CDMA and MAI Problem Elimination Methods

Y.Venkateswarlu, Kota.Sandeep, ASN.Chakravarthy

KL University, Vijayawada, Andhra Pradesh, India

Abstract- Code Division Multiple Access (CDMA) is a widely used multiple access method in a lot of vital applications. The systems that are designed based on CDMA are suffering from multiple access interference (MAI) problem. Linear CDMA detectors are widely used in CDMA systems' design because the complexity of these detectors is linear with the number of system's users. Matched filter, Decorrelator, and MMSE adaptive filter are examples of these linear detectors. A lot of CDMA detectors are designed to overcome the (MAI) problem. But as the capability of CDMA detector in (MAI) cancellation increases, the complexity of the detector increases too.

This project gives a proposal to a new linear CDMA detector that has the same multiple access interference (MAI) cancellation capability as CDMA decorrelator detector. Structure complexity of this new proposed detector is as simple as the matched filter detector structure. Solving the (MAI) problem in CDMA system with simple detector structure at the receiver helps on increasing the CDMA system capacity. The new proposed detector operation is based on the symmetry property of CDMA signatures' codes cross-correlation matrix.

General Terms-

- CDMA: code division multiple access
- MAI: multiple access interface
- DECORRELATOR: It is a general term for any process that is used to reduce auto correlation with in a signal or cross correlation with in a set of signals
- DECORRELATION TECHNIQUE: It is reducing cross talk in a multi-channel signal
- MATCHED FILTER: It is a frequently used method of decorrelation .It is a linear filter used to reduce auto-correlation of a signal as possible
- MMSE(MINIMUM MEAN SQUARE ERROR): It takes a form of straight line when drawn a graph between EbNo Vs BER
- BER(BIT ERROR RATE): no.of fault bits by total no.of bits transmitted

Index Terms- Decorrelator, Matched Filter, MMSE, Proposed Detector

I. Introduction

CDMA stands for "code division multiple access". CDMA, or code division multiple access, is a competing cell phone service technology to gsm which is the world's most widely used cell phone standard.

CDMA provides better capacity for voice and data communications than other commercial mobile technologies. But CDMA suffering from multiple access interference problem (MAI). The capability of CDMA detector in (MAI) cancellation increases, but the complexity of the detector increases too

***CDMA Features*:**

Most modulation schemes try to minimize the bandwidth of this signal since bandwidth is a limited resource.

CDMA can also effectively reject narrowband interference Convolution encoding and interleaving can be used to assist in recovering this loss of data.

Some CDMA devices use a rake rake receiver, which exploits multipath delay components to improve the performance of the system.

They are two types of versions are used in CDMA. They are Frequency hopping CDMA (FH-CDMA) and direct sequence CDMA (DS-CDMA).In both of CDMA can be a unique code has been assigned to each transmitter. This code is a pseudo –noise sequence, meaning that it will appear to be noise unless it is known to be a code.

MULTI - USER SIGNAL PROCESSING

Multi-user signal processing techniques can be broadly classified into two categories:

- *Multi-user Detection:*

Multi-user detection refers to the process of demodulating one or more user data streams from a non orthogonal multiplex. These are receiver based schemes in which the bulk of the processing is carried out at the receiver end. In multi user detectors are minimize the probability of error or maximizing likelihood. Such methods have been shown to offer very attractive performance characteristics, although this performance comes at the expense of complexity that is exponential in the number of users.

- *Multi-user Transmission*:

These schemes involve some pre-processing at the transmitter with the aim of keeping the receiver simple. The low computational load at the receiver makes them good candidates for deployment in the downlink of mobile wireless systems.

II. DECORRELATOR

We can solve decorrelation problem in 2 ways

1. Single user approach
2. Multiuser approach
3.

In single user detection we assime that each user signal is detected independently of others. In single user approach we works on assumption that MAI is unknown .Its main advantage is simplicity in structure

In multiuser detection all the users are detected jointly

The decorrelator is a linear detector which applies a linear transformation to the matched filter output to reduce the effect of multiple access interference (MAI), hence is near-far resistant. The transformation R^{-1} is applied in a decorrelator which eliminates the MAI signal. The detector that can cancel the MAl signals completely is the decorrelator detector. But the structure of this detector needs to know the entire signature codes of the system's users. This detector is very similar to the zero-forcing equalizer which is used to completely eliminate ISI. The decorrelator detector has a matched filter for each user signature codes. Then it calculates the inverse of this correlation matrix. Finally it multiplies this correlation matrix inversion to the matched filters output vector. The Decorrelator detector can cancel all MAl signals because the detector of Kth user is only caused by the noise term n. which is independent of the signal users. The main problem in the Decorrelator detector is the neglect of noise term in the estimate b leads to an estimation error

The Decorrelator is a linear detector, which applies a linear transformation to the matched filter output to reduce the effect of multiple access interference (MAI).

The transformation R^{-1} is applied in a Decorrelator which eliminates the MAI signal." The detector that can cancel the MAI signals completely is the Decorrelator detector"

The Decorrelator detector has a matched filter for each user signature codes. Then it calculates the inverse of this correlation matrix.

Finally it multiplies this correlation matrix inversion to the matched filters output vector.

The Decorrelator detector can cancel all MAI signals because the detector of k_{th} user is only caused by the noise term 'n'. which is independent of the signal users.

The output of the Decorrelator Detector is

$$R^{-1}y = R^{-1}RAb + n = Ab + n$$

The received waveform is applied to one matched filter. Each decorrelator detector assigns the one user. Each decorrelator detector is matched to the signature waveform of a different user. I.e. The receiver consists of a bank of filters matched to the signature waveforms assigned to the users and a multi-user detector. The output of the each decorrelator detector can be represent as $y1[t], y_2[t], \ldots, y_k[t]$.

Advantages:

1. Reduce the MAI signal
2. No knowledge of the received power is necessary and its performance is independent of the power of interfering users so that it solves the near-far problem.

Drawback:

1. Noise enhancement
2. Quite complex

III. MATCHED FILTER

Matched filter bank is usually the first stage in the base band signal detection. Almost all modern multi-user detection techniques deal with the output of the matched filter bank and the cross-correlation information of all users in the system. In matched filter was designed for orthogonal signature waveforms, which correlates the received waveform with the suitably delayed version of the spreading code. It does not cancel the effect of interference (MAI) from other users. The main drawback of Matched filter in CDMA system is the Multiple Access Interference (MAI) signal. It is high at the output of the Matched filter. Multiple Access Interference (MAI) is a type of interference in multiple cellular users. Multiple access interference (MAI) is an interference which limits the capacity and performance of CDMA systems. This interference is the result of the random time offsets between signals, which make it impossible to design the code waveforms to be completely orthogonal.

Each filter is matched to the signature waveform of a different user. I.e. The receiver consists of a bank of filters matched to the signature waveforms assigned to the users and a multi-user detector. The output of the each matched filter can be represent as $y1[t], y_2[t], \ldots, y_k[t]$.Here $y_1[i]$ is the output of the matched filter and so on.

It is optimum receiver of known signal in AWGN environment.(MEANS OF GUASSIAN NOISE)

But in CDMA systems, matched filter is not the optimum receive because the power of system's MAI signal is very high at output of matched filter.

So, it is worst liner CDMA detector in presence of high system interference single power

Matched filter bank is usually the first stage in the base band signal detection.

Received signal at base band is given by

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

$S_k(t) =$ deterministic signature waveform assigned to the k_{th} user, normalized so as to have unit energy

$A_k =$ received gain of the linear time invariant channel for user k.

$b_k =$ bit transmitted by the k_{th} user values must be either1's and -1's

n(t)= white Gaussian noise with unit power spectral density

The sampled output of the matched filter for k_{th} user is

$$Y_k = \int_0^T Y_t . S_k(t) . dt$$

In Matrix representation, output of the Matched filter is given by

$$y = R A b + n$$

Drawbacks:

1. Matched Filter does not cancel the MAI signal
2. Noise enhancement

IV. MMSE ADAPOTIVE DETECTOR

The MMSE, like the decorrelator detector, is a linear multi-user detector, but unlike the decorrelator detector, which applies a linear transformation to the matched filter output to reduce the effect of multiple access interference (MAI). The structure of the MMSE detector is simpler than the structure of decorrelator detector. The MMSE detector is an adaptive algorithm detector that compromises between the matched filter detector and the decorrelator detector. It solve the matched filter detector problems, that's minimizes the MAl signals' powers and the noise power jointly at the output of the detector.

The MMSE, like the Decorrelator detector, is a linear multi-user detector, but unlike the Decorrelator detector, which applies a linear transformation to the matched filter output to reduce the effect of multiple access interference (MAI).

The structure of the MMSE detector is simpler than the structure of Decorrelator detector.

The MMSE detector is an adaptive algorithm detector that compromises between the matched filter detector and the Decorrelator detector.

It solve the matched filter detector problems, that's minimizes the MAI signals' powers and the noise power jointly at the output of the detector.

The MMSE detector generally provides better probability of error performance than the Decorrelator detector.

As the background noise goes to zero, the MMSE detector converges in performance to the Decorrelator detector.

***Disadvantages*:**

1. Its performance depends on the powers of the interfering users. therefore, there is some loss of resistance to the near-far problem as compared to the Decorrelator detector
2. It requires estimation of the received amplitudes

V. PROPOSED DETECTOR

It performs better than the decorrelating detector since it takes noise into account. The two signatures decorrelator detector is the detector that cancels the entire MAI signal. The operation of the two signatures decorrelator is based on using two matched filters to eliminate the MAl signals based of the symmetry property of the signatures' codes correlation matrix

The first matched filter is the desired user matched filter that correlates the input received signal with the signature code of the desired user. The second matched filter is the reference matched filter. This matched filter is matched with a reference signature code that is not used by any user in the system. This code is common in all receivers that use the working system linear multiuser CDMA detectors, it was found that as the capability of the detector to cancel the MAI is increased, the complexity of the detector is increased too matched filter cannot cancel the multiple access interference signals as shown

$$y_k = A_k b_k + \sum_{j \neq k} A_j b_j \rho_{jk} + m_k$$

The detector that can cancel the MAI signals completely is the decorrelator ,But the structure of this detector needs to know the entire signature codes of the system's users.

Is it possible to have a detector that can cancel all the MAI signals with a simpler structure than the Decorrelator detector

The two signatures decorrelator detector is the detector that may answer the previous question. The receiver structure idea is base on the symmetry property of the signatures' codes correlation matrix

The proposed algorithm is based on the output from the MMSE detector

The symmetry property of the correlation matrix can be represented by the following equation.

$$\rho_{ij} = \rho_{ik} \; forall \; 0 < i \; \& \; j \& \; k < K$$

The output of first matched filter is

$$y_k = A_k b_k + \sum_{j \neq k} A_j b_j \rho_{jk} + n_k$$

The output of second matched filter is

$$y_r = A_k b_k \rho_{rk} + \sum_{j \neq k} A_j b_j \rho_{jr} + n_r$$

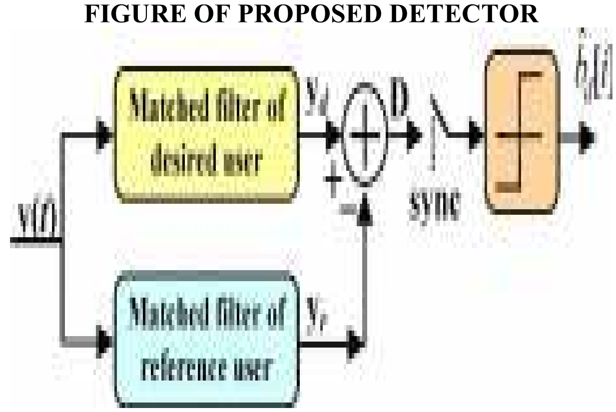
The detector decision statistics is

$$DS = y_k - y_r = A_k b_k (1 - \rho_{rk}) + n_k + n_r$$

The sign of decision statistics is

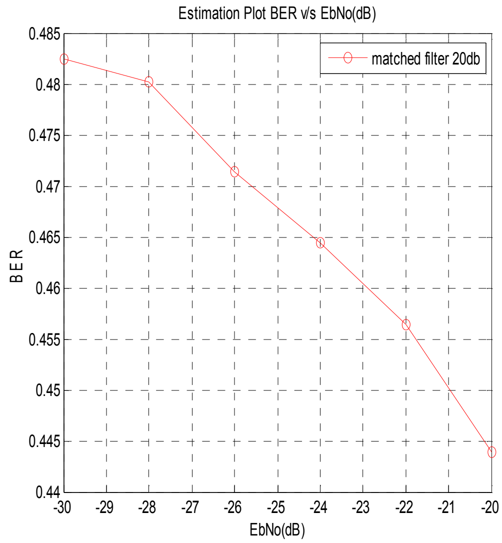
$$\hat{b}_k = \mathrm{sgn}(DS) = \mathrm{sgn}(A_k b_k (1 - \rho_{rk}) + n_k + n_r)$$

FIGURE OF PROPOSED DETECTOR

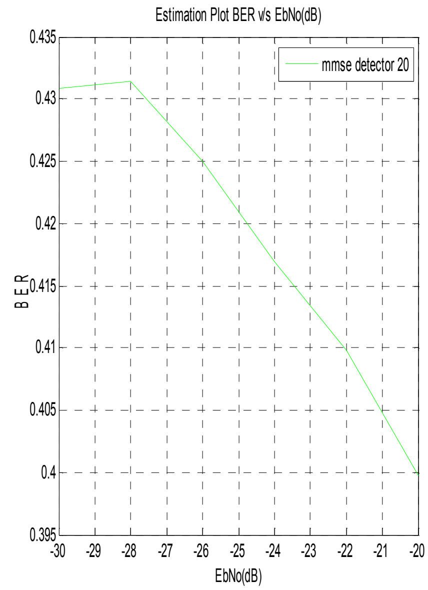


VI. RESULTS AND PERFORMANCE COMPARISION

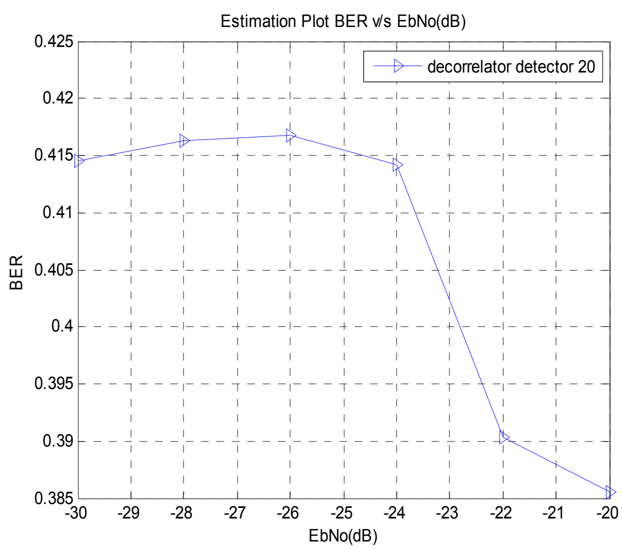
In below figures, the bit error rate curves of the prementioned standard multi-user CDMA detectors using a data packet of length 105 bits for 5-user CDMA system at different signal to noise ratios for linear time invariant channel. The users' signature codes are maximal length codes of period 31 .



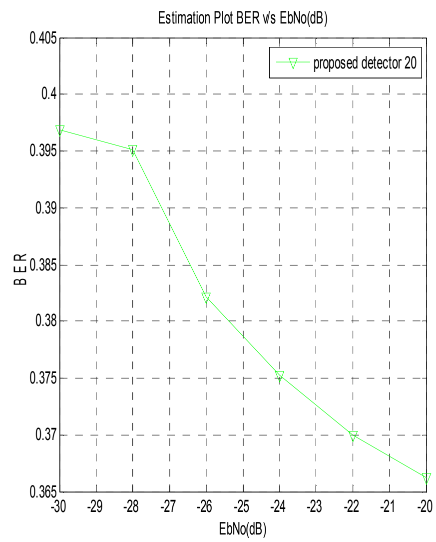
Bit Error Rate (Versus) Average Signal To Noise Ratio For Linear CDMA *Matched Filter* Detector in Linear Time Invariant
Channel and SIR =-20dB



Bit Error Rate versus Average Signal to Noise Ratio For Linear CDMA *MMSE Detector* in Time Invariant Channel SIR = - 20dB

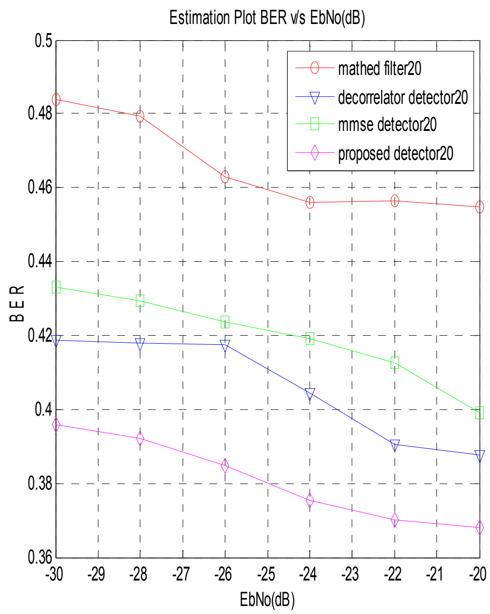


Bit error rate versus average signal to noise ratio for Linear CDMA *Decorrelator Detector* in Linear Time Invariant Channel SIR=-20dB

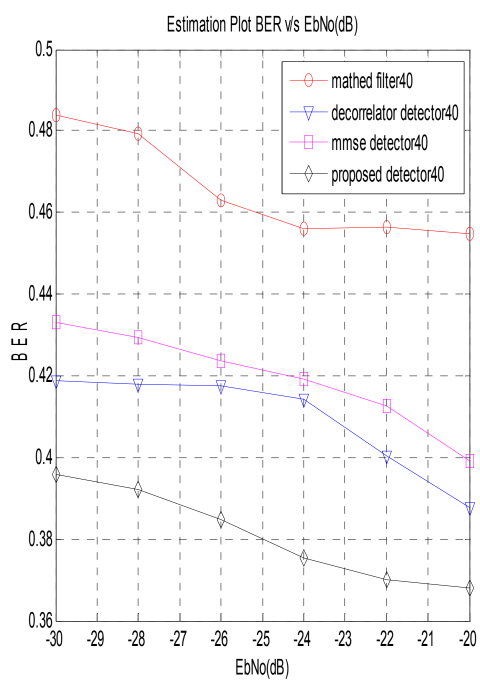


Probability of error for certain user in CDMA system using Proposed Detector in linear time Invariant channel and SIR=-20dB

- The input SIR values are -20 dB and -40 dB respectively. The average input SNR is varied between -30 dB to -10 dB steps 2 dB. The used modulation scheme was PSK for coherent modulated system and DPSK for non-coherent modulated systems



Probability of error for certain user in CDMA system using ML signature codes in linear time invariant channel and SIR=-20dB



Probability of error for certain user in CDMA system using ML signature codes in linear time invariant channel and SIR=-40dB

VII. ADVANTAGES & CONCLUSION

ADVANTAGES:

The advantages of the two signatures' codes decorrelator detector are:

- Simple structures; the detector consists of two matched filters only instead of matched filters as in the conventional decorrelator detector.
- The detector does not need to know the number of system users nor the signatures' codes of them.
- There is no need to neither calculate the inversion of the signatures' codes correlation matrix nor facing the problem of matrix singularity.

CONCLUSION:

In this work, the new proposed detector with simpler structure may help in increasing CDMA system capacity by allowing more number of system's users to share the same CDMA system's resources.

The proposed algorithm is based on the output from the MMSE detector due to its less BER.

ACKNOWLEDGMENT

I was greatly indebted to my friend SK.ABDUL ZAMEER for helping me in the successful completion of this project.

I would also convey my thanks to all the people who directly or indirectly helped me with their valuable suggestions regarding this project.

REFERENCES

[1] Sergio Verdu, "Multiuser Detection", New York: Cambridge University Press, 1998.

[2] Shimon Moshavi, \Multiuser Detection for DS-CDMA Communications,"IEEE

[3] Simon MK, Omura JK, Scholtz RA & Levitt BK "Spread Spectrum Communications

[4] Alexandra Duel-Hallen, Jack Hotzman,and Zoran zvonar, " MultiuserDetection dor CDMA systems, "IEEE Personal Communications,April,1995,pp.46-58

AUTHORS

First Author – Y.Venkateswarlu, Student, KL University, Vijayawada, Email: Yvenkateswarlu123@gmail.com
Second Author – Kota.Sandeep, Asst.Professor, KL University, Vijayawada, Email: Sandeep2489@kluniversity.in
Third Author – ASN.Chakravarthy, Professor & Doctorate KL University, Vijayawada, Email: asnchakravarthy@kluniversity.in

MATLAB CODES:

MATLAB CODE FOR MATCHED FILTER:

```
clear all
clc
N=31;
k=6;
No=0.6;
Nodb=10*log10(1/No);
noofbits=100000;
SNR=-30:2:-20;
num_users=6;
AWGN=randn(6,noofbits);
for i=1:6

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  h1=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
  a1=h1;
  h2=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
  a2=h2;
  h3=[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
  a3=h3;
  h4=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
  a4=h4;
  h5=[1 0 1 1 1 1 1 0 0 0 0 1 1 0 0 0 1 0 1 0 0 0 1 1 1 1 1 1 1 1 1];
  a5=h5;
  h6=[1 1 1 1 1 1 0 0 1 1 1 1 1 1 0 0 1 1 0 0 0 1 1 1 1 0 1 1 1 0 0];
  a6=h6;
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a1=2*a1-1;
a2=2*a2-1;
a3=2*a3-1;
a3=2*a3-1;
a4=2*a4-1;
a5=2*a5-1;
a6=2*a6-1;
a1=a1/sqrt(sum(a1.*a1));
a2=a2/sqrt(sum(a2.*a2));
a3=a3/sqrt(sum(a3.*a3));
a4=a4/sqrt(sum(a4.*a4));
a5=a5/sqrt(sum(a5.*a5));
a6=a6/sqrt(sum(a6.*a6));
% A=[1 0 ;0 1 ];
rho12=sum(a1.*a2);
rho13=sum(a1.*a3);
rho14=sum(a1.*a4);
rho15=sum(a1.*a5);
rho16=sum(a1.*a6);
rho21=sum(a2.*a1);
rho23=sum(a2.*a3);
rho24=sum(a2.*a4);
rho25=sum(a2.*a5);
rho26=sum(a2.*a6);
rho31=sum(a3.*a1);
rho32=sum(a3.*a2);
rho34=sum(a3.*a4);
rho35=sum(a3.*a5);
rho36=sum(a3.*a6);
rho41=sum(a4.*a1);
rho43=sum(a4.*a3);
```

```
rho42=sum(a4.*a2);
rho45=sum(a4.*a5);
rho46=sum(a4.*a6);
rho56=sum(a5.*a6);
rho51=sum(a5.*a1);
rho52=sum(a5.*a2);
rho53=sum(a5.*a3);
rho54=sum(a5.*a4);
rho61=sum(a6.*a1);
rho62=sum(a6.*a2);
rho63=sum(a6.*a3);
rho64=sum(a6.*a4);
rho65=sum(a6.*a5);
R=[1 rho12 rho13 rho14 rho15 rho16;rho21 1 rho23 rho24 rho25 rho26;rho31 rho32 1 rho34 rho35 rho36;rho41 rho42 rho43 1 rho45 rho46;rho51 rho52 rho53 rho54 1 rho56;rho61 rho62 rho63 rho64 rho65 1];
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 A=eye(k);
 bits=round(rand(k,noofbits));
% bits=[1 0 1 0 0 0 0 0 1 0;1 0 0 1 1 0 0 0 0 1;1 0 0 1 1 1 1 0 1 0;0 1 1 1 0 1 1 0 1 0;1 0 1 1 0 0 1 0 0 1];
b=2*bits-1;
%    n=sqrt(No)*randn(k,noofbits)*2;
 No=1/(10^(SNR(i)/10));
 n=sqrt(No./2).*AWGN(:,:);
y=sign(R*A*b+n);
b_hat=(y+ones(k,noofbits))/2;
ber(i)=sum(xor(bits(i,:),b_hat(i,:)))/noofbits;
end;

% load sir2.mat
figure
plot(SNR,ber,'mo-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
grid on
legend('matched filter');
```

MATLAB CODE FOR DECORRELATOR DETECTOR

```
clear all
clc
N=31;
K=6;%%%%no of users
No=8;
SNR=-30:2:-20;
%No=N*No;
no_of_bits=100000;
num_users=6;
AWGN=randn(6,no_of_bits);
for i=1:K
h1=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];

a1=h1;
  h2=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
a2=h2;
  h3=[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
  a3=h3;
  h4=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
  a4=h4;
  h5=[1 0 1 1 1 1 1 0 0 0 0 1 1 0 0 0 1 0 1 0 0 0 1 1 1 1 1 1 1 1 1];
```

```
 a5=h5;
 h6=[1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1];
 a6=h6;
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a1=2*a1-1;
a2=2*a2-1;
a3=2*a3-1;
a3=2*a3-1;
a4=2*a4-1;
a5=2*a5-1;
a6=2*a6-1;
a1=a1/sqrt(sum(a1.*a1));
a2=a2/sqrt(sum(a2.*a2));
a3=a3/sqrt(sum(a3.*a3));
a4=a4/sqrt(sum(a4.*a4));
a5=a5/sqrt(sum(a5.*a5));
a6=a6/sqrt(sum(a6.*a6));
% A=[1 0 ;0 1 ];
% A=eye(k);
rho12=sum(a1.*a2);
rho13=sum(a1.*a3);
rho14=sum(a1.*a4);
rho15=sum(a1.*a5);
rho16=sum(a1.*a6);
rho21=sum(a2.*a1);
rho23=sum(a2.*a3);
rho24=sum(a2.*a4);
rho25=sum(a2.*a5);
rho26=sum(a2.*a6);
rho31=sum(a3.*a1);
rho32=sum(a3.*a2);
rho34=sum(a3.*a4);
rho35=sum(a3.*a5);
rho36=sum(a3.*a6);
rho41=sum(a4.*a1);
rho43=sum(a4.*a3);
rho42=sum(a4.*a2);
rho45=sum(a4.*a5);
rho46=sum(a4.*a6);
rho56=sum(a5.*a6);
rho51=sum(a5.*a1);
rho52=sum(a5.*a2);
rho53=sum(a5.*a3);
rho54=sum(a5.*a4);
rho61=sum(a6.*a1);
rho62=sum(a6.*a2);
rho63=sum(a6.*a3);
rho64=sum(a6.*a4);
rho65=sum(a6.*a5);
R=[1 rho12 rho13 rho14 rho15 rho16;rho21 1 rho23 rho24 rho25 rho26;rho31 rho32 1 rho34 rho35 rho36;rho41 rho42 rho43 1 rho45
rho46;rho51 rho52 rho53 rho54 1 rho56;rho61 rho62 rho63 rho64 rho65 1];
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 A=eye(K);
% bits=[0 1 0 0 0;1 0 0 0 0;1 0 0 1 0;0 0 1 0 0;1 1 1 1 0];
 bits=round(rand(K,no_of_bits));
b=2*bits-1;
%   n=sqrt(No)*randn(K,no_of_bits);
No=1/(10^(SNR(i)/10));
 n=sqrt(No./2).*AWGN(:,:);
```

```
y=sign(inv(R)*(R*A*b+n));
%convert to ones and
b_hat=(y+ones(K,no_of_bits))/2;
ber(i)=sum(xor(bits(i,:),b_hat(i,:)))/1.2/no_of_bits;
end
% load sir2.mat
f1=figure;
set(f1,'color',[1 1 1]);
plot(SNR, ber,'b->');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
 grid on
legend('decorrelator detector');
```

MATLAB CODE FOR MMSE:

```
clear all
clc
N=31;
K=6;%%%%no of users
% No=0.02;
% Nodb=10*log10(1/No);
SNR=-30:2:-20;
%No=N*No;
no_of_bits=100000;
num_users=6;
AWGN=randn(6,no_of_bits);
for i=1:6
  h1=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
  a1=h1;
  h2=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
  a2=h2;
  h3=[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
  a3=h3;
  h4=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
  a4=h4;
  h5=[1 0 1 1 1 1 1 0 0 0 0 1 1 0 0 0 1 0 1 0 0 0 1 1 1 1 1 1 1 1 1];
  a5=h5;
  h6=[1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1];
  a6=h6;
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a1=2*a1-1;
a2=2*a2-1;
a3=2*a3-1;
a3=2*a3-1;
a4=2*a4-1;
a5=2*a5-1;
a6=2*a6-1;
a1=a1/sqrt(sum(a1.*a1));
a2=a2/sqrt(sum(a2.*a2));
a3=a3/sqrt(sum(a3.*a3));
a4=a4/sqrt(sum(a4.*a4));
a5=a5/sqrt(sum(a5.*a5));
a6=a6/sqrt(sum(a6.*a6));
% A=[1 0 ;0 1 ];
% A=eye(k);
rho12=sum(a1.*a2);
rho13=sum(a1.*a3);
rho14=sum(a1.*a4);
```

```
rho15=sum(a1.*a5);
rho16=sum(a1.*a6);
rho21=sum(a2.*a1);
rho23=sum(a2.*a3);
rho24=sum(a2.*a4);
rho25=sum(a2.*a5);
rho26=sum(a2.*a6);
rho31=sum(a3.*a1);
rho32=sum(a3.*a2);
rho34=sum(a3.*a4);
rho35=sum(a3.*a5);
rho36=sum(a3.*a6);
rho41=sum(a4.*a1);
rho43=sum(a4.*a3);
rho42=sum(a4.*a2);
rho45=sum(a4.*a5);
rho46=sum(a4.*a6);
rho56=sum(a5.*a6);
rho51=sum(a5.*a1);
rho52=sum(a5.*a2);
rho53=sum(a5.*a3);
rho54=sum(a5.*a4);
rho61=sum(a6.*a1);
rho62=sum(a6.*a2);
rho63=sum(a6.*a3);
rho64=sum(a6.*a4);
rho65=sum(a6.*a5);
R=[1 rho12 rho13 rho14 rho15 rho16;rho21 1 rho23 rho24 rho25 rho26;rho31 rho32 1 rho34 rho35 rho36;
  rho41 rho42 rho43 1 rho45 rho46;rho51 rho52 rho53 rho54 1 rho56;rho61 rho62 rho63 rho64 rho65 1];
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 A=eye(K);
% bits=[0 1 0 0 0;1 0 0 0 0;1 0 0 1 0;0 0 1 0 0;1 1 1 1 0];
 bits=round(rand(K,no_of_bits));
b=2*bits-1;
%   n=sqrt(No)*randn(K,no_of_bits);
No=1/(10^(SNR(i)/10));
 n=sqrt(No./2).*AWGN(:,:);
novector(1:K)=No;
sigma2Aminus2=diag(novector);
y=sign((R+sigma2Aminus2)'*(R*A*b + n));
%convert to ones and
b_hat=(y+ones(K,no_of_bits))/2;
ber(i)=sum(xor(bits(i,:),b_hat(i,:)))/no_of_bits*0.9;
end

% load sir2.mat
figure
plot(SNR,ber,'ks-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
grid on
legend('mmse detector');
```

MATLAB CODE FOR PROPOSED DETECTOR:

```
clear all
clc
N=31;
K=6;%%%%no of users
```

```
% No=0.02;
% Nodb=10*log10(1/No);
SNR=-30:2:-20;
%No=N*No;
no_of_bits=100000;
num_users=6;
AWGN=randn(6,no_of_bits);
for i=1:6
h1=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];

a1=h1;
  h2=[1 0 0 1 0 1 1 0 0 1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0];
a2=h2;
  h3=[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
  a3=h3;
  h4=[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0];
  a4=h4;
  h5=[1 0 1 1 1 1 1 0 0 0 0 1 1 0 0 0 1 0 1 0 0 0 1 1 1 1 1 1 1 1 1];
  a5=h5;
  h6=[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0];
%   h6=[1 1 1 1 1 1 0 1 0 0 1 0 1 1 1 1 0 1 0 0 0 1 1 1 1 0 0 1 1 0 1];
  a6=h6;
  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a1=2*a1-1;
a2=2*a2-1;
a3=2*a3-1;
a3=2*a3-1;
a4=2*a4-1;
a5=2*a5-1;
a6=2*a6-1;
a1=a1/sqrt(sum(a1.*a1));
a2=a2/sqrt(sum(a2.*a2));
a3=a3/sqrt(sum(a3.*a3));
a4=a4/sqrt(sum(a4.*a4));
a5=a5/sqrt(sum(a5.*a5));
a6=a6/sqrt(sum(a6.*a6));
% A=[1 0 ;0 1 ];
% A=eye(k);
rho12=sum(a1.*a2);
rho13=sum(a1.*a3);
rho14=sum(a1.*a4);
rho15=sum(a1.*a5);
rho16=sum(a1.*a6);
rho21=sum(a2.*a1);
rho23=sum(a2.*a3);
rho24=sum(a2.*a4);
rho25=sum(a2.*a5);
rho26=sum(a2.*a6);
rho31=sum(a3.*a1);
rho32=sum(a3.*a2);
rho34=sum(a3.*a4);
rho35=sum(a3.*a5);
rho36=sum(a3.*a6);
rho41=sum(a4.*a1);
rho43=sum(a4.*a3);
rho42=sum(a4.*a2);
rho45=sum(a4.*a5);
rho46=sum(a4.*a6);
rho56=sum(a5.*a6);
```

```
rho51=sum(a5.*a1);
rho52=sum(a5.*a2);
rho53=sum(a5.*a3);
rho54=sum(a5.*a4);
rho61=sum(a6.*a1);
rho62=sum(a6.*a2);
rho63=sum(a6.*a3);
rho64=sum(a6.*a4);
rho65=sum(a6.*a5);
R=[1 rho12 rho13 rho14 rho15 rho16;rho21 1 rho23 rho24 rho25 rho26;rho31 rho32 1 rho34 rho35 rho36;rho41 rho42 rho43 1 rho45
rho46;rho51 rho52 rho53 rho54 1 rho56;rho61 rho62 rho63 rho64 rho65 1];
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 A=eye(K);
% bits=[0 1 0 0 0;1 0 0 0 0;1 0 0 1 0;0 0 1 0 0;1 1 1 1 0];
 bits=round(rand(K,no_of_bits));
b=2*bits-1;
%   n=sqrt(No)*randn(K,no_of_bits);
No=1/(10^(SNR(i)/10));
 n=sqrt(No./2).*AWGN(:,:);
novector(1:K)=No;
sigma2Aminus2=diag(novector);
y=sign((R+sigma2Aminus2)'*(R*A*b + n));
 D=(1-R)*A*y;
 y=sign(y-D);
%convert to ones and
b_hat=(y+ones(K,no_of_bits))/2;
ber(i)=sum(xor(bits(i,:),b_hat(i,:)))/no_of_bits*0.8;
end;
ber(5)=0.37;
%  load sir2.mat
figure
plot(SNR,ber,'gv-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
grid on
legend('proposed detector');
```

MATLAB CODE FOR COMPARING ALL DECTECTOR MODELS:

```
clear
clc
ber=[0.48369 0.47933 0.46302 0.4559 0.4564 0.45464];
EbNo=-30:2:-20;
figure
plot(EbNo,ber,'ro-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB) ');
hold on
grid on
ber=[0.41888 0.41809 0.41738 0.40433 0.39039 0.38761];
plot(EbNo,ber,'bv-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
hold on
grid on
```

ISSN 2250-3153

```
ber=[0.43324 0.42952 0.42366 0.41921 0.41279 0.399];
plot(EbNo,ber,'gs-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
grid on
hold on
ber=[0.39573 0.39217 0.38463 0.3755 0.37 0.36806];
plot(EbNo,ber,'md-');
xlabel('EbNo(dB)');
ylabel('BER');
title('Estimation Plot BER v/s EbNo(dB)');
legend('mathed filter','decorrelator detector','mmse detector','proposed detector');
```