MATLAB Code

```
clear;
clf;
%pathloss calculation
% pathloss when fc = 2.4
fc = 2.4; % in GHz
distance = [100: 200: 7000];
htx = 2;
hrx = 2;
PL_dB = 40*log10(distance) +  20*log10(fc) -
20*log10(htx*hrx);
PL = 10.^(PL_dB/10);
plot(distance, PL_dB , 'b-o');
axis([100 6000 70 160])
set(gca,'fontsize',12,'fontweight','b');
grid on;
title('Green-Obaidat Path-loss
Model','fontsize',12,'fontweight','b');
xlabel('Distance[m]','fontsize',12,'fontweight','b');
ylabel('Path loss[dB]','fontsize',12,'fontweight','b');
%pathloss when fc = 5 GHz
fc = 5 ;
PL_dB1 = 40*log10(distance) +  20*log10(fc) -
20*log10(htx*hrx);
PL1 = 10.^(PL_dB1/10);
hold on
plot(distance, PL_dB1 , 'm-o');
legend('fc = 2.4 GHz','fc = 5 GHz' )
%SNR calculation
%SNR when Fc = 2.4
GT1 =12.3;  %linear 10.9dBi f=2.4Ghz
GR1 =12.3;  %linear 10.9dBi f=2.4Ghz
GT2 =22.3;  %linear 13.5dBi f=5Ghz
GR2 =22.3;  %linear 13.5dBi f=5Ghz
pt=0.1;     %watt
f=2.5;      %noise figure 4dB
b=20e6 ;    %Bandwidth
n=4e-21;    %noise spectral density
SNR1 = (pt*Gt1*Gr1)./(PL*f*b*n); % fc= 2.4 BW = 20
SNR_dB1 = 10*log10(SNR1);
figure
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plot(distance, SNR_dB1 , 'b-o');
axis([500 6000 -20 40])
grid on;
title('SNR vs distance, Fc = 2.4
GHz','fontsize',12,'fontweight','b');
xlabel('Distance[m]','fontsize',12,'fontweight','b');
ylabel('SNR[dB]','fontsize',12,'fontweight','b');
set(gca,'fontsize',12,'fontweight','b');
b=40e6 ;    %Bandwidth
SNR2 = (pt*Gt1*Gr1)./(PL*f*b*n); % fc= 2.4 BW = 40
SNR_dB2 = 10*log10(SNR2);
hold on
plot(distance, SNR_dB2 , 'm-o');
legend('BW = 20 MHz','BW = 40 MHz' )
% SNR when fc = 5 GHz
b=20e6 ;    %Bandwidth
SNR3 = (pt*Gt2*Gr2)./(PL1*f*b*n); % fc= 5 BW =20
SNR_dB3 = 10*log10(SNR3);
figure
plot(distance, SNR_dB3 , 'b-o');
axis([500 6000 -20 40])
grid on;
title('SNR vs distance, Fc = 5
GHz','fontsize',12,'fontweight','b');
xlabel('Distance[m]','fontsize',12,'fontweight','b');
ylabel('SNR[dB]','fontsize',12,'fontweight','b');
set(gca,'fontsize',12,'fontweight','b');
b=40e6 ;    %Bandwidth
SNR4 = (pt*Gt2*Gr2)./(PL1*f*b*n); % fc = 5 BW =40
SNR_dB4 = 10*log10(SNR4);
hold on
plot(distance, SNR_dB4 , 'm-o');
grid on;
legend('BW = 20 MHz','BW = 40 MHz' )
% capacity calculation
% case1 using SNR1 fc= 2.4 BW = 20
N_iter=1000;
for Icase=1:6
if Icase==1,  nT=4; nR=4;       % 4x4
elseif Icase=2, nT=3;  nR=3; % 3x3
elseif Icase=3, nT=2;  nR=2; % 2x2
elseif Icase=4, nT=1;  nR=1; % 1x1
elseif Icase=5, nT=1;  nR=2; % 1x2
else   nT=2;  nR=1;           % 2x1
end
   n=min(nT,nR);  I = eye(n);
   C(Icase,:) = zeros(1,length(SNR_dB1));
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for iter=1:N_iter
      H = sqrt(0.5)*(randn(nR,nT)+j*randn(nR,nT));
if nR>=nT,  HH = H'*H;  else  HH = H*H';  end
for i=1:length(SNR_dB1) %random channel generation
         C(Icase,i) =
C(Icase,i)+log2(real(det(I+SNR1(i)/nT*HH)));
end
C = C/N_iter ;
dr = C * 20 ; % Mbps
figure
plot(distance,C(1,:),'b--', distance,C(2,:),'r--',
distance,C(3,:),'m--',distance,C(4,:),'k-');
hold on
xlabel('distance [m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case1(fc=2.4 BW=20)
','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=4,{\it N_R}=4';
S2='{\it N_T}=3,{\it N_R}=3';
S3='{\it N_T}=2,{\it N_R}=2';
S4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
figure
plot(distance,C(4,:),'k-', distance,C(3,:),'m--');
hold on
plot(distance,C(5,:),'b--',distance,C(6,:),'r--');
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case1 (fc=2.4
BW=20)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=1,{\it N_R}=1';
S2='{\it N_T}=2,{\it N_R}=2';
S3='{\it N_T}=1,{\it N_R}=2';
S4='{\it N_T}=2,{\it N_R}=1';
legend(s1,s2,s3,s4)
%data rate
figure
plot(distance,dr(1,:),'b--', distance,dr(2,:),'r--',
distance,dr(3,:),'m--',distance,dr(4,:),'k-');
hold on
xlabel('distance[m]','fontsize',12,'fontweight','b');
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ylabel('data ratre [Mbps]','fontsize',12,'fontweight','b');
title('data rate vs distance,  case 1(fc=2.4
BW=20)','fontsize',12,'fontweight','b')
axis([3000 6000 0 50])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=4,{\it N_R}=4';
S2='{\it N_T}=3,{\it N_R}=3';
S3='{\it N_T}=2,{\it N_R}=2';
S4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
% case 2using SNR2 fc= 2.4 BW = 40
N_iter=1000;
for Icase=1:6
if Icase==1,  nT=4; nR=4;       % 4x4
elseif Icase=2, nT=3;  nR=3; % 3x3
elseif Icase=3, nT=2;  nR=2; % 2x2
elseif Icase=4, nT=1;  nR=1; % 1x1
elseif Icase=5, nT=1;  nR=2; % 1x2
else   nT=2;  nR=1;           % 2x1
end
   n=min(nT,nR);  I = eye(n);
   C(Icase,:) = zeros(1,length(SNR_dB2));
for iter=1:N_iter
      H = sqrt(0.5)*(randn(nR,nT)+j*randn(nR,nT));
if nR>=nT,  HH = H'*H;  else  HH = H*H';  end
for i=1:length(SNR_dB2) %random channel generation
         C(Icase,i) =
C(Icase,i)+log2(real(det(I+SNR2(i)/nT*HH)));
end
C = C/N_iter ;
dr = C * 40 ; % Mbps
figure
plot(distance,C(1,:),'b--', distance,C(2,:),'r--',
distance,C(3,:),'m--',distance,C(4,:),'k-');
hold on
xlabel('distance [m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case2(fc=2.4
BW=40)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=4,{\it N_R}=4';
S2='{\it N_T}=3,{\it N_R}=3';
S3='{\it N_T}=2,{\it N_R}=2';
S4='{\it N_T}=1,{\it N_R}=1';
```

```
legend(s1,s2,s3,s4)
figure
plot(distance,C(4,:),'k-', distance,C(3,:),'m--');
hold on
plot(distance,C(5,:),'b--',distance,C(6,:),'r--');
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case2 (fc=2.4
BW=40)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=1,{\it N_R}=1';
S2='{\it N_T}=2,{\it N_R}=2';
S3='{\it N_T}=1,{\it N_R}=2';
S4='{\it N_T}=2,{\it N_R}=1';
legend(s1,s2,s3,s4)
%data rate
figure
plot(distance,dr(1,:),'b--', distance,dr(2,:),'r--',
distance,dr(3,:),'m--',distance,dr(4,:),'k-');
hold on
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('data ratre [Mbps]','fontsize',12,'fontweight','b');
title('data rate vs distance, case 2(fc=2.4
BW=40)','fontsize',12,'fontweight','b')
axis([3000 6000 0 50])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=4,{\it N_R}=4';
S2='{\it N_T}=3,{\it N_R}=3';
S3='{\it N_T}=2,{\it N_R}=2';
S4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
% case3 using SNR3 fc= 5 BW =20
N_iter=1000;
for Icase=1:6
if Icase==1,  nT=4; nR=4;       % 4x4
elseif Icase=2, nT=3;  nR=3; % 3x3
elseif Icase=3, nT=2;  nR=2; % 2x2
elseif Icase=4, nT=1;  nR=1; % 1x1
elseif Icase=5, nT=1;  nR=2; % 1x2
else   nT=2;  nR=1;           % 2x1
end
   n=min(nT,nR);  I = eye(n);
   C(Icase,:) = zeros(1,length(SNR_dB3));
for iter=1:N_iter
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      H = sqrt(0.5)*(randn(nR,nT)+j*randn(nR,nT));
if nR>=nT,  HH = H'*H;  else  HH = H*H';  end
for i=1:length(SNR_dB3) %random channel generation
         C(Icase,i) =
C(Icase,i)+log2(real(det(I+SNR3(i)/nT*HH)));
end
C = C/N_iter ;
dr = C * 20 ; % Mbps
figure
plot(distance,C(1,:),'b--', distance,C(2,:),'r--',
distance,C(3,:),'m--',distance,C(4,:),'k-');
hold on
xlabel('distance [m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case3 (fc=5
BW=20)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=4,{\it N_R}=4';
S2='{\it N_T}=3,{\it N_R}=3';
S3='{\it N_T}=2,{\it N_R}=2';
S4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
figure
plot(distance,C(4,:),'k-', distance,C(3,:),'m--');
hold on
plot(distance,C(5,:),'b--',distance,C(6,:),'r--');
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case3 (fc=5
BW=20)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
S1='{\it N_T}=1,{\it N_R}=1';
S2='{\it N_T}=2,{\it N_R}=2';
S3='{\it N_T}=1,{\it N_R}=2';
S4='{\it N_T}=2,{\it N_R}=1';
legend(s1,s2,s3,s4)
%data rate
figure
plot(distance,dr(1,:),'b--', distance,dr(2,:),'r--',
distance,dr(3,:),'m--',distance,dr(4,:),'k-');
hold on
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('data ratre [Mbps]','fontsize',12,'fontweight','b');
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title('data rate vs distance case 3(fc=5
BW=20)','fontsize',12,'fontweight','b')
axis([3000 6000 0 50])
set(gca,'fontsize',12,'fontweight','b');
grid on
s1='{\it N_T}=4,{\it N_R}=4';
s2='{\it N_T}=3,{\it N_R}=3';
s3='{\it N_T}=2,{\it N_R}=2';
s4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
% case4 using SNR4 fc=5 BW=40
N_iter=1000;
for Icase=1:6
if Icase==1,  nT=4; nR=4;       % 4x4
elseif Icase==2, nT=3;  nR=3; % 3x3
elseif Icase==3, nT=2;  nR=2; % 2x2
elseif Icase==4, nT=1;  nR=1; % 1x1
elseif Icase==5, nT=1;  nR=2; % 1x2
else   nT=2;  nR=1;           % 2x1
end
   n=min(nT,nR);  I = eye(n);
   C(Icase,:) = zeros(1,length(SNR_dB4));
for iter=1:N_iter
      H = sqrt(0.5)*(randn(nR,nT)+j*randn(nR,nT));
if nR>=nT,  HH = H'*H;  else  HH = H*H';  end
for i=1:length(SNR_dB4) %random channel generation
         C(Icase,i) =
C(Icase,i)+log2(real(det(I+SNR4(i)/nT*HH)));
end
C = C/N_iter ;
dr = C * 40 ; % Mbps
figure
plot(distance,C(1,:),'b--', distance,C(2,:),'r--',
distance,C(3,:),'m--',distance,C(4,:),'k-');
hold on
xlabel('distance [m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case4(fc=5
BW=40)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
s1='{\it N_T}=4,{\it N_R}=4';
s2='{\it N_T}=3,{\it N_R}=3';
s3='{\it N_T}=2,{\it N_R}=2';
s4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
```

```
figure
plot(distance,C(4,:),'k-', distance,C(3,:),'m--');
hold on
plot(distance,C(5,:),'b--',distance,C(6,:),'r--');
xlabel('distance[m]','fontsize',12,'fontweight','b');
ylabel('capacity [bps/Hz]','fontsize',12,'fontweight','b');
title('capacity vs distance, case4 (fc=5
BW=40)','fontsize',12,'fontweight','b')
axis([1000 6000 0 5])
set(gca,'fontsize',12,'fontweight','b');
grid on
s1='{\it N_T}=1,{\it N_R}=1';
s2='{\it N_T}=2,{\it N_R}=2';
s3='{\it N_T}=1,{\it N_R}=2';
s4='{\it N_T}=2,{\it N_R}=1';
legend(s1,s2,s3,s4)
%data rate
figure
plot(distance,dr(1,:),'b--', distance,dr(2,:),'r--',
distance,dr(3,:),'m--',distance,dr(4,:),'k-');
hold on
xlabel('distance[m]','fontsize',12,'fontweight','b')
ylabel('data ratre [Mbps]','fontsize',12,'fontweight','b')
title('data rate vs distance, case 4(fc=5
BW=40)','fontsize',12,'fontweight','b')
axis([3000 6000 0 50])
set(gca,'fontsize',12,'fontweight','b');
grid on
s1='{\it N_T}=4,{\it N_R}=4';
s2='{\it N_T}=3,{\it N_R}=3';
s3='{\it N_T}=2,{\it N_R}=2';
s4='{\it N_T}=1,{\it N_R}=1';
legend(s1,s2,s3,s4)
```