PERFORMANCE ANALYSES OF A MULTI-CARRIER CDMA WIRELESS COMMUNICATION SYSTEM WITH CHANNEL IMPAIRMENT

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DECLARATION

We hereby declare that this thesis is based on the results found by ourselves. Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

Signature of Supervisor

Signature of Author

ACKNOWLEDGEMENTS

By the grace of God we have completed our thesis. We would like to thank our supervisor Dr. Satya Prasad Majumder for giving us the opportunity to work under his supervision. He has always help us by giving suggestions, ideas, advice and support to solve all our problems and guided us to developed this thesis for last two semester.

We also thankful to Apurba Saha, Supriyo Shafkat Ahmed, Nazmus Saquib and Rumana Rahman for their inspiration and kind cooperation.

We have worked hard and gave our best. Hopefully, our work will appreciated by our supervisor and respected faculties.

ABSTRACT

Analysis of the Bit Error Rate (BER) will be carried out for a Multi Carrier CDMA wireless communication link considering the effect of channels limitations like fading, delay spread etc. Different schemes of MC-CDMA will be considered and performance result will be evaluated by numerical computations. Performance degradations due to above system impairments will be evaluated and optimum system design parameters will be determined.

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CHAPTER I: INTRODUCTION

1.1 Introduction to CDMA

Mobile communications are rapidly becoming more and more necessary for everyday activities. With so many more users to accommodate, more efficient use of bandwidth is a priority among cellular phone system operators. Equally important is the security and reliability of these calls. One solution that has been offered is a Code Division Multiple Access system.

Multiple Access is a technique where many subscribers or local stations can share the use of the use of a communication channel at the same time or nearly so despite the fact originate from widely different locations. A channel can be defined as a portion of the limited radio resource, which is temporarily allocated for a specific purpose or user, such as someone's phone call. A multiple access method is a definition of how the radio spectrum is divided into channels and how the channels are allocated to the many users of the system. There are three basic techniques of multiple access.

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

1.1.1 Basic Concept

In code division multiple access (CDMA) system, the narrowband massage signal is multiplied by a very large bandwidth signal called the spreading signal. All CDMA users use the same carrier frequency and may transmit simultaneously which we see in figure 1. Each user has its own pseudorandom codeword. The receiver performs a time correlation operation to detect only the specific desired codeword. All other codeword appear as noise. Each user operates independently with no knowledge of the other users.

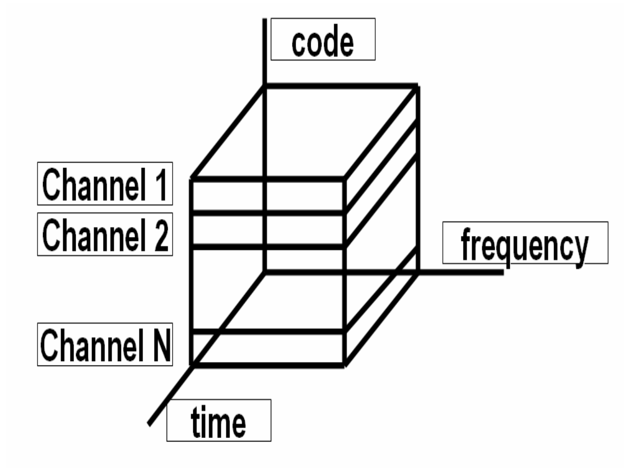

Figure 1: CDMA techniques where each channel is assigned a unique pseudo noise code.

The near far problem occurs when many mobile users share the same channel. In general, the strongest received mobile signal will capture the demodulator at a base station. In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received. To overcome this problem, power control is used. Power control is provided by each base station in a cellular system and assures that each mobile within the base station coverage area provided the same signal level to the base station receiver.

There are three ways to spread the bandwidth of the signal:

- Frequency hopping: The signal is rapidly switched between different frequencies within the hopping bandwidth pseudo-randomly, and the receiver knows before hand where to find the signal at any given time.
- Time hopping: The signal is transmitted in short bursts pseudo-randomly, and the receiver knows beforehand when to expect the burst.
- Direct sequence: The digital data is directly coded at a much higher frequency. The code is generated pseudo-randomly, the receiver knows how to generate the same code, and correlates the received signal with that code to extract the data.

1.1.2 Frequency Hopping Code Division Multiple Access (FH-CDMA)

FH – CDMA is a kind of spread spectrum technology that enables many users to share the same channel by employing a unique hopping pattern to distinguish different users' transmission. The type of spread spectrum in which the carrier hops randomly from one frequency to another is called FH spread spectrum. A common modulation format for FH system is that of M-ary frequency shift keying (MFSK).

A major advantage of frequency hopping is that it can be implemented over a much larger frequency band than it is possible to implement DS-spreading, and the band can be noncontiguous. Another major advantage is that frequency hopping provides resistance to multiple – access interference while not requiring power control to prevent near – far problems. In DS – systems, accurate power control is crucial but becomes less effective as the carrier frequency is increased.

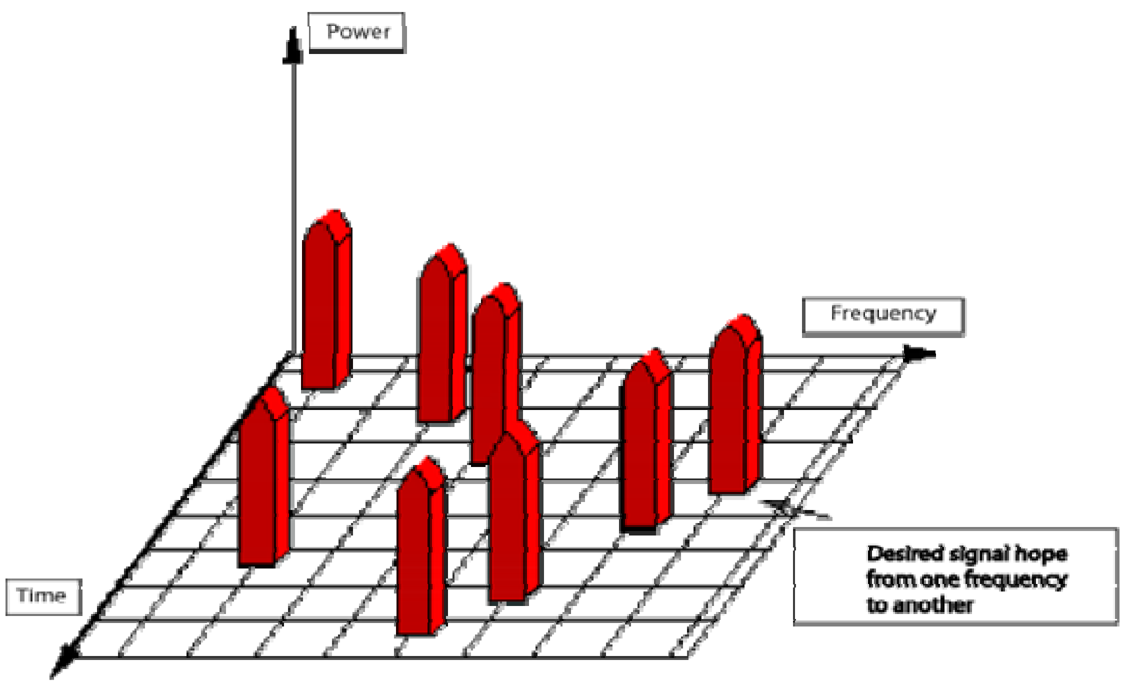

Figure 2: frequency hopping.

Frequency hopping does not cover the entire spread spectrum instantaneously. In frequency hopping systems, the transmitter changes the carrier frequency according to a certain hopping pattern. The advantage is that the signal sees a different channel and a different set of interfering signals during each hop. This avoids the problem of failing communication at a particular frequency. There are two basic types of frequency hopping.

1. *Slow frequency hopping*, In this case one or more data bits are transmitted within one hop. An advantage is that coherent data detection is possible. Often, systems using slow hopping also employ (burst) error control coding to restore loss of (multiple) bits in one hop.

2. *Fast frequency hopping,* In this case one data bit is divided over multiple hops. In fast hopping, coherent signal detection is difficult, and seldom used. Mostly, FSK or MFSK modulation is used.

1.1.3 Direct Sequence Code Division Multiple Access (DS-CDMA)

Direct sequence code division multiple access (DS-CDMA) is an attractive allocation technique that allows users to be simultaneously active over the total available bandwidth. In Direct Sequence CDMA system transmission, the user data signal is multiplied by a pseudo random code sequence.

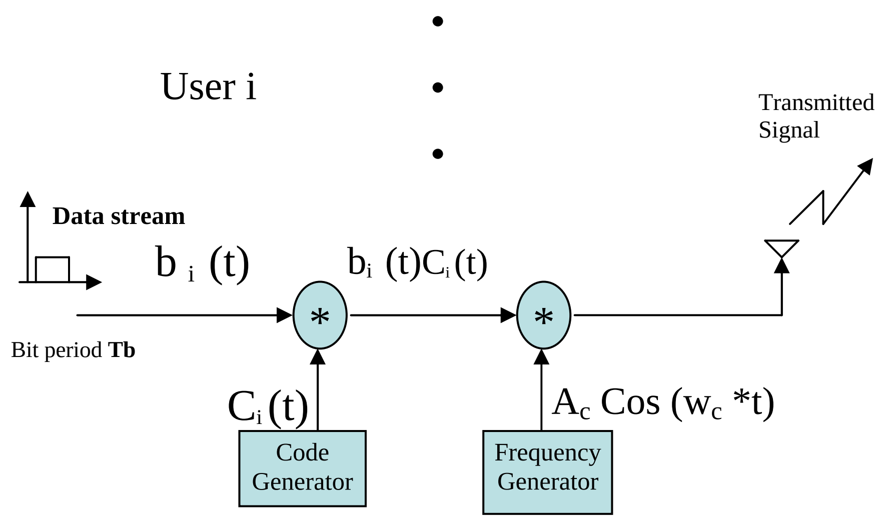

Figure 3 DS-CDMA transmitter

In figure 3 the DS-CDMA transmitter is design by the capacity of *i* number of user. The DS-CDMA transmitter combines the original data stream using a given spreading code in the time domain. Here, *t* is time, $b_i(t)$ is the data stream of i^{th} user C_i (t) is the pseudo random code. $b_j(t)C_i(t)$ is i^{th} user data stream after combines the code width. The transmitter generates unique code for each user over one bit period; T_b by the Code Generator, The Frequency Generator generates one carrier frequency $\{A_c$ Cos $(w_c *t)\}$ for each user for phase shift keying modulation technique. After combining and modulation of digital data, it is transmitted by the CDMA antenna over the wireless media like air.

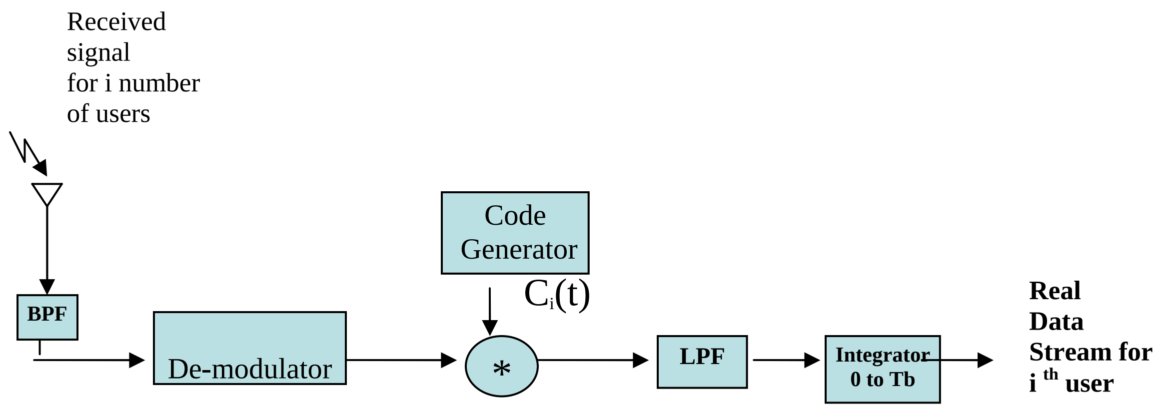

Figure 4 DS-CDMA receiver

In figure 4 the DS-CDMA receiver is designed by the capacity of *i* number of user. Then it will face the MAI for user 1 to user (i-1). At First the CDMA antenna received the transmitted signal and then it passes through a band pass filter (BPF). BPF remove any unwanted signal. Demodulator demodulates the signal with {A_c Cos (w_c *t)}. Then the received signal is again multiplied by the same code $C_i(t)$. After this the code has been removed, so we get the original transmitted user data. The low pass filter rejects the high frequency portion of data signals. At last, the integrator provides the real i^{th} user digital data. Integrator reduces the multi-access interference (MAI).

1.2 Multi Carrier Code Division Multiple Access (MC-CDMA)

Multi Carrier Code Division Multiple Access (MC-CDMA) is a relatively new concept. Its development aimed at improved performance over multipath links. MC-CDMA is a modulation method that uses multi carrier transmission of DS-CDMA type signals. An MC-CDMA transmitter spreads the original data stream in the frequency domain over different sub carriers using a given spreading code. In this system the sub carriers convey the same information at one time. The MC-CDMA offers better frequency diversity to combat frequency selective fading.

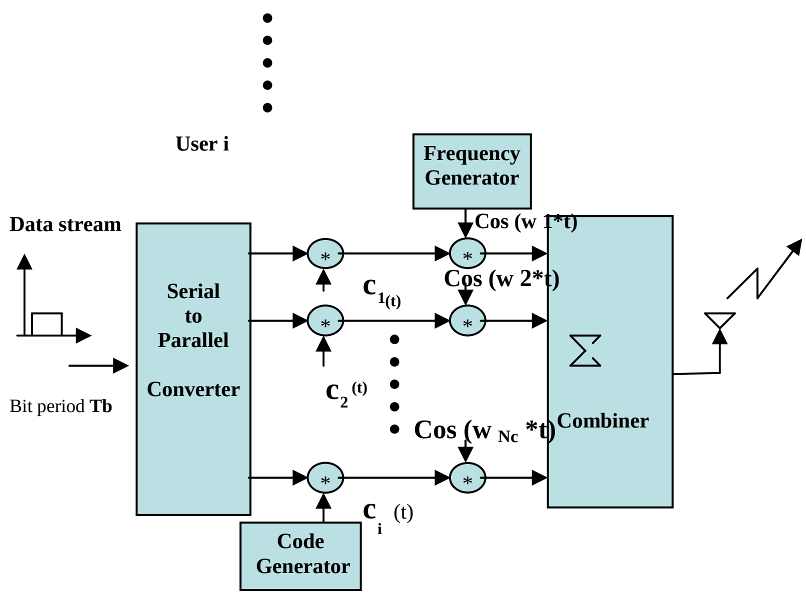

Figure 5 MC-CDMA transmitters

In figure 5 we see the transmitter MC-CDMA system for *i* number of user. The MC-CDMA transmitter spreads the original data stream using a given spreading code in the frequency domain. The code generator creates different unique codes for each different user and then combines together. Then the frequency generator combines different carrier frequency to the data signal and then combines the entire signal together by a combiner. After combining all the signals the CDMA antenna transmits the signals over the wireless media.

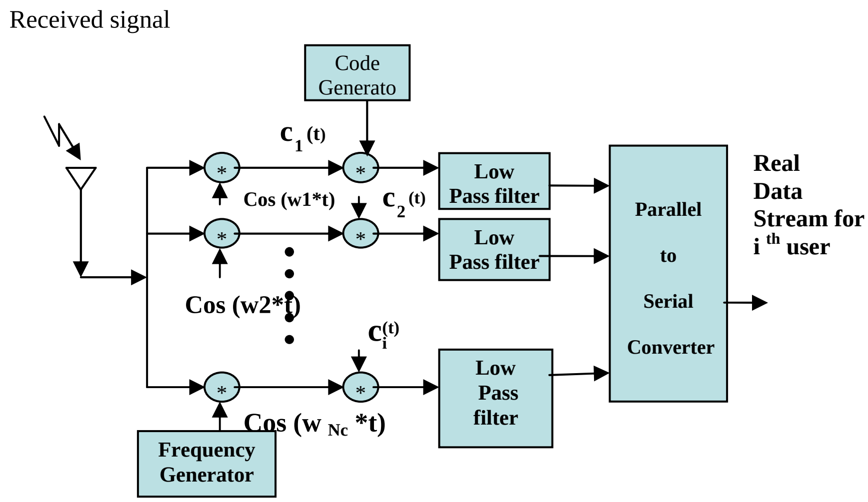

Figure 6 MC-CDMA receiver

In figure 6 the MC-CDMA receiver is designed by the capacity of *i* number of user. MC-CDMA receiver also receives the transmitted signal as a summation of i number of users. At first demodulates the received signal by the same career frequency of each signal and then the signals multiply with the specific codes given by the receiver code generator. Then we get the signal of i^{th} user which is same for transmitter and receiver. After that low pass filter remove the high frequencies portion of the signal. Finally, the P/S converter presents the actual digital data signal.

1.3 Limitation of communication system with CDMA techniques:

Communication system has some limitation. Bandwidth, Noise and Fading are some major limitation of the system.

Bandwidth is the measurement of a particular frequency range. When we fixed a bandwidth for a channel then we transmit that amount of data in one second of time. So if the frequency range is very high then we can transmit or receive more data for a period of time. In a communications system lack of bandwidth means lack of throughput of intelligible data. So that Bandwidth limitation means restricting the quantity of information transmitted from sender to receiver per second. This either means the information arrives slower, or the information contains less detail.

Noise will also affect intelligibility. The noise is additive, i.e., the received signal equals the transmit signal plus some noise, where the noise is statistically independent of the signal.

Fading is a fluctuation in the received signal strength at the receiver or a random variation in the received signal is known as fading. Fading of radio waves is the undesired variation in the intensity or loudness f the waves received at the receiver. There are two types of fading limitations. Frequency-selective fading & Time Selective Fading.

1.4 Objective of the Thesis Work

Work to be carried out for analysis of MC CDMA system with fading and interference. Different schemes of MC-CDMA will be considered and performance result will be evaluated. To evaluate the performance results in terms of Bit Error Rate. To determine the optimum system parameters at a given system BER.

CHAPTER II: ANALYSIS OF MC-CDMA

2.1 Analysis of CDMA

Here we discuss about the Bit Error Rate on the MC-CDMA system. After combining the transmitted signal signals the CDMA antenna transmits the signals over the wireless media. In receiver side we get the all combing signal with some unexpected signal which are MUI, ICI and Noise signal. So in the receiver side after combining all sub-carrier signals we get the received signal is

$$x = x_0 + x_{MUI} + x_{ICI} + x_{noise} \quad \text{[1]}$$

Where,

x_0 = wanted signal;

x_{MUI} = multi-user interference (due to imperfect restoration of the sub-carrier amplitudes);

x_{ICI} = inter-carrier interference (due to crosstalk $\beta_{m,n}$ between a_n and y_m);

x_{noise} = noise;

We can write the wanted signal as,

$$x_0 = b_0 \frac{T_s}{N}\left[\sum_{n=0}^{N-1}\beta_{n,n}\omega_{n,n} + \sum_{m\neq 0}\sum_{n=0}^{N-1}\beta_{m,n}\omega_{n,n}c_0[n]c_0[n-m]\right] \quad \text{[2]}$$

Where,

N = number of subscriber,

n = subscriber number,

$\beta_{n,n}$ = crosstalk between the user.

T_s = Sampling time.

$\omega_{n,n}$ = weight factors which is constant.

$c_0[n]c_0[n-m]$ = orthogonal spreading codes

The variance of x_0 became zero for large number of N , i.e., the system working like non fading channel.

The multi-user interference signal is

$$x_{MUI} = T_s \sum_{k=1}^{N-1} b_k \left[\sum_{n=0}^{N-1} \beta_{n,n} \omega_{n,n} c_0[n] c_k[n] \right] \text{...[3]}$$

We can write the x_{MUI} as,

$$x_{MUI} = T_s \sum_{k=1}^{N-1} b_k \left[\sum_{n \in A_+} \beta_{n,n} \omega_{n,n} - \sum_{n \in A_-} \beta_{n,n} \omega_{n,n} \right] \text{.................................[4]}$$

Where,

$A_- = \{n : c_j[n] c_k[n] = -1/N\}$ is the sets of orthogonal code of the sub career index *n*

$A_+ = \{n : c_j[n] c_k[n] = 1/N\}$ is the sets of orthogonal code of the sub career index *n*

And $A_+ \cup A_- = A$ is the value of $\sum_{A_+ \cup A_-} c_j[n] c_k[n] = 0$.

So the variance of MUI,

$$\sigma^2_{MUI} = E_{ch} E\, x_{MUI} x^*_{MUI}$$

$$= \frac{(N-1)T_s}{N^2} \left[E_{ch} \left(\sum_{n \in A_+} \beta_{n,n} \omega_n \right)^2 + E_{ch} \left(\sum_{n \in A_-} \beta_{n,n} \omega_n \right)^2 - 2E_{ch} \left(\sum_{n \in A_+} \beta_{n,n} \omega_n \right) \times \left(\sum_{n \in A_-} \beta_{n,n} \omega_n \right) \right]$$

........................[5]

If we may assume that fading of the sub-carriers is independent, we can write

$$E_{ch}\left(\sum_{n\in A_+}\beta_{n,n}\omega_n\right)^2=\frac{N}{2}M_{22}+\frac{N}{2}\left(\frac{N}{2}-1\right)M_{11}^2 \text{ ....[6]}$$

and,

$$E_{ch}\left(\sum_{n\in A_+}\beta_{n,n}\omega_n\right)\times\left(\sum_{n\in A_-}\beta_{n,n}\omega_n\right)=\left(\frac{N}{2}\right)^2 M_{11}^2 \text{ ....[7]}$$

Where

$$M_{11}=E\,\beta_{n,n}^2 \big/ N_0 = P_0 \big/ N_0$$
$$M_{22}=E\,\beta_{n,n}^4 \big/ N_0^2 = 2P_0^2 \big/ N_0^2$$

P_0 = power of the signal.

N_0 = power of the noise signal.

After simplify all the equation we get the variance,

$$\sigma_{MUI}^2=\frac{(N-1)T_s^2}{N}\left(M_{22}+M_{11}^2\right) \text{ ....[8]}$$

The ICI comes from the crosstalk between sub carriers. Inter-carrier interference signal is,

$$x_{ICI}=T_s\sum_{n=0}^{N-1}a_n\sum_{\Delta\neq 0}\beta_{n+\Delta,n}\omega_{n+\Delta,n+\Delta}c_0[n+\Delta] \text{ ....[9]}$$

Here,

Δ = distance of signal between two subscriber, Now after putting $a_n = \sum_k c_k[n]b_k$ in the equation,

$$x_{ICI} = \sum_{\Delta \neq 0} \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} b_k c_k[n] \beta_{n+\Delta,n} \times \omega_{n+\Delta,n+\Delta} c_0[n+\Delta]$$

…………………..[10]

So the variance of ICI,

$$\sigma_{ICI}^2 = E_{ch} E\, x_{ICI} x_{ICI}^*$$

$$= T_s^2 E_{ch} E \left[\sum_{m=1}^{N-1} \sum_{k=1}^{N-1} b_k \sum_{n=0}^{N-1} \beta_{mn} \omega_n c_0(n) c_k(n-m) \right]^2$$ ……………………..[11]

After simplify the equation we get the variance

$$\sigma_{ICI}^2 = \sum_{\Delta \neq 0} p_\Delta M_{02} T_s^2$$ …………………...…………………………[12]

Where $M_{02} = E\beta_{n,n}^2 / N_0^2 = P_0 / N_0^2$

p_Δ = variation of the signal power between of any two subscriber.

The variance of the noise collected over all sub-carriers weighted by $\omega_{n,n}$ becomes,

$$\sigma_{noise}^2 = N M_{02} N_0 T_s$$ ………………………………..…………………………[13]

Now

$$\frac{E_N}{N_0} = \frac{M_{11}^2 T_s^2}{\sigma_{ICI}^2 + \sigma_{MUI}^2 + \sigma_{noise}^2}$$

$$= \frac{M_{11}^2}{\left(M_{22} + M_{11}^2\right) + M_{02}\left[\sum_{\Delta \neq 0} p_\Delta + \frac{N_0}{T_s}\right]}$$

…………………………[14]

Since we consider many different channels, x_{MUI}, x_{ICI} and x_{noise} are zero-mean complex Gaussian. So BER is,

$$B = \frac{1}{2} erfc \sqrt{\frac{E_N}{N_0}}$$ ………………………………………………………[15]

CHAPTER III: RESULTS AND DISCUSSION

3.1 Results and Discussion

Here, we take the number of subscriber *N* is 16; number of chips per bit (code length) *L* is taken as 16. Bit rate R_b is 10000 bit per sample.

Noise power N_0 has been taken 10 micro watts. We take different Signal power P_o in dB which is 10dB, 7dB, 5dB, 2dB, 0dB, -2dB, -5dB and -10dB.

The equation we use here to find,

$$T_b = 1/R_b \qquad \text{...[16]}$$

$$E_b = P_o \times T_b$$

$$SNR = \frac{P_o}{N_o \times R_b} = \frac{P_o}{N_o \times \frac{1}{T_b}} = \frac{P_o \times T_b}{N_o} = \frac{E_b}{N_o} \qquad \text{...[17]}$$

$$T_s = T_b / L \qquad \text{...[18]}$$

Here we take p_Δ = 10% of p_0 . ……………………………………………...[19]

3.1.1 Plots of Variance of multi-user interference versus number of user:

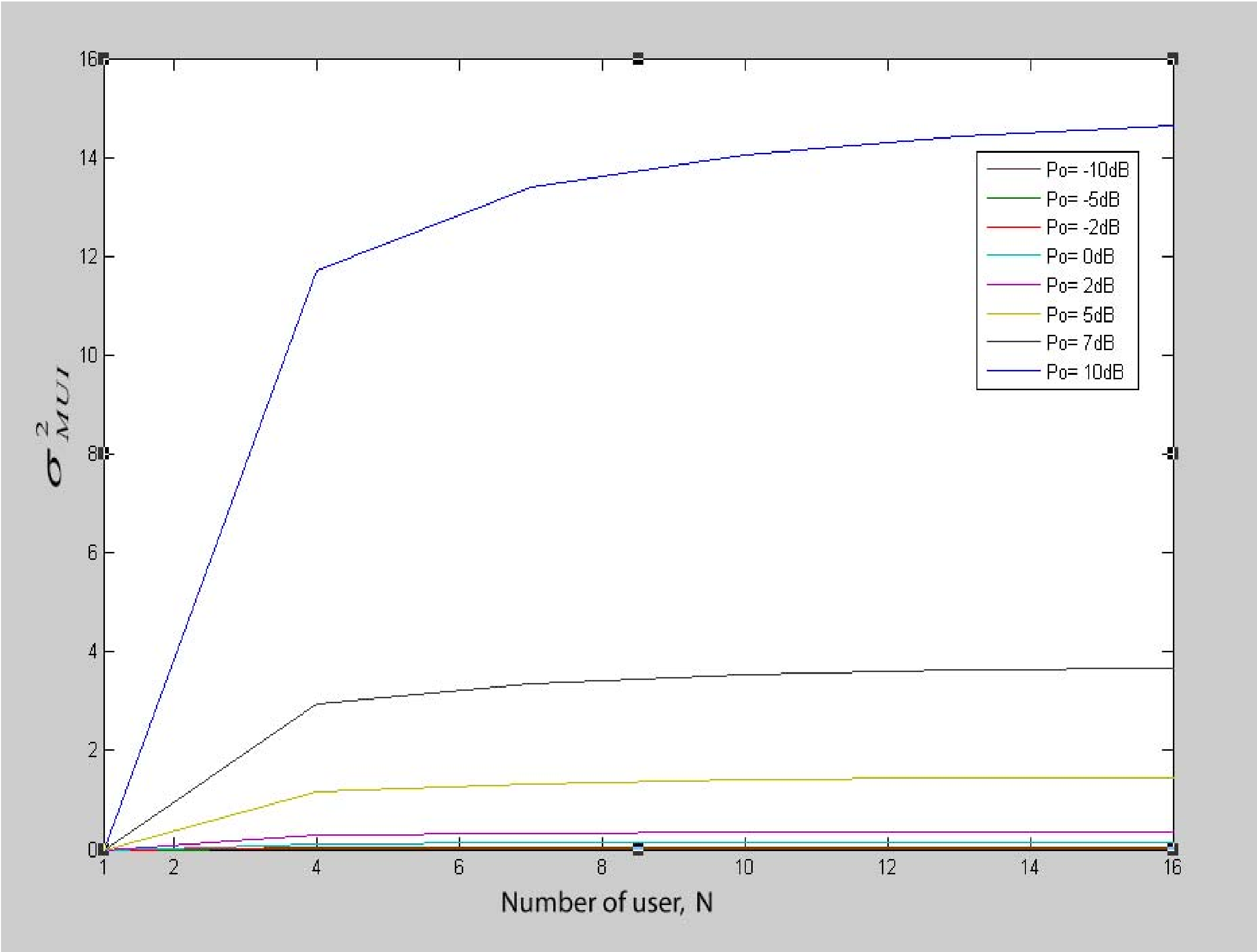

Figure 7 Plots of σ^2_{MUI} versus number of user in MC-CDMA system

Figure 7 shows the plots of σ^2_{MUI} versus number of user in MC-CDMA system. This figure comes from equation [8]. We see that if we increase the number of user then the interference between different user increases. The variance of the multi user interference depends on signal power. If we increase the power then the interference increases gradually. For example, in this graph variance of MUI for 10dB power is very high and it is more than 14. Whereas for low power like 5dB variance of MUI is less than 2. and it is close to zero for very low power like -10dB.

3.1.2 Plots of Variance of inter carrier interference versus number of user:

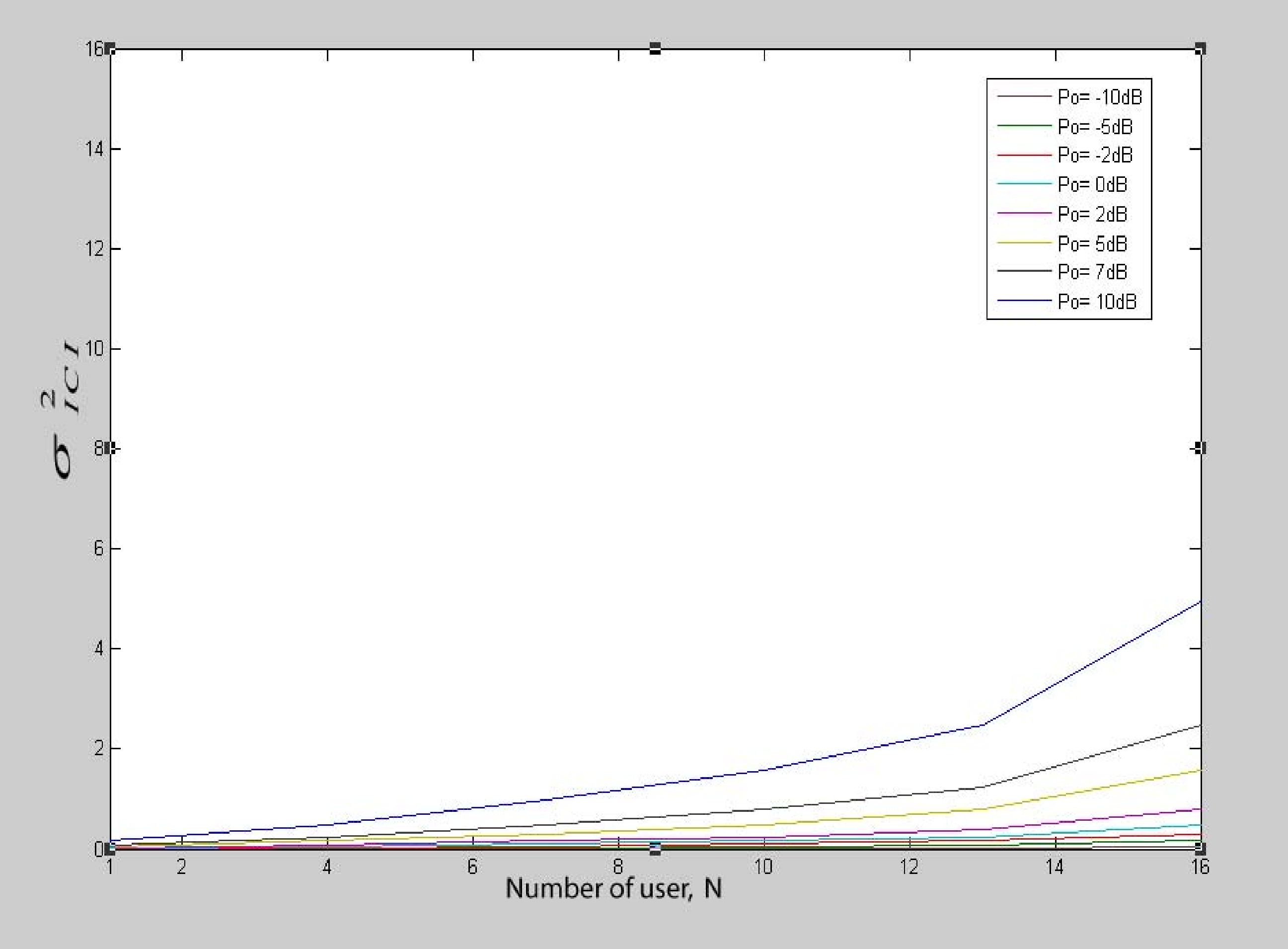

Figure 8 Plots of σ^2_{ICI} versus number of user in MC-CDMA system

Figure 8 shows the plots of σ^2_{ICI} versus number of user in MC-CDMA system. This figure comes from equation [12]. We see that if we increase the number of user then the variance of ICI increase. The variance of the ICI also depends on the signal power. If power is low then the interference between the carrier is very low but when we increase the power then the inter carrier interference also increase and that case the crosstalk between the sub carrier occurs very rapidly.

3.1.3 Plots of E_N/N_0 versus number of user:

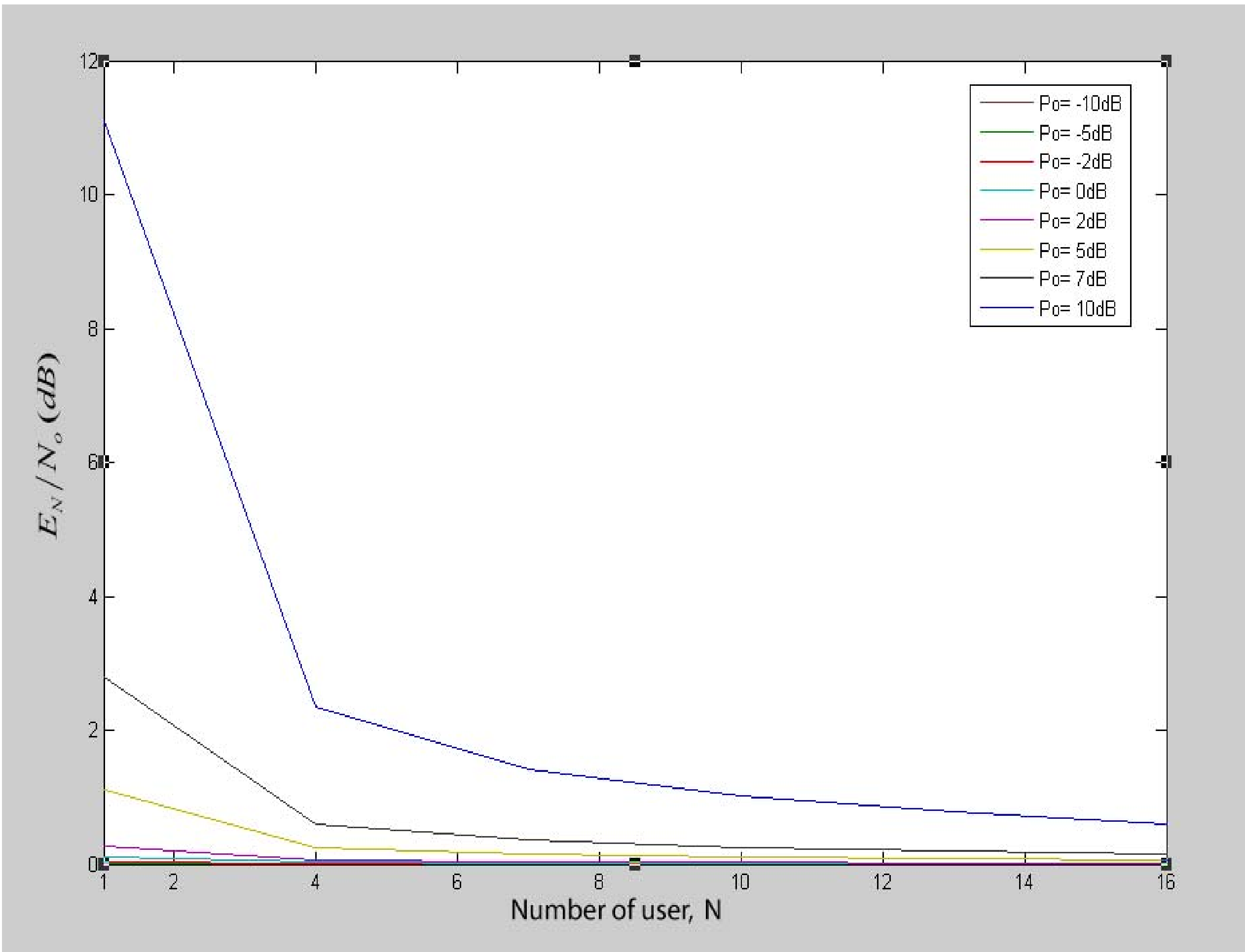

Figure 9 Plots of E_N/N_0 versus number of user in MC-CDMA system

Figure 9 shows the plots of E_N/N_0 versus number of user in MC-CDMA system. This figure comes from equation [14]. E_N/N_0 have an inverse relationship with no of subscriber. If we increase number of user then E_N/N_0 decreases.

3.1.4 Plots of Bit Error Rate versus E_N/N_0 :

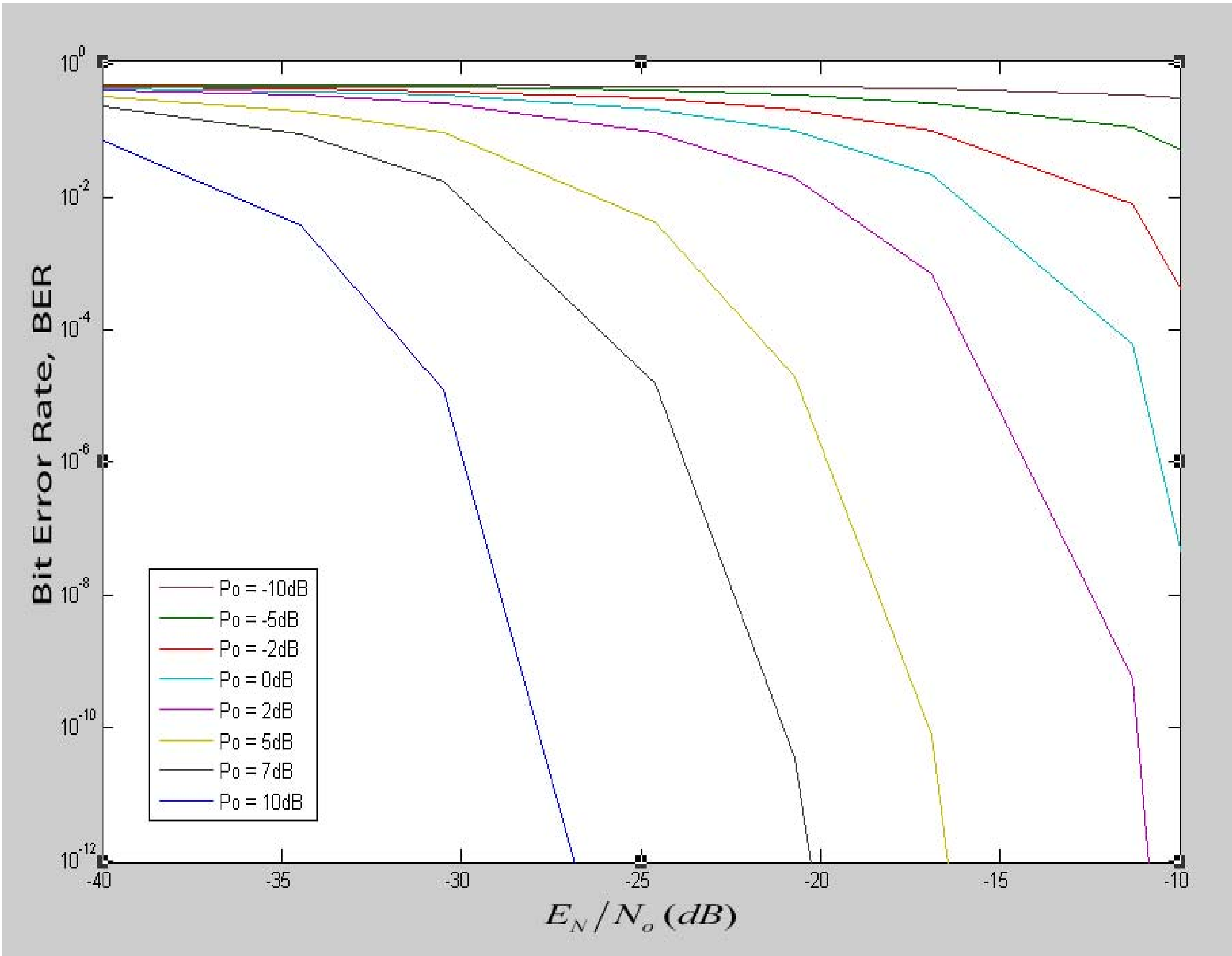

Figure 10 Plots of Bit Error Rate versus E_N/N_0 in MC-CDMA system

Figure 10 shows the Plots of Bit Error Rate versus E_N/N_0 in MC-CDMA system. This figure comes from equation [15]. It is found that BER decreases with respect to E_N/N_0 for a particular signal power. I signal power is very high than BER decrease rapidly with respect to E_N/N_0 . But if signal power is very low then BER decreases very slowly with respect to E_N/N_0 . We prefer lower BER in Wireless communication system and that's why we should use high signal power.

In below figure 11, if we draw a axis with parallel to E_N/N_0 from a particular BER 10^{-6} we see that the axis intersect the Po curve in 10dB, 7dB, 5dB and 2dB.

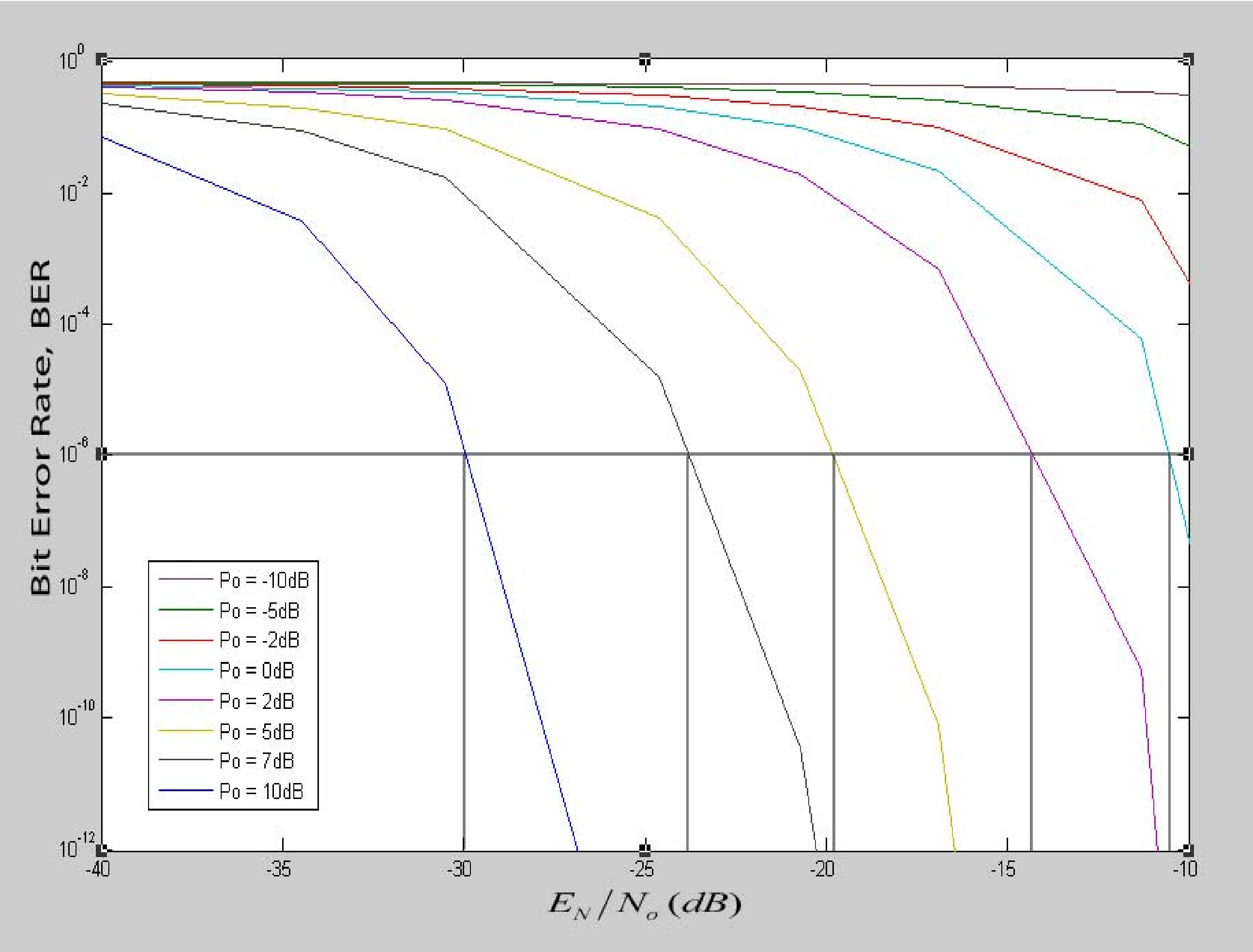

Figure 11 Plots of Bit Error Rate versus E_N/N_0 in MC-CDMA system

By this graph we are able to find out the combination of signal power and E_N/N_0 for related BER. From above graph we find the combinations are:

P_o **dB**	E_N/N_0 **dB**
10	- 29.9 = -30 (approx)
7	-23.8 = - 24 (approx)
5	-19.8 = - 20 (approx)

2	-14.3 = -14 (approx)
0	-10.6= -11 (approx)

3.1.5 Plots of Signal Power versus E_N / N_0 :

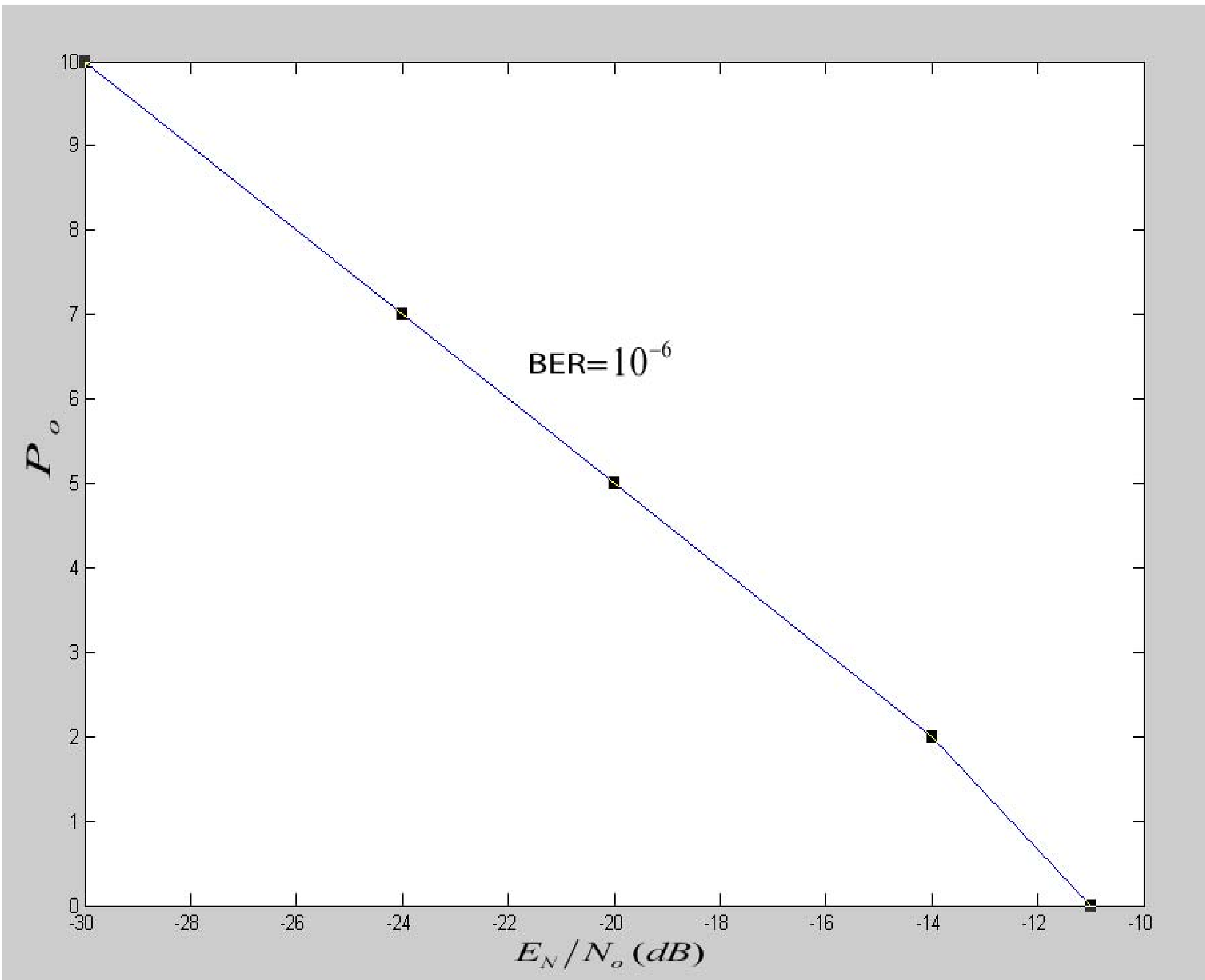

Figure 12 Plots of Signal Power versus E_N / N_0 in MC-CDMA system

We have to plot the combination value of signal power and E_N / N_0 which we find in figure 11. After that we can find the graph for of signal power versus E_N / N_0 for a particular BER 10^{-6} which we see in figure 12.

3.1.6 Plots of Bit Error Rate versus number of user:

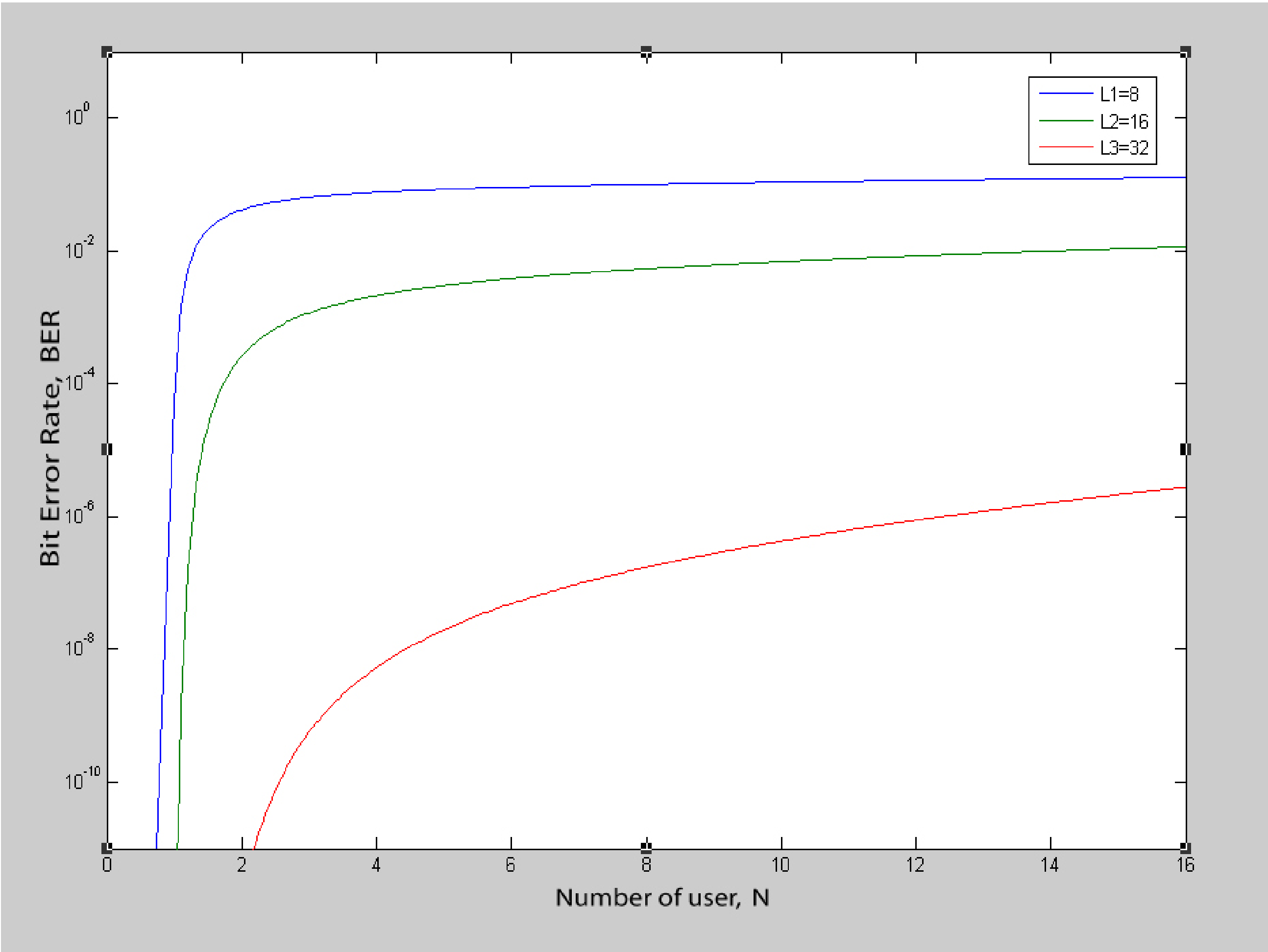

Figure 13 Plots of **bit error rate** versus number of user in MC-CDMA system

Figure 13 shows the plots Bit Error Rate versus number of user in MC-CDMA system. Here we three different code length which is 8bit , 16bit and 32 bit. It is show that the number of user increases and at the same time BER also increases. Since grater BER is not accepted in wireless communication system and it is essential to reduce higher BER. We can easily do that by increasing the number of chips per bit. When we increase the code length the BER decreases and at the same time we can easily give service more number of user.

In below figure 14, if we draw a axis with parallel to Number of user from a particular BER 10^{-6} we see that the axis intersect the Code length curve in L=8, L=16 and L=32.

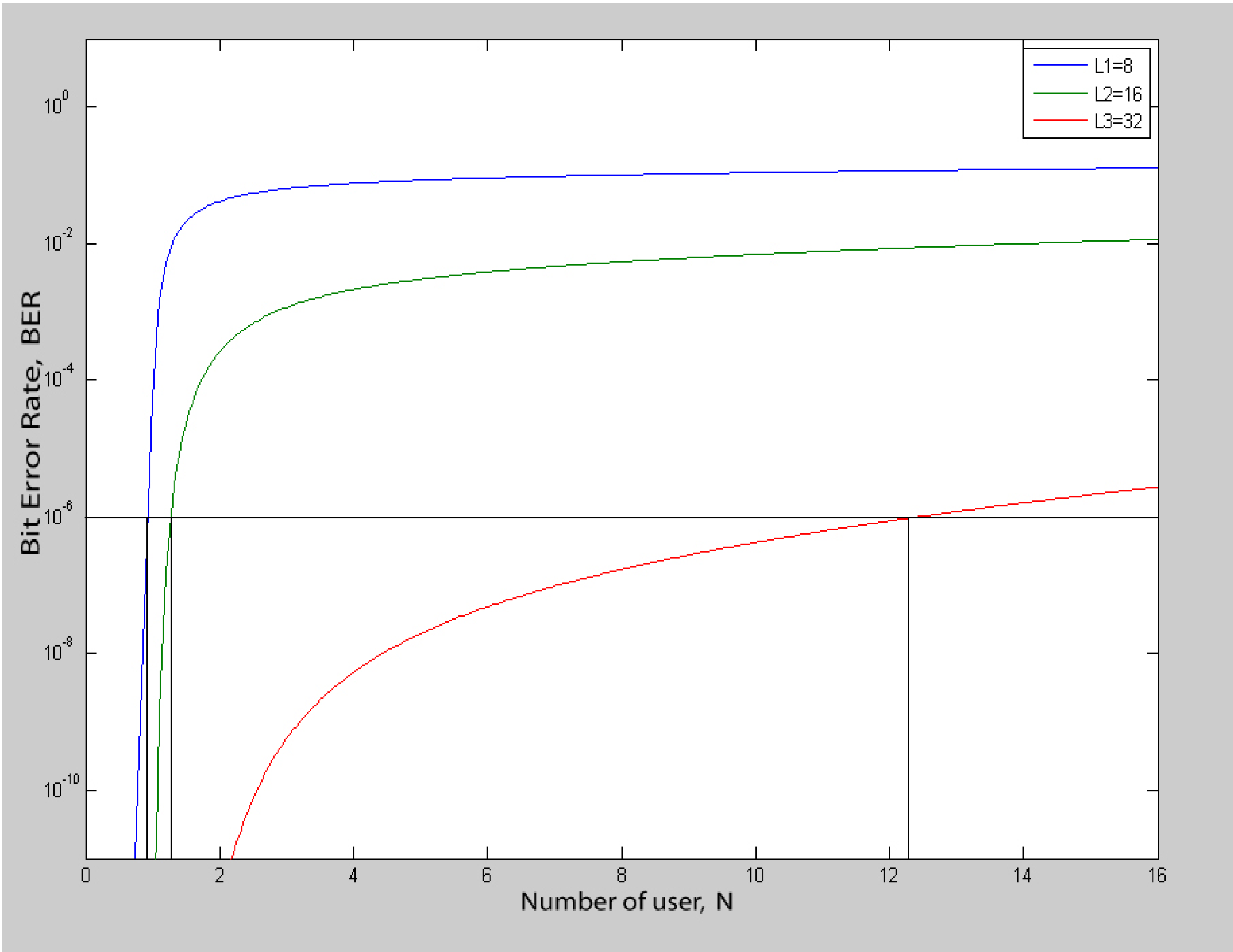

Figure 14 Plots of **bit error rate** versus number of user in MC-CDMA system

By this graph we can easily find the combination of Code length and Number of user for related BER. From above graph we find the combinations are:

Code length (L)	Number of User (N)
8bit	0.8 = 1 (approx.)
16bit	1.2 =1 (approx)
32bit	12.3 = 12(approx.)

3.1.7 Plots of Code Length versus number of subscriber:

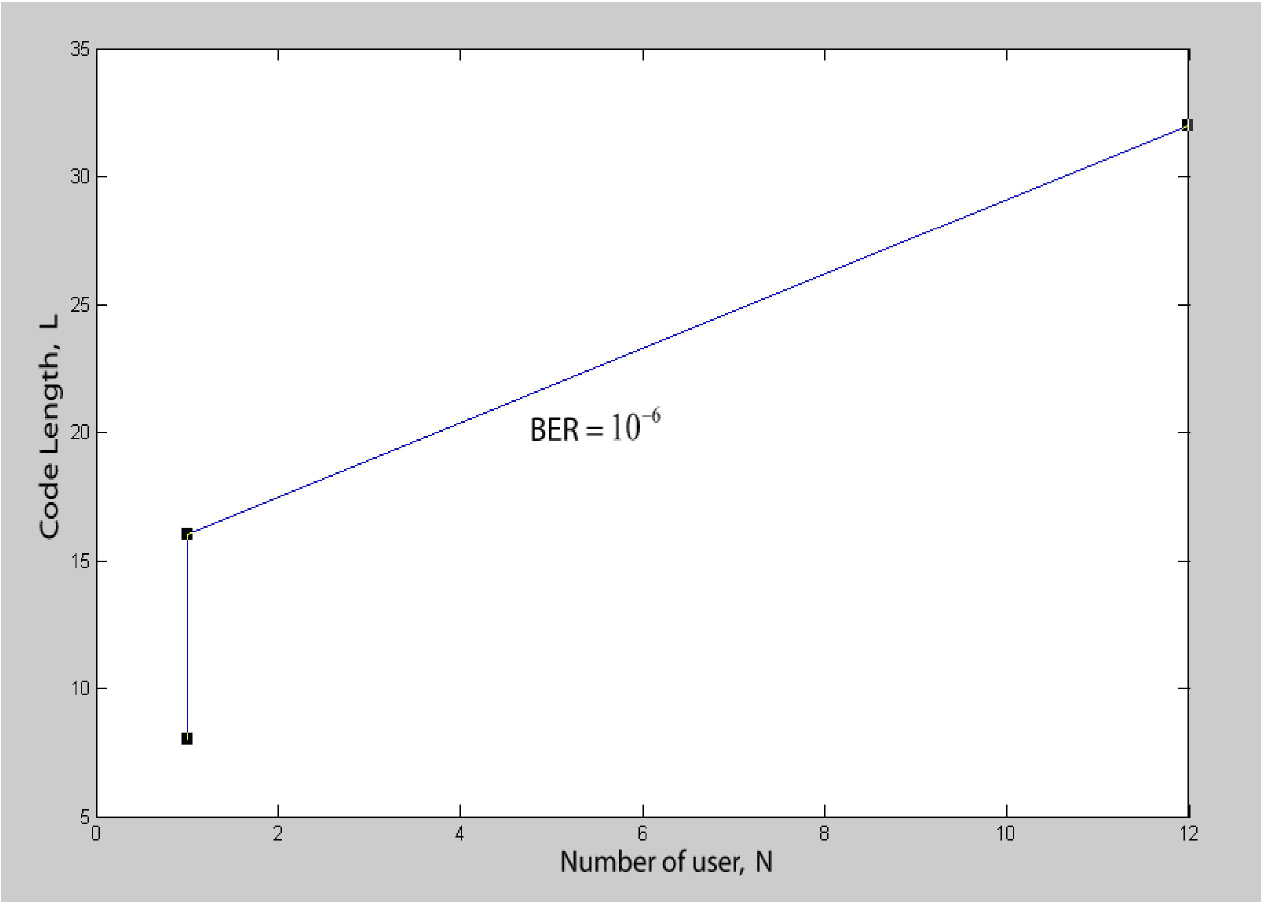

Figure 15 Plots of Code Length versus number of user in MC-CDMA system

We have to plot the combination value of Code length and Number of user which we find in figure 14. after that we can find the graph for Code length versus Number of user for related BER 10^{-6} which we see in figure 15. Here we see that for a particular BER if we increase the Code length then we can easily give support to the more number of users. For more number of users that particular BER may be low and that is acceptable in our system. But if user is less and this reason that particular BER became high for system and that is not acceptable.

CHAPTER IV: CONCLUSION AND FUTURE WORK

4.1 Future Work

- Further research can be carried out on MC-CDMA system considering the effect of fading and frequency offset between the sub-carriers in the receiver.
- Work can be carried out to find the improvement in BER performance while using Rake Receiver to combat the effect of fading and delay spread.
- Works can be initiated to find optimum user code length for a given number of users in a MC-CDMA system in presence of channel effects.

4.2 Conclusion

In this thesis paper we have used some basic equation to find out our expected results. No new equation was deriving on this thesis paper.

We saw the performance result for Multi-user interference and Inter carrier interference for certain number of user. If we increase the user then the MUI and ICI occurs more and more.

By BER versus ratio of Energy of bit and Noise density analysis we saw that if we increase the value of E_N / N_0 then the BER became low. In communication system we can not prefer high BER. If BER is low then the channel can transfer the signal more perfectly

We also saw that how can the Code length effect the user capacity in the system. For a particular accepted BER we can easily serve more number of users if the code length is high.

. The major problem of MC-CDMA is Multi carrier interference and inter carrier interference occur. Near far problem and Multi-path fading also another disadvantage of this system. We saw that in CDMA system due to code difference between the users they can easily share the same frequency. That's why the capacity of serving user easily can increase

Reference:

[1] Jean-Paul M. G. Linnartz – “Performance Analysis of Synchronous MC-CDMA in Mobile Rayleigh Channel with Both Delay and Doppler Spreads”, IEEE transactions on vehicular technology, vol. 50, no. 6, November 2001

[2] S. Hara and R. Prasad, “Overview of multicarrier CDMA,” IEEE. Communication Magazine., vol. 35, no. 12, pp. 126–133, Dec. 1997

[3] Vijay K. Garg - “Wireless Communication and Networking”

[4] Theodore S. Rappaport –“Wireless Communications principle and practice”

[5] Saimoon Ara Amin and Md.Mahbubul Alam – “Performance analyses of Multi-Carrier DS-CDMA wireless communication systems.”

[6] http://www.telecomspace.com/cdma.html

[7] http://www.wirelesscommunication.nl/reference/chaptr05/cdma/cdma.htm

MATLAB code:

Matlab Code for Variance of Multi user interference versus number of user:

```
clc
clear all
close all
N=1:3:23;
N0=10^-6;
Rb=10000;
L=8;
P0dB=[-10 -5 -2 0 2 5 7 10 ];

for s=1:length(P0dB)
    P0(s)=10.^(P0dB(s)./10);
end

Tb=1./Rb;
Eb=P0.*Tb;
SNR=Eb./N0;
M11=P0/N0;
M02=P0/N0^2;
M22=2*P0.^2/N0.^2;
Pdel=0.1*P0;
Ts=Tb/L;

for j=1:length(SNR)
    for i = 1:length(N)
    sMUI(i)=sqrt(((N(i)-1)/N(i))* Ts.^2*(M22(j)-M11(j).^2));
    end
    SMUI(:,j)=sMUI;
end
Smui=(SMUI.^2)./1000;

for k=1:length(Pdel);
    for l = 1:length(SNR);
    sICI(l)=sqrt((Pdel(k).*M02(l)).*Ts.^2);
    snoise(l)=sqrt(N(l).*(M02(k).*N0).*Ts);
    end
    SICI(:,k)=sICI;
    Snoise(:,k)=snoise;
end
```

```
format long

for y=1:length(P0);
    for z = 1:length(P0)

EN(z)=(N0*(M11(y).^2.*Ts.^2))./(SICI(z).^2+SMUI(z).^2+Snoise(z).^2);
    end
    En(:,y)=EN;
    En1(:,y)=EN/N0;
  EndB(y)=10*log10(En1(y));
end

Sici=(SICI.^2)./100;
  en=En1./1000;
  BER=(1./2)*erfc(sqrt(En./N0));

plot(N,Smui)
axis([1 16 0 16])
legend('Po=-10dB','Po=-5dB','Po=-
2dB','Po=0dB','Po=2dB','Po=5dB','Po=7dB','Po=10dB',8)
```

MATLAB Code for Inter carrier Interference versus Number of user:

```
clc
clear all
close all
N=1:3:23;
N0=10^-6;
Rb=10000;
L=8;
P0dB=[-10 -5 -2 0 2 5 7 10 ];

for s=1:length(P0dB)
    P0(s)=10.^(P0dB(s)./10);
end

Tb=1./Rb;
Eb=P0.*Tb;
SNR=Eb./N0;
M11=P0/N0;
M02=P0/N0^2;
M22=2*P0.^2/N0.^2;
Pdel=0.1*P0;
Ts=Tb/L;

for j=1:length(SNR)
    for i = 1:length(N)
    sMUI(i)=sqrt(((N(i)-1)/N(i))* Ts.^2*(M22(j)-M11(j).^2));
    end
    SMUI(:,j)=sMUI;
end
Smui=(SMUI.^2)./1000;
```

```
for k=1:length(Pdel);
    for l = 1:length(SNR);
    sICI(l)=sqrt((Pdel(k).*M02(l)).*Ts.^2);
    snoise(l)=sqrt(N(l).*(M02(k).*N0).*Ts);
    end
    SICI(:,k)=sICI;
    Snoise(:,k)=snoise;
end

format long

for y=1:length(P0);
    for z = 1:length(P0)

EN(z)=(N0*(M11(y).^2.*Ts.^2))./(SICI(z).^2+SMUI(z).^2+Snoise(z).^2);
        end
    En(:,y)=EN;
    En1(:,y)=EN/N0;
  EndB(y)=10*log10(En1(y));
end

Sici=(SICI.^2)./100;
  en=En1./1000;
  BER=(1./2)*erfc(sqrt(En./N0));

plot(N,Sici)
axis([1 16 0 16])
legend('Po=-10dB','Po=-5dB','Po=-
2dB','Po=0dB','Po=2dB','Po=5dB','Po=7dB','Po=10dB',8)
```

<u>MATLAB Code for EnNo versus Numberof user:</u>

```
clc
clear all
close all
N=1:3:23;
N0=10^-6;
Rb=10000;
L=8;
P0dB=[-10 -5 -2 0 2 5 7 10 ];

for s=1:length(P0dB)
    P0(s)=10.^(P0dB(s)./10);
end

Tb=1./Rb;
Eb=P0.*Tb;
SNR=Eb./N0;
M11=P0/N0;
M02=P0/N0^2;
M22=2*P0.^2/N0.^2;
Pdel=0.1*P0;
```

```
Ts=Tb/L;

for j=1:length(SNR)
    for i = 1:length(N)
    sMUI(i)=sqrt(((N(i)-1)/N(i))* Ts.^2*(M22(j)-M11(j).^2));
    end
    SMUI(:,j)=sMUI;
end
Smui=(SMUI.^2)./1000;

for k=1:length(Pdel);
    for l = 1:length(SNR);
    sICI(l)=sqrt((Pdel(k).*M02(l)).*Ts.^2);
    snoise(l)=sqrt(N(l).*(M02(k).*N0).*Ts);
    end
    SICI(:,k)=sICI;
    Snoise(:,k)=snoise;
end

format long

for y=1:length(P0);
    for z = 1:length(P0)

EN(z)=(N0*(M11(y).^2.*Ts.^2))./(SICI(z).^2+SMUI(z).^2+Snoise(z).^2);

    end
    En(:,y)=EN;
    En1(:,y)=EN/N0;
  EndB(y)=10*log10(En1(y));
end

Sici=(SICI.^2)./100;

  en=En1./1000;
  BER=(1./2)*erfc(sqrt(En./N0));

plot(N,en)
axis([1 16 0 12])
legend('Po=-10dB','Po=-5dB','Po=-
2dB','Po=0dB','Po=2dB','Po=5dB','Po=7dB','Po=10dB',8)
```

Matlab Code for BER versus EnNo:

```
clc
clear all
close all
N=1:3:25;
N0=10^-6;
Rb=10000;
L=8;
P0dB=[-10 -5 -2 0 2 5 7 10];
```

```
for s=1:length(P0dB)
    P0(s)=10.^(P0dB(s)./10);
end

Tb=1./Rb;
Eb=P0.*Tb;
SNR=Eb./N0;
M11=P0/N0;
M02=P0/N0^2;
M22=2*P0.^2/N0.^2;
Pdel=0.1*P0;
Ts=Tb/L;

for j=1:length(SNR)
    for i = 1:length(N)
    sMUI(i)=sqrt(((N(i)-1)/N(i))* Ts.^2*(M22(j)-M11(j).^2));
    end
    SMUI(:,j)=sMUI;
end
Smui=(SMUI.^2)./1000;

for k=1:length(Pdel);
    for l = 1:length(SNR);
    sICI(l)=sqrt((Pdel(k).*M02(l)).*Ts.^2);
    snoise(l)=sqrt(N(l).*(M02(k).*N0).*Ts);
    end
    SICI(:,k)=sICI;
    Snoise(:,k)=snoise;
end
SICI;
format long

for y=1:length(P0);
    for z = 1:length(P0)
        EN(z)=(N0*(M11(y).^2))./(((M22(z)-
(M11(z).^2))+M02(z).*(Pdel(z)+(N0./Ts))));
    end
    En(:,y)=EN;
    En1(:,y)=EN/N0;
  EndB(y)=10*log10(En1(y));
end

  BER=(1./2)*erfc(sqrt(En./N0));

semilogy(EndB,BER)
axis([-40 -10 10e-12 10e-0])

legend('Po=-10dB','Po=-5dB','Po=-
2dB','Po=0dB','Po=2dB','Po=5dB','Po=7dB','Po=10dB',8)
```

MATLAB Code for BER vs Number of user:

```
clc
clear all
close all
P0=10;
N=1:0.05:16
N0=10^-6;
Rb=10000;
Tb=1/Rb;
L=[32 16 8]

for a=1:length(L)
    Ts(a)=Tb/L(a)
end
Eb=P0*Tb;
SNR=Eb/N0;
M11=P0/N0;
M02=P0/N0^2;
M22=2*P0.^2/N0.^2;
Pdel=0.1*P0;

for j=1:length(L);
    for i = 1:length(N);
    sMUI(i)=sqrt(((N(i)-1)/N(i))* Ts(j)^2*(M22-M11^2));
    end
    SMUI(:,j)=sMUI;
end

for k=1:length(L);
    for l = 1:length(N);
    sICI(l)=sqrt((Pdel.*M02)*Ts(k)^2);
    snoise(l)=sqrt(N(l).*(M02*N0)*Ts(k));
    end
    SICI(:,k)=sICI;
    Snoise(:,k)=snoise;
end

 format long
 for y=1:length(L);
    for z = 1:length(N);
    EN(z)=(N0*(M11^2*Ts(y)^2))/(SICI(z)^2+SMUI(z)^2+Snoise(z)^2);
    end

    En(:,y)=EN;
    En1(:,y)=EN/N0;
end

BER=(1/2)*erfc(sqrt(En1))

semilogy(N,BER)
 axis([0 16 10e-12 10e-0])
 legend('L1=8','L2=16','L3=32',3)
```