, the bit error rate is reduced for proposed multisub correlation technique. The BER decreases gradually beyond 8 dB SNR. The parallel interference cancellation (PIC) multistage multiuser detector with multisub of correlation factor technique gives the decrease in BER for a given SNR among the described detectors because MAI infected terms are eliminated from desired signal.

6. Conclusion

The simulation results show that bit error rate (BER) is minimum for 15-users. The bit error rate reduces for proposed parallel interference cancellation (PIC) multistage multiuser detector with multisub of correlation factor technique in comparison with conventional matched filter single user detector and PIC multistage multiuser detector without multisub of correlation factor technique. Result of Table 3 and 4 shows that if the number of users increase from 15 to 20, BER is increases because of more multiple access interference. These results describe that proposed technique reduces bit error rate in comparison with presently available techniques. Multi-user Detection (MUD) is a efficient digital signal processing technique used to overcome limitations posed by MAI, which significantly limits the performance and capacity of conventional DS-CDMA systems.

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Biography

Lokesh Tharani has done BE from Govt. Engineering College Kota (Now University College of Engineering, Rajasthan Technical University) in 1999 and received M.Tech. degree in Electronics & Communication Engineering from Malaviya National Institute of Technology (MNIT), Jaipur in 2003. He is also pursuing his Ph.D. in CDMA technology from MNIT, Jaipur. He has a teaching experience of more than 9 years and has published several papers in national & international symposiums and conferences. He is also co-author of book "Wireless Communication". Presently he is working as Associate Professor in the Department of Electronics and Communication Engineering, JNIT, Jaipur, Rajasthan, India.

Dr.R.P.Yadav received M. Tech. degree in integrated electronics and circuits in 1987 from Electrical Engineering Department, IIT Delhi and completed Ph.D. in Communication Engineering from University of Rajasthan in 2001. He is active member of various professional bodies like IEEE and IETE. He has published over 50 papers in national & international journals and conferences. He actively involves in research areas like MIMO, adhoc networking, multiuser detection, information theory & coding and microstrip antennas. Presently he is working as Professor and Head in the Department of Electronics and Communication Engineering, MNIT, Jaipur, Rajasthan, India.