TERM PROJECT REPORT

EE 620 – MIMO WIRELESS COMMUNICATIONS

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INDEX

An Overview On 5G Cellular Wireless Communication And The Significance Of Massive MIMO Technology

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ABSTRACT

Since last few years, there has been great development in building 5G cellular wireless communication. There have been various technologies adopted, however one of the most prominent one is MIMO technology. MIMO technology which was earlier introduced during Long Term Evolution (LTE)/4G and for Wireless Local Area Network (WLAN) has taken a step further and has been evolved as a new child technology called Massive MIMO technology, which is widely used in 5G cellular wireless communication . In this report we discuss in detail the key requirements of 5G cellular model, and how massive MIMO technology plays its role in fulfilling these requirements. Also, we would see other prominent technologies which are used in 5G systems.

INTRODUCTION

The mobile access technology is going through a revolutionary change every ten years. From the past few years researches have been made to step up from Long Term Evolution (LTE)/4G cellular to 5G and even Beyond 5G (B5G).Each generation of mobile technology has also provided significant performance enhancements. This transformation, coupled with an expanding cache of bandwidth hungry applications have triggered demands for higher data rates. Mobile data traffic has been forecasted to grow more than 800-fold between 2015 and 2025 [1]. Today there are various emerging applications such as : Big Data Analysis, Artificial Intelligence, Internet of Things , Internet of everything and so on, which requires significant amount of data traffic. Among the various kind of data traffic Video traffic and Internet of Things are more dominant for this near future. Video traffic already constitutes significant fraction of mobile traffic volume, almost 77% in 2019 [1]. Thus we need to look into what are the requirements that a 5G cellular system should fulfil compared to that of previous cellular standards.

1. Engineering Requirements for 5G:

The following items are the key characteristics of 5G network model, however not all of these need to be satisfied simultaneously. Different applications will place different requirements on the performance. For example, very-high-rate applications such as streaming high-definition video may have relaxed latency and reliability requirements compared to driverless cars or public safety applications, where latency and reliability are paramount but lower data rates can be tolerated.

a) *Data Rate:*

- The need to support the mobile data traffic explosion is unquestionably the main driver behind 5G. Aggregate data rate or area capacity is supposed to be roughly more than 1000 times that of 4G in 5G. That is , it should lie between 1 to 20Gbits/sec.

- Also, the edge rate or 5% rate which is the worst data rate that a user can reasonably expect to receive when in range of the network.[3] Goals for the 5G edge rate range from 100 Mbps (easily enough to support high-definition streaming) to as much as 1 Gbps.[3] This requires about a 100× advance since current 4G systems have a typical 5% rate of about 1 Mbps, although the precise number varies quite widely depending on the load, the cell size, and other factors[3].
- Peak rate is the best-case data rate that a user can hope to achieve under any conceivable network configuration. The peak rate is a marketing number, devoid of much meaning to engineers and likely to be in the range of tens of Gbps.

b) *Latency:*
- Current 4G roundtrip latencies are on the order of about 15 ms, and are based on the 1 ms subframe time with necessary overheads for resource allocation and access. Although this latency is sufficient for most current services, however in 5G we have stringent requirements for reliability, latency and availability.
- Some examples are intelligent transport systems, transportation safety, remote medical surgery, smart grids, public protection and disaster relief, wireless control of industrial manufacturing, etc. In such cases one cannot compromise due to latency. As a result, 5G will need to be able to support a roundtrip latency of about 1 ms, an order of magnitude faster than 4G.[3]

c) *Network Synchronization:*
- It is commonly expected that 5G technologies will require wide bandwidth and high spectral efficiency, which are needed to meet the demand of high throughput. Therefore, it is reasonable to believe that future 5G networks will operate at higher frequency bands, including millimeter waves (mm-waves), in which available unlicensed bands may be found.[6]
- However, taking advantage of mm-waves to enable highly densified networks creates other transmission problems.As an example, imagine a scenario in which hundreds or thousands of people are crowded into Times Square, New York City, on the night of 31 December to celebrate New Year's Eve. Everyone has at least one smartphone with high received signal strength, but no one can successfully initiate a phone call, except for an emergency. The main reason is that all preambles congest and interfere with one another, and none arrive at a Base Station clearly.
- Additionally, many surrounding antennas exist in a wireless 5G network, and the cell search process, consisting of several initial synchronization tasks, e.g., beam search, timing synchronization, frequency offset compensation, sector identification, and cell identification, can become extremely complicated. Thus network densification with crowded cells is generally expected to play an important role in satisfying the requirements of wireless 5G networks.[6]

d) *Energy and Cost:*
- As we move to 5G, costs and energy consumption should decrease. However, there is a lot of survey and discussions made on the energy and cost requirement of 5G network systems, as it is said that there won't be a need to build a new

base station for 5G, rather a digital box near every local area would all that would be needed.

- However, researchers are discussing about the fact that though 5G small cells are wireless, one cable remains: the power cable. That cable is very expensive. Long distances in rural areas and concrete in urban areas would increase the cost of connecting it to the electric grid. To achieve maximum benefit, 5G networks need to cut that last cord and be wirelessly powered. Otherwise, the 5G rollout will be too costly and slow. [4]

2. Standardization for 5G Wireless Communication:

The standards for 5G are to be approved by the ITU-R. Working Party (WP) 5D is currently preparing evaluation criteria [4] to be followed by submissions of proposals and evaluation of candidate technologies. This process is expected to be completed by late 2019, leading to the first certified 5G standards.[2]
The standardization of NR started in the 3GPP in April 2016, with the goal of making it commercially available before 2020. The 3GPP is taking a phased approach to defining the 5G specifications. It is mainly broken into two phases.

(i) Phase-1 includes fulfilling the requirements as mentioned above that is data rate, latency and cost to some extent. In fact, IMT 2020 is envisaged to support a diverse variety of usage scenarios/use cases in three broad categories: such as Enhanced mobile broadband (eMBB), Ultra-reliableand low latency communications(URLLC), Massive machine type communications (mMTC). These all are included in phase-1. [7]

(ii) And the second phase includes incorporating more functions to extend the capabilities of 5G to progressively support more services, scenarios and much higher frequency bands (e.g., above 40 GHz). Phase 2 will be completed around the end of 2019 in Release 16.[2]

Some key decisions have been reached in the study from Phase-1 report, such as the focus on data rate and latency use cases. IEEE has recently begun a 5G track to oversee the roadmap of enhancements that will occur for numerous existing and new IEEE technologies such as: 802.11ax and 802.1 lay (WLAN), 802.15 (short range technologies), 802.22 (Fixed Wireless Broadband), P1914.3 (fronthaul solutions to support Cloud RAN), P1918.1 (tactile and haptic Internet). Timelines for completion vary for the individual specification groups.[5]

3. Key Technologies for 5G network model:

The requirements for 5G network are hugely challenging. There are diverse capacity and quality of service requirements to be met and one technology may not fulfil all requirements.[2]
Here I have mentioned a few key technologies which are being used for 5G network model inorder to increase the capacitive gains, however we have explained massive MIMO in detail and other technologies in brief:

(i) Massive MIMO (Multiple Input Multiple Output)
(ii) Non- and quasi-orthogonal multiple access
(iii) Millimeter wave communications

(iv) Device-to-device communications

(v) Machine to Machine(M2M) and Internet of Things Communications

3.1 Massive MIMO:

Lets begin with our main topic of our interest: MIMO technology.

Traditional MIMO has been studied extensively in 3G and 4G systems. It is congenital to believe that the capacity would increase linearly with the scale of antennas array. However, due to the complexity and antennas size issues, the practical number of antennas is no more than 8 even in latest LTE-A standard. It seems a dead end to increase the capacity via increasing the number of antennas. But from the conclusions of [8], if the number of antennas increases largely, i.e., orders of magnitude higher than current configuration, even the simple zero-forcing (ZF) detector would work well, which leads to the so-called massive MIMO.

By using these simple linear signal processing techniques, massive MIMO provides BS with a huge number of antennas. Fig. 1 [9]demonstrates a massive MIMO enabled BS. The grid of antennas is capable of directing horizontal and vertical beams. Time Division Duplexing (TDD) is the preferred choice for massive MIMO systems to avoid the complexity associated with channel estimation and channel sharing in Frequency Division Duplexing (FDD). [9]

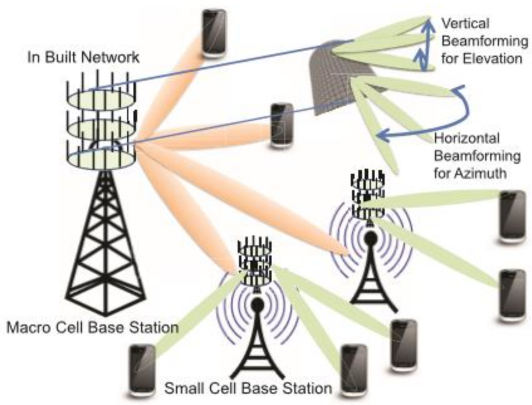

Fig1 *:Massive MIMO and beamforming*

Now let us see how the next generation mobile communication systems would benefit from massive MIMO, as follows:

• *Capacity:* Let n_t and n_r be the number of transmitting antennas and receiving antennas, and γ be the signal-to-noise ratio. The capacity of MIMO can be bounded by

$$\log_2(1 + \gamma n_r) \leq C \leq \min(n_t,n_r) \cdot \log_2(1 + (\gamma \max(n_t,n_r))/ n_t) \ldots\ldots\ldots\ldots\ldots(1)$$

In a cellular system, it is likely that the base stations are equipped with massive MIMO antennas while the user equipments (UEs) only have a limited number of antennas, e.g. less than 8. From (equation :1), the capacity would increase dramatically in both uplink (UL) and downlink (DL) transmission.

• *Latency:* The latency of wireless data transmission is deeply affected by fading, because the retransmission or low rate error control coding would be adopted to resist fading. By employing massive MIMO, the receiving signal would benefit from a large number of space diversity and MIMO signal processing, such as beamforming and precoding, which could compensate the fading.

• *Cost and power:* Although the number of antennas of massive MIMO is up to the hundreds, the radiated energy efficiency is improved by the hundreds as well [8]. By sharping the signal in a very small region, massive MIMO can obtain a higher gain with a much lower emitting power per antenna. Actually, the total power of massive MIMO is even much less than traditional MIMO, which means that the low-cost and low-power amplifiers with milli-Watt emitted power would replace the traditional much more expensive ultra-linear amplifiers with tens of Watt power.

3.2 Non- and quasi-orthogonal multiple access:

The need to improve the spectral efficiency has been regarded as the most important but yet challenging task in the design of future wireless communication systems, due to the fact that the rapid growth of multimedia services, such as interactive game and television applications, cannot be coped with the scarce radio frequency (RF) spectrum resources. Non-orthogonal multiple access (NOMA) [2] and sparse code multiple access (SCMA) [2] are used by allowing more users to share the same radio resources at the same time, thus improving system capacity, however by one would require more complex receivers.

NOMA:

- Non-orthogonality is deliberately introduced in the transmitter by superimposing the signals in the power domain, thus allowing reuse of same radio resources by more users, and thus improving the network capacity.

SCMA:

- SCMA is a multi-dimensional codebook-based non-orthogonal multiple access technique. The key component is SCMA encoder which joins modulation and spreading. It maps user’s data bits to a K-dimensional complex sparse codeword selected from the given codebook, where K is the length of an SCMA codeword. In other words, user’s data bits are spread on K resources after SCMA encoder.
- SCMA has several advantages as follows: (1) Overloading increases overall throughput and connectivity; (2) Sparsity helps to reduce the complexity of detection; (3) Multi-dimensional codewords bring shaping gain and better spectral efficiency; (4) Spreading with factor K helps to achieve robust link adaptation.

3.3 Millimeter wave communications

- One of the efficient ways to satisfy rapid increase of data rates, especially those up to tens of Gbps in 5G systems, is bandwidth expansion.
- Most of the cellular networks work below 3 GHz which has been fully occupied already. Bandwidth shortage has motivated the exploration of the rich millimeter wave (mmWave) frequency spectrum which ranges from 3 to 300 GHz.

- There are potential dozens of GHz available frequency resources at 28, 38, 45, and 60 GHz. It is expected that the gains of network capacity up to 10 times can be obtained from mmWave frequency spectrum [2], which is quite attractive for 5G systems.
- Since the radio waves of different frequency bands have different propagation characteristics, the channel models of traditional cellular wireless communication cannot be directly applied to mmWave communications. The first task of mmWave communications is to understand the propagation characteristics. Several measurements campaigns have been conducted.
- However, the characteristics of higher frequencies are yet not much clear, and according to my study I believe ,channel modelling for different scenarios and environments will be required before transmission technologies can be designed for mmWave.

3.4 Device-to-device communications(D2D)

- D2D communications in cellular networks are a highly efficient way to enhance system capacity and improve spectrum efficiency because it can directly communicate with each other by sharing network frequency resources.
- Besides, D2D user equipments (DUEs) can act as transmission relay for each other to set up multi-hop communication links. Therefore, it also helps to improve and extend network coverage by DUE relaying.
- The gain of D2D communications depends on the number of available DUE pairs in various application scenarios.
- In the release 14, 3GPP is already expanding the D2D communications to vehicle-to-everything(V2X)applications, adding enhancements for high speed,high user density,improved synchronization, and low latency. [1]

3.5 Machine to Machine (M2M) and Internet of Things Communications:

- One of the major problem which has to be faced by 5G systems is the massive machine type communications. Which would increase the network intensity as well. As very large number of sensors and actuators will be connected to the Internet.
- However,they will send low amount of information during short periods of time using low data rates and reduced bandwidth channel.(Note: These machines are embedded , and not a full fledged computers)
- The transceivers must be as simple as possible, so that they are low-cost and low-power consuming, capable of operating with the same battery for several years.
- In last few years several M2M standards have been formed.
- In 3GPP,three cellular M2M/IoT standards were defined for use in the licensed spectrum bands: Machine Type Communication(MTC),Narrowband – IoT(NB-IoT), and Enhanced Coverage GSM – IoT (EC-GSM-IoT).
- To achieve reduced power consumption,all the 3GPP M2M technologies include a Power Saving Mode(PSM), which enables the terminals to enter deep sleep mode when they do not need to transmit or receive

There are various other technologies as well which are used in 5G.However as said earlier, every key technology brings its own pros-and-cons, using the best technology depends upon what the consumer need is.

CONCLUSION:

In this report, a number of potential techniques for the 5G systems have been enumerated and explained. Although these techniques may be only a small portion of what is used in 5G systems, however explaining them I have tried to shed light on promising technology developing trends. There has already been great breakthroughs in wireless communication technology, the goal of IMT-2020 is soon going to be achieved . We also saw how the MIMO technology used in 4G LTE systems has been redefined and used progressively in 5G system as Massive MIMO technology with extremely great results. Soon by the beginning of 2020, many people around the globe will have 5G cellular devices, this indeed would be a great revolution not just for cellular devices but also for all the embedded devices (IoT devices) connected to the network which is going to increase in large numbers by the end of five years.

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2. MATLAB SIMULATIONS:

```
%We assume that the MIMO system uses bandwidth of 30 KHz
at the 800MHz frequency band,
%and a mobile user with moving velocity of 50 miles/hour.
We also assume the slow fading
%channel experiences Rayleigh fading.
%(i) Use Jakes' fading simulator (with M = 8 oscillators
or N = 34) to generate four independent fading channels
(to be used in simulations). Generate 105
%channel samples for each
%channel (note: normalize channel coefficients such that
the average power of each channel
%coefficient is 1). In one figure, plot the first 500
channel samples for the four channels
%(showing the channel amplitude, |h(t)|, in dB).
clc;
clear all;
close all;
M=8;
N=34;
BW=30000;
Ts=1/BW;

Fmax=59.6052;
sum_a=zeros(1,8);
sum_b=zeros(1,8);
chann1=zeros(1,100000);
chann2=zeros(1,100000);
chann3=zeros(1,100000);
chann4=zeros(1,100000);

channel1=zeros(1,100000);
channel2=zeros(1,100000);
channel3=zeros(1,100000);
channel4=zeros(1,100000);

normalized_11 = 0;
normalized_12 = 0;
normalized_13 = 0;
normalized_14 = 0;


normalized_1 = 0;
normalized_21 = 0;
normalized_22 = 0;
normalized_23 = 0;
normalized_24 = 0;
```

```
H = hadamard(M);

for k=1:100000
    sum_a=zeros(1,8);

    for l=1:M
        for n=1:M
            B(n)=(pi*n)/(M+1);
            tht(n)=(2*pi*n)/N;
            A(l,n)=H(l,n);
            gamma(n,l)=(2*pi*(l+1)*n)/(M+1);
            temp1=
A(l,n)*exp(1i*B(n))*(cos((2*pi*k*Ts*Fmax*cos(tht(n))+gamm
a(n,l))));
            sum_a(l)=temp1+sum_a(l);
        end


    end
     chann1(k)=sum_a(1)+chann1(k);
     chann2(k)=sum_a(2)+chann2(k);
     chann3(k)=sum_a(3)+chann3(k);
     chann4(k)=sum_a(4)+chann4(k);
end
for k=1:100000
    sum_b=zeros(1,8);
    for l=1:M-4
        for n=1:M
            B(n)=(pi*n)/(M+1);
            tht(n)=(2*pi*n)/N;
            A(l,n)=H(l,n);
            gamma(n,l)=(2*pi*(l+1)*n)/(M+1);
            temp2=
A(l,n)*exp(1i*B(n))*(cos((2*pi*k*Ts*Fmax*cos(tht(n))+gamm
a(n,l))));
            sum_b(l)=temp2+sum_b(l);
        end

    end
    channel1(k)=sum_b(1);
     channel2(k)=sum_b(2);
     channel3(k)=sum_b(3);
     channel4(k)=sum_b(4);
end
% To calculate the normalized channel coefficient for
k=100000
% For channel 1 (100000)
```

```
for i=1:100000
    temp3=abs(chann1(i))^2;
    normalized_11=temp3+normalized_11;
end
normalized_11=normalized_11/100000;
chann1=chann1./sqrt(normalized_11);

% In db
for q=1:100000
    Z11(q)=10*(log(abs(chann1(q)))/log(10));
end

%For channel 2 (100000)

for i=1:100000
    temp3=abs(chann2(i))^2;
    normalized_12=temp3+normalized_12;
end
normalized_12=normalized_12/100000;
chann2=chann2./sqrt(normalized_12);

% In db
for q=1:100000
    Z12(q)=10*(log(abs(chann2(q)))/log(10));
end

%For channel3 (100000)
for i=1:100000
    temp3=abs(chann3(i))^2;
    normalized_13=temp3+normalized_13;
end
normalized_13=normalized_13/100000;
chann3=chann3./sqrt(normalized_13);

% In db
for q=1:100000
    Z13(q)=10*(log(abs(chann3(q)))/log(10));
end
%for channel 4 (100000)

for i=1:100000
    temp3=abs(chann4(i))^2;
    normalized_14=temp3+normalized_14;
end
normalized_14=normalized_14/100000;
chann4=chann4./sqrt(normalized_14);

% In db
```

```
for q=1:100000
    Z14(q)=10*(log(abs(chann4(q)))/log(10));
end


% To calculate the normalized channel coefficient for
k=500
% Channel 1

temp5=sum(abs(channel1).^2)/500;

normalized_21=temp5/500;
channel1=channel1./sqrt(temp5);
for q=1:500
    Z1(q)=10*(log(abs(channel1(q)))/log(10));
end
%Channel 2

normalized_22=sum(abs(channel2).^2)/500;
channel2=channel2./sqrt(normalized_22);
for q=1:500
    Z2(q)=10*(log(abs(channel2(q)))/log(10));
end

%Channel 3
normalized_23=sum(abs(channel3).^2)/500;
channel3=channel3./sqrt(normalized_23);
for q=1:500
    Z3(q)=10*(log(abs(channel3(q)))/log(10));
end

%Channel 4
normalized_24=sum(abs(channel4).^2)/500;
channel4=channel4./sqrt(normalized_24);
for q=1:500
    Z4(q)=10*(log(abs(channel4(q)))/log(10));
end



figure;

x=1:500;
plot(x,Z1);
hold on;

title('Amplitude of first 500 samples');
xlabel('sample points');
```

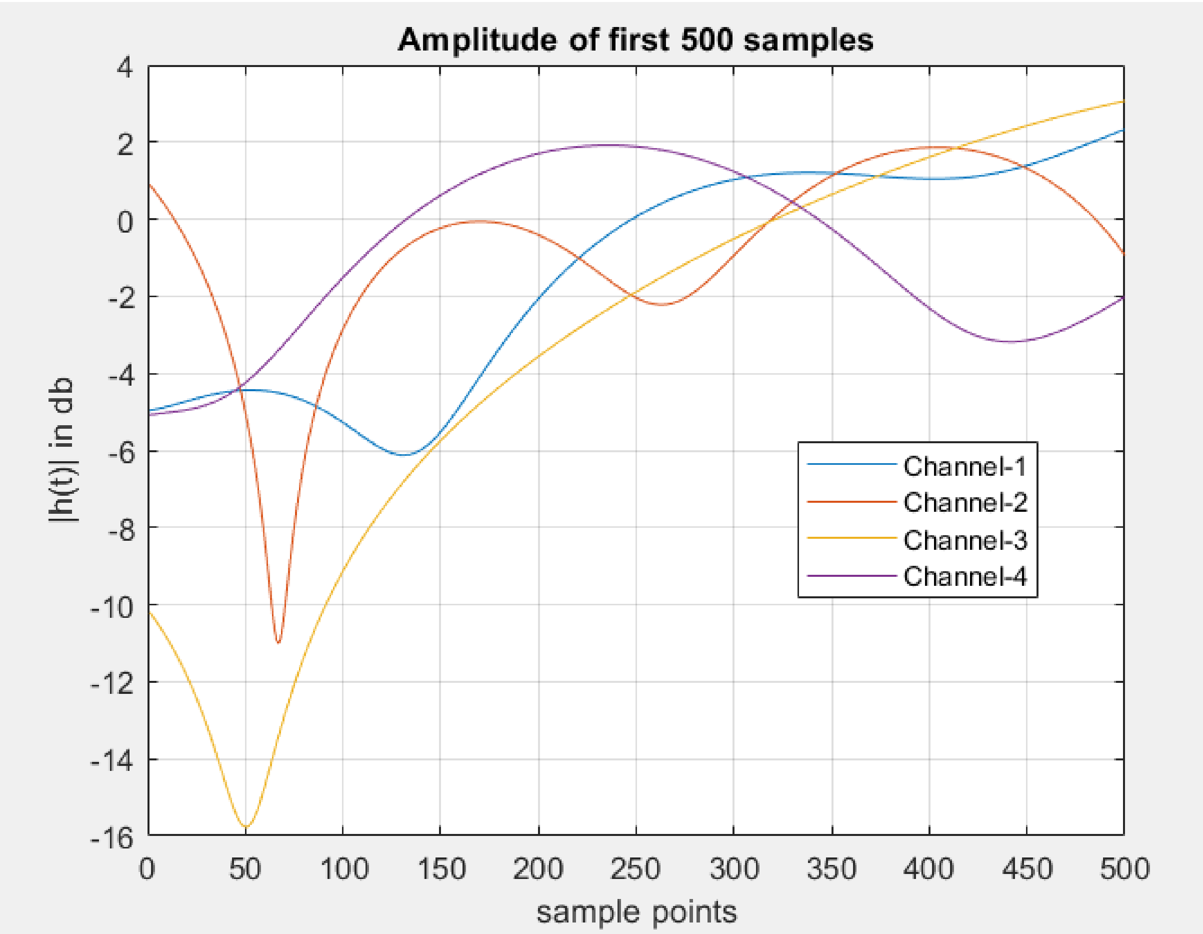
```
ylabel('|h(t)| in db');

q=1:500;
plot(q,Z2);
hold on;

r=1:500;
plot(r,Z3);
hold on;


b=1:500;
plot(b,Z4);

legend('Channel-1','Channel-2','Channel-3','Channel-4');
grid on;



% (ii) When Mr = 1, use two fading channels generated in
(i) to simulate
%the di?erential MIMO system. Plot the symbol error rate
curve vs SNR.
%(iii) When Mr = 2, use four fading channels generated in
%(i) to simulate the di?erential MIMO system. Plot the
symbol error rate curve vs
%SNR in the same ?gure in (ii). Compare the two curves
and explain your observation.


% When Mr=1 and Mt =2 , to simulate MIMO system and to
plot symbol error
% rate vs SNR
Mt = 2;
Mr =1;
SNR_dB = 1:20;
SNR = 10.^(SNR_dB./10);
L=1000;
F=zeros();
C_l=zeros();
C_bar=zeros();
PER=0;
Y1=zeros();
max=0;

for m=1:length(SNR_dB)
    H_chan = [chann1(1);chann2(1)];
    N= sqrt(0.5)*randn(Mt,Mr)+1j*sqrt(0.5)*randn(Mt,Mr);
```

```
    S0=(sqrt(0.5))*eye(Mt);
    for l=0:3

C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        val=det(C);
        if val>max
            max=val;
            C_l=C;
        end
    end
    S1=(sqrt(0.5))*C_l*S0;
    Y1=(sqrt(SNR(m)/Mt)*(S1*H_chan))+N;
    for t=2:L
       for l=0:3

C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        val=det(C);
        if val>max
            max=val;
            C_l=C;
        end
       end
    N_t=
sqrt(0.5)*randn(Mt,Mr)+1j*sqrt(0.5)*randn(Mt,Mr);
    N=N_t-((sqrt(0.5)).*C_l.*N);
    Y_prev=Y1;
    Y1=((sqrt(0.5)).*C_l.*Y_prev)+N;

    for l=0:3

C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        C_bar(l+1)=norm(Y1-
(sqrt(0.5).*C.*Y_prev),'fro')^2;
    end
    C_bar_t=min(C_bar(:));
    if C_bar_t~=C_l
        PER=PER+1;
    end
    end
end
total_PER=PER/(L);
figure;
semilogy(SNR_dB,total_PER);
grid on;
```

```
hold on;

% When Mr=2
Mr=2;
L=1000;
F=zeros();
C_l=zeros();
C_bar=zeros();
PER_n=0;
Y1=zeros();
max=0;
total_PER_n=zeros();
for m=1:length(SNR_dB)
    H_chan = [chann1(1),chann2(1);chann3(1),chann4(1)];
    N= sqrt(0.5)*randn(Mt,Mr)+1j*sqrt(0.5)*randn(Mt,Mr);
    S0=(sqrt(0.5))*eye(Mt);
    for l=0:3

C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        val=det(C);
        if val>max
            max=val;
            C_l=C;
        end
    end
    S1=(sqrt(0.5))*C_l*S0;
    Y1=(sqrt(SNR(m)/Mt)*(S1*H_chan))+N;
    for t=2:L
       for l=0:3

C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        val=det(C);
        if val>max
            max=val;
            C_l=C;
        end
       end
    N_t=
sqrt(0.5)*randn(Mt,Mr)+1j*sqrt(0.5)*randn(Mt,Mr);
    N=N_t-((sqrt(0.5)).*C_l.*N);
    Y_prev=Y1;
    Y1=((sqrt(0.5)).*C_l.*Y_prev)+N;

    for l=0:3
```

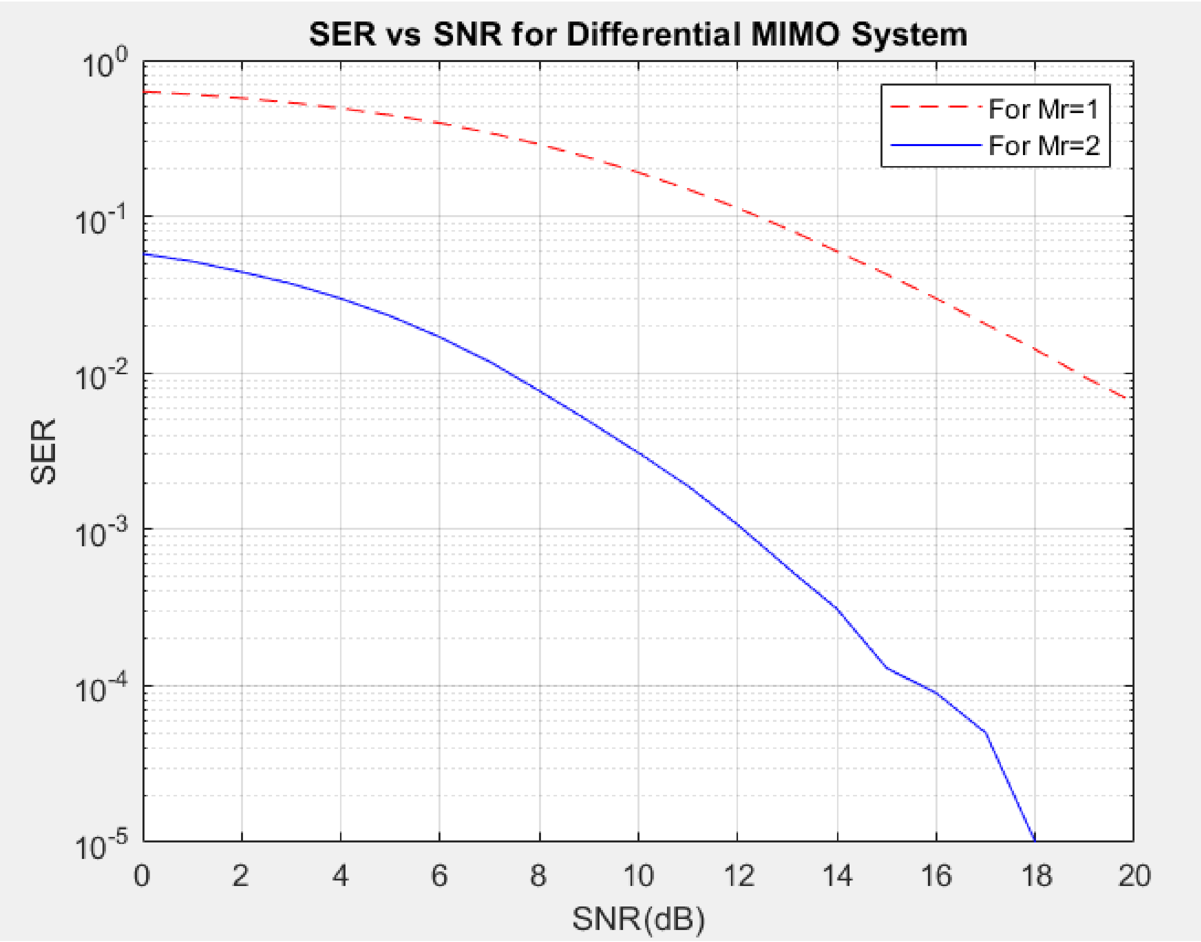
```
C=[(sqrt(2))*exp(1j*(l*pi)*(0.5)),0;0,(sqrt(2))*exp(1j*(l
*pi)*(0.5))];
        C_bar(l+1)=norm(Y1-
(sqrt(0.5).*C.*Y_prev),'fro')^2;
    end
    C_bar_t=min(C_bar(:));
    if C_bar_t~=C_l
        PER_n=PER_n+1;
    end
    end

end
total_PER_n=PER_n/(L);
semilogy(SNR_dB,total_PER_n);
xlabel('SNR(dB)');
ylabel('SER');
legend('For Mr=1 ','For Mr=2');
title('SER vs SNR for Differential MIMO System');
grid on;
```

OUTPUT-1:



This is the output plot for the first 500 channel samples for the four independent channels generated from the Jake's fading simulator

OUTPUT-2:



On the basis of the graph we can observe that MIMO system with two receiving antennas is better than MIMO system with one receiving antenna. To be noted that both of them have same number of transmitting antennas. We can conclude that higher the Mr , higher would be the diversity order.