EENGM30010: Mobile Communication Systems 2021

Mobile Communication System Course Work

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1. Mobile Communications Systems – Part 1

Coursework 1 Instructions
For this coursework you need to write a technical note with detailed answers to the three questions. Additionally, for the question Q1.3 you need to submit a MATLAB script that was used to plot your results. The marking schemes and the deadlines are at the end of this instruction sheet

1.1 Question 1.1(10 Marks)

Q1.1: Compute the capacity for the Binary Double Erasure Channel given in Figure 1.1. Provide all main steps in the answer

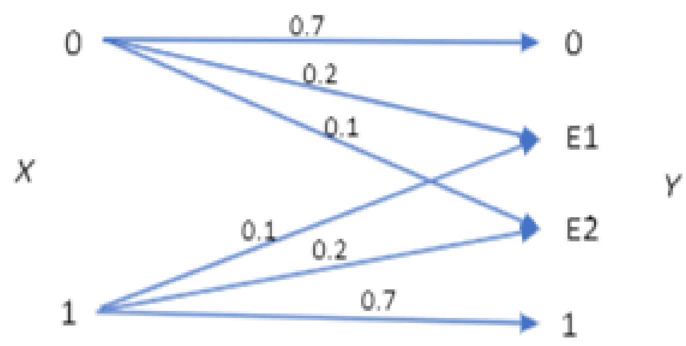


Figure 1.1: Binary Double Erasure Channel.

Answer:
As the given graph, we know the transition matrix:

$$P(y|x) = \begin{bmatrix} P(y=0|x=0) & P(y=e_1|x=0) & P(y=e_2|x=0) & P(y=1|x=0) \\ P(Y=0|X=1) & P(y=e_1|x=1) & P(y=e_2|x=1) & P(y=1|x=1) \end{bmatrix} \quad (1)$$

Assign the given values

$$P(y|x) = \begin{bmatrix} 0.7 & 0.2 & 0.1 & 0 \\ 0 & 0.1 & 0.2 & 0.7 \end{bmatrix} \quad (2)$$

Assume P(x=0)=p then P(x=1)=1-p

$$P(x,y) = [p \quad 1-p][P(y|x)] \quad (3)$$

$$P(x,y) = \begin{bmatrix} 0.7p & 0.2p & 0.1p & 0 \\ 0 & 0.1(1-p) & 0.2(1-p) & 0.7(1-p) \end{bmatrix} \tag{4}$$

By $P(x,y)$:
$P(Y=0) = 0.7p \qquad P(Y=e_1) = 0.1(1+p)$
$P(Y=e_2) = 0.2 - 0.1p \qquad P(Y=1) = 0.7(1-p)$

$$\begin{aligned} H(Y) &= \sum_{i}^{n} p(y_i) log_2 \frac{1}{P(y_i)} \\ H(Y|X) &= \sum_{x,y} p(x,y) log_2 \frac{1}{p(y|x)} \end{aligned} \tag{5}$$

$$\begin{aligned} H(Y) &= 0.7p * log_2 \frac{1}{0.7p} + 0.1(1+p) * log_2 \frac{1}{0.1(1+p)} \\ &+ (0.2-0.1p) * log_2 \frac{1}{0.2-0.1p} + 0.7(1-p) * log_2 \frac{1}{0.7(1-p)} \\ \\ H(Y|X) &= 0.7p * log_2 \frac{1}{0.7} + 0.2p * log_2 \frac{1}{0.2} \\ &+ 0.1p * log_2 \frac{1}{0.1} + 0.1(1-p) * log_2 \frac{1}{0.1} \\ &+ 0.2(1-p) * log_2 \frac{1}{0.2} + 0.7(1-p) * log_2 \frac{1}{0.7} \end{aligned} \tag{6}$$

The Capacity of channel will be:

$$C = max_{p(x)} I(X;Y) = max_p [H(Y) - H(Y|X)] \tag{7}$$

When p=0.5, the value I(X;Y) takes max,then:

$$\begin{aligned} X(Y) &= 1.881 \qquad (p=0.5) \\ H(Y|X) &= 1.157 \qquad (p=0.5) \end{aligned} \tag{8}$$

The channel capacity is

$$\begin{aligned} C &= H(Y) - H(Y|X) \\ &= 0.724 \end{aligned} \tag{9}$$

1.2 Question 1.2(20 Marks)

Q1.2: A DMC (non-symmetric) channel is shown in Figure 1.2. **Compute the capacity for this channel** for the error probabilities $p(x|y)$ given in the Figure 1.2

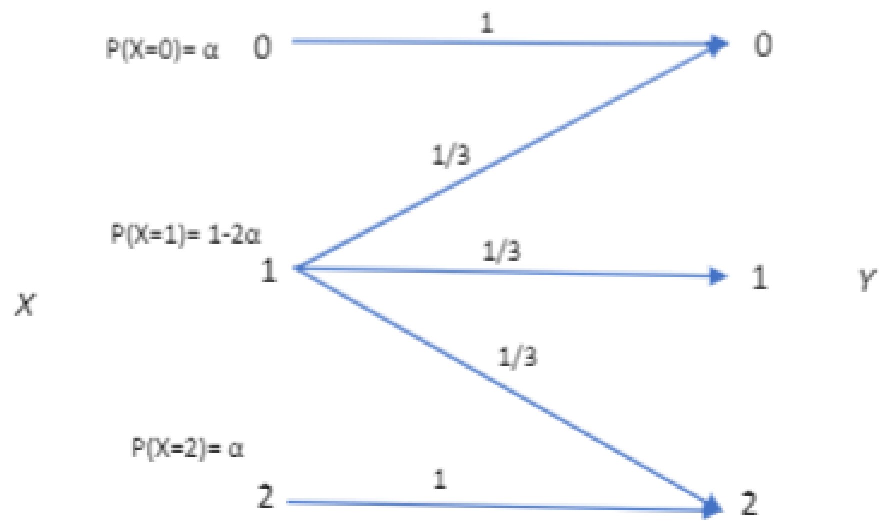


Figure 1.2: Binary Non-Symmetric Channel.

Tip: The mutual information needs to be maximised explicitly with respect to input $pmf P(X)$. For this purpose, parametrise the input pmf using a single parameter as follows: $P(X = 0) = P(X = 2) = \alpha, P(X = 1) = 1 - 2\alpha$.Provide all main derivation steps in the answer.

Answer:

To present the given graph to a transition matrix(3×3):

$$P(Y|X) = \begin{bmatrix} P(Y=0|X=0) & P(Y=1|X=0) & P(Y=2|X=0) \\ P(Y=0|X=1) & P(Y=1|X=1) & P(Y=2|X=1) \\ P(Y=0|X=2) & P(Y=1||X=2) & P(Y=2|X=2) \end{bmatrix} \tag{10}$$

Assign the value:

$$P(Y|X) = \begin{bmatrix} 1 & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ 0 & 0 & 1 \end{bmatrix} \tag{11}$$

According to problem description,the probability distribution of X will be:

$$
\begin{aligned}
&P(X=0)=\alpha \\
&P(X=1)=1-2\alpha \\
&P(X=2)=\alpha
\end{aligned}
\tag{12}
$$

We can calculate the H(X):

$$
H(X)=\sum_{i}^{n} p(x_i) log_2 \frac{1}{P(x_i)} \tag{13}
$$

$$
\begin{aligned}
H(X) &= -\alpha * log_2\alpha-(1-2\alpha)log_2(1-2\alpha)-\alpha log_2\alpha \\
&= -2\alpha log_2\alpha-(1-2\alpha)log_2(1-2\alpha)
\end{aligned}
\tag{14}
$$

Then we calculate the probability distribution of Y:

$$
\begin{aligned}
&P(Y=1)=\frac{1-2\alpha}{3} \\
&P(Y=0)=P(Y=2)=\alpha+\frac{1-2\alpha}{3} \\
&=\frac{1+\alpha}{3}
\end{aligned}
\tag{15}
$$

According to the graphwhen Y=1,there is no surprise that the transmitted symbol is 1.

$$
H(X|Y=1)=0 \tag{16}
$$

When Y=0 or 2, the probability distribution is equal to:

$$
[\alpha, \frac{1-2\alpha}{3}] \tag{17}
$$

Through normalisation:

$$
\begin{aligned}
&[p, 1-p] \\
&p=\frac{\alpha}{\alpha+\frac{\alpha}{\alpha+\frac{1-2\alpha}{3}}} \\
&=\frac{3\alpha}{1+\alpha}
\end{aligned}
\tag{18}
$$

Then the entropy will be:

$$
H(X|Y=2)=H(X|Y=0)=H_2(\frac{3\alpha}{1+\alpha}) \tag{19}
$$

The value of H(X—Y) will be:

$$\begin{aligned}
H(X|Y) &= P(Y=0)H(X|Y=0) \\
&= P(Y=1)H(X|Y=1) \\
&= P(Y=2)H(X|Y=2) \\
&= \frac{1+\alpha}{3} * 0 * 2 + \frac{1-2\alpha}{3} * H_2(\frac{3\alpha}{1+\alpha}) \\
&= \frac{1-2\alpha}{3} * H_2(\frac{3\alpha}{1+\alpha})
\end{aligned} \tag{20}$$

$$\begin{aligned}
C &= H(X;Y) = H(X - H(X|Y) \\
&= -2\alpha log_2\alpha - (1-2\alpha)log_2(1-2\alpha) - \frac{1-2\alpha}{3} * H_2(\frac{3\alpha}{1+\alpha})
\end{aligned} \tag{21}$$

where,

$$H_2(p) = H(O, 1-P) = -plog_2 p - (1-p)log_2(1-p) \tag{22}$$

1.3 Question 1.3(20 Marks)

Compute and plot on the same graph the outage capacity for the following cases: a) AWGN channel; b) SISO Rayleigh fading channel; c) MIMO wireless channel where the individual channels in the wireless MIMO system are all independent and *iid* complex circular symmetric Gaussian $h_{i,jj}\ \mathscr{CN}(0,1)$;d) Wireless "MIMO" system where only individual channel coefficients on the main diagonal are non-zero, all other channel (off the main diagonal) are zero; i.e. $h_{i,j}\ \mathscr{CN}(0,1)$ and $h_{i,j\neq i} = 0$. An example of such (3×3) channel is below:

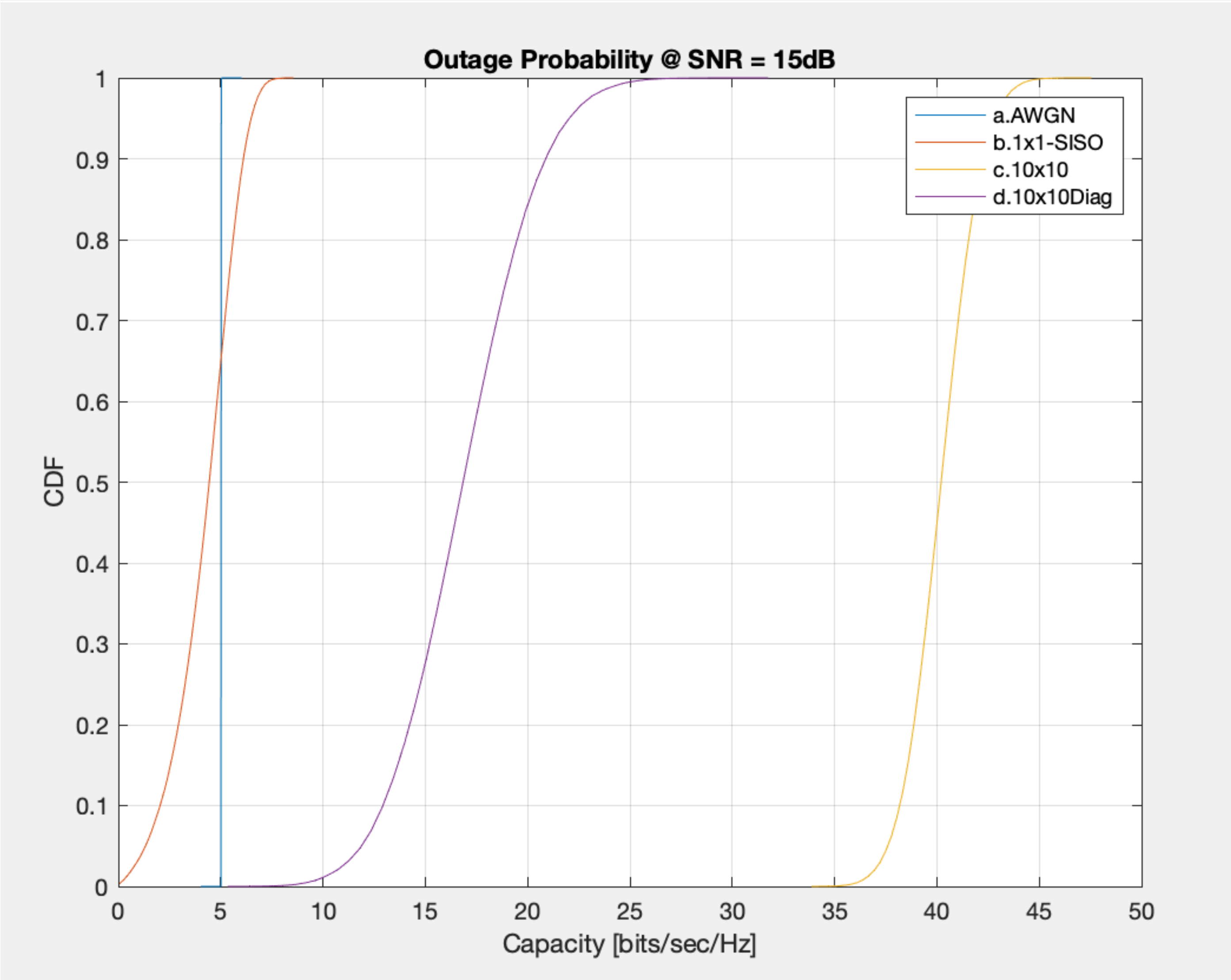
$$\mathbf{H} = \begin{bmatrix} h_{1,1} & 0 & 0 \\ 0 & h_{2,2} & 0 \\ 0 & 0 & h_{3,3} \end{bmatrix}$$

Assume Gaussian signalling input X, and Addictive White Gaussian Noise $N\ CN(0, \theta_N^2 I)$.

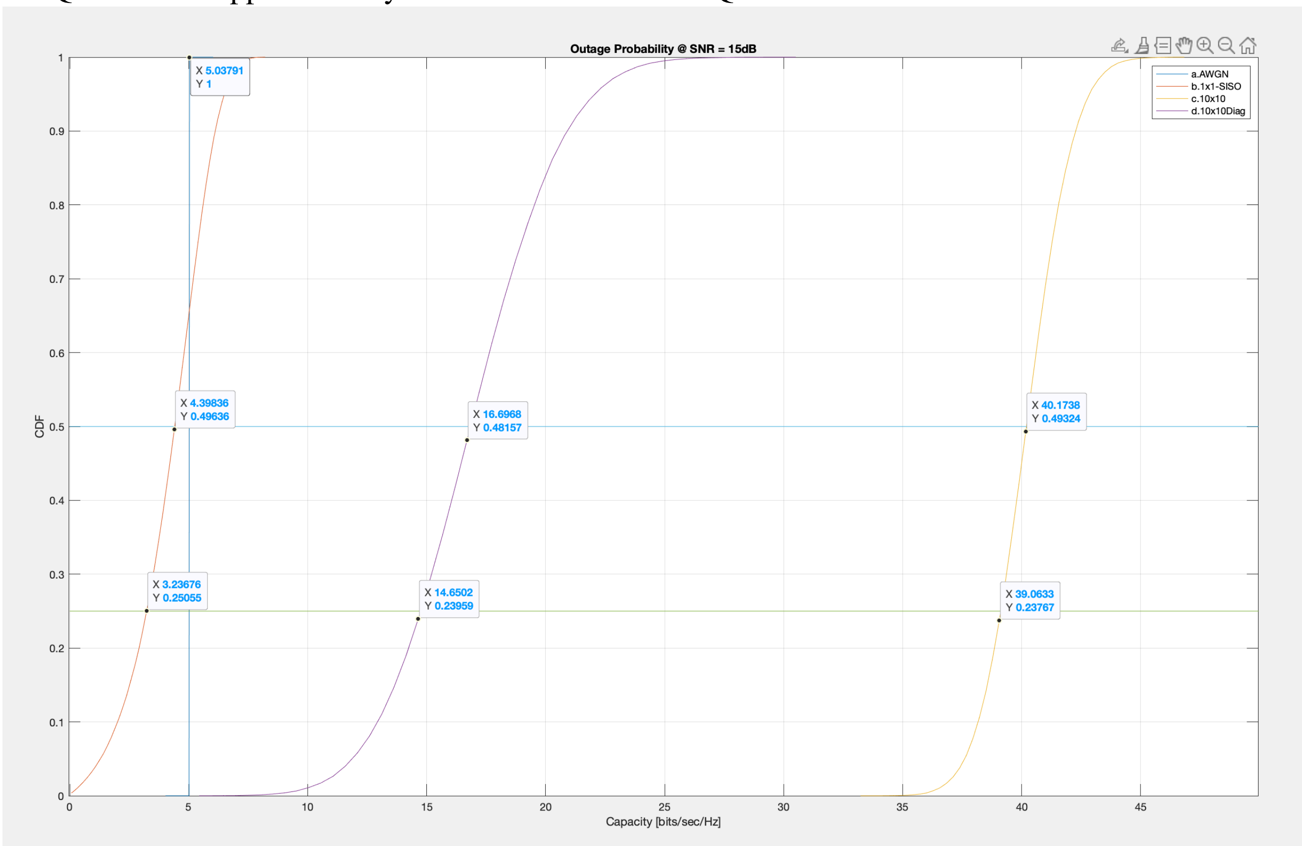
- Write in MATLAB a code that plots the outage capacity curves for a case where SNR=15dB; additionally for c) and d) assume $n_T = n_R = 10$. the 3x3 from the example)
- What is the outage capacity for Q1 and Q2 quantiles(25% and 50%) Discucss ypur results.

Answer: Question 1:

The final outputs:



Question 2: Approximately value on 25% and 50% Quantiles:

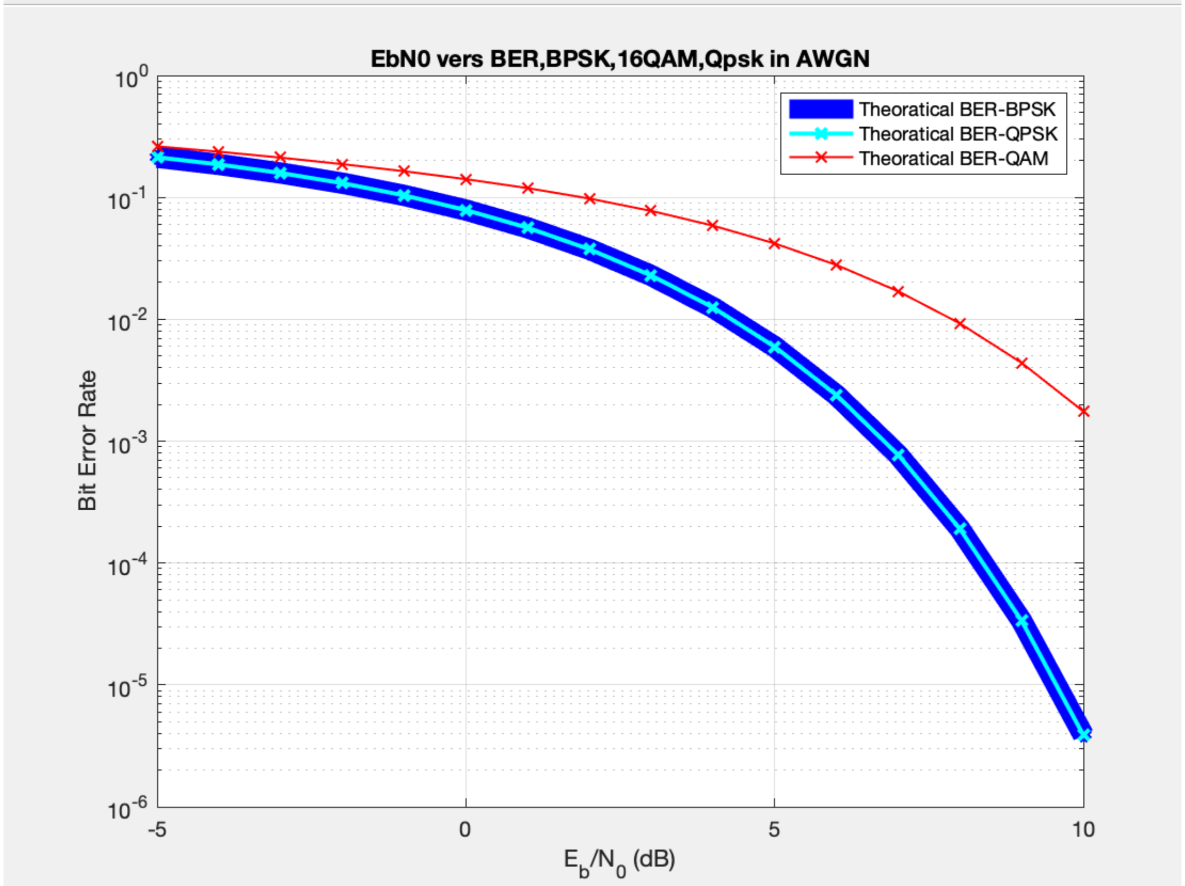


2. Mobile Communications Systems – Part 2

2.1 Q2.1 Course work assignment using Matlab(30 marks)

a.Plot the theoretical error probability for BPSK, QPSK and 16QAM in AWGN for different Eb/No values. Explain why the performance of 16QAM is worse than QPSK. Comment on the data rates/spectral efficiency they can provide
Note: For this part, you can use the functions provided by Matlab (see above) or write your own code based on the equations for the theoretical error probability that can be found in your notes and a number of books.

Answer:



The primitive difference between the QAM and QPSK is that the spectral width of QAM is narrower than the QPSK, the QPSK is easier to be demodulated. QPSK is a low-level modulation compared to 16QAM, under the same channel conditions, the low-level modulation signal is easier to distinguish the correct signal, so the bit error rate is lower, and its data rate will be lower.

b.Write a program in Matlab to perform a baseband simulation of a QPSK communication system in AWGN and compare the performance with the theoretical curves above (create some random data to be transmitted). Explain the structure of the code and justify the matlab functions and parameters used.

Answer:

Code are in the file 2-1b.m. All structure will be explained in the code comments.

Simulation part:

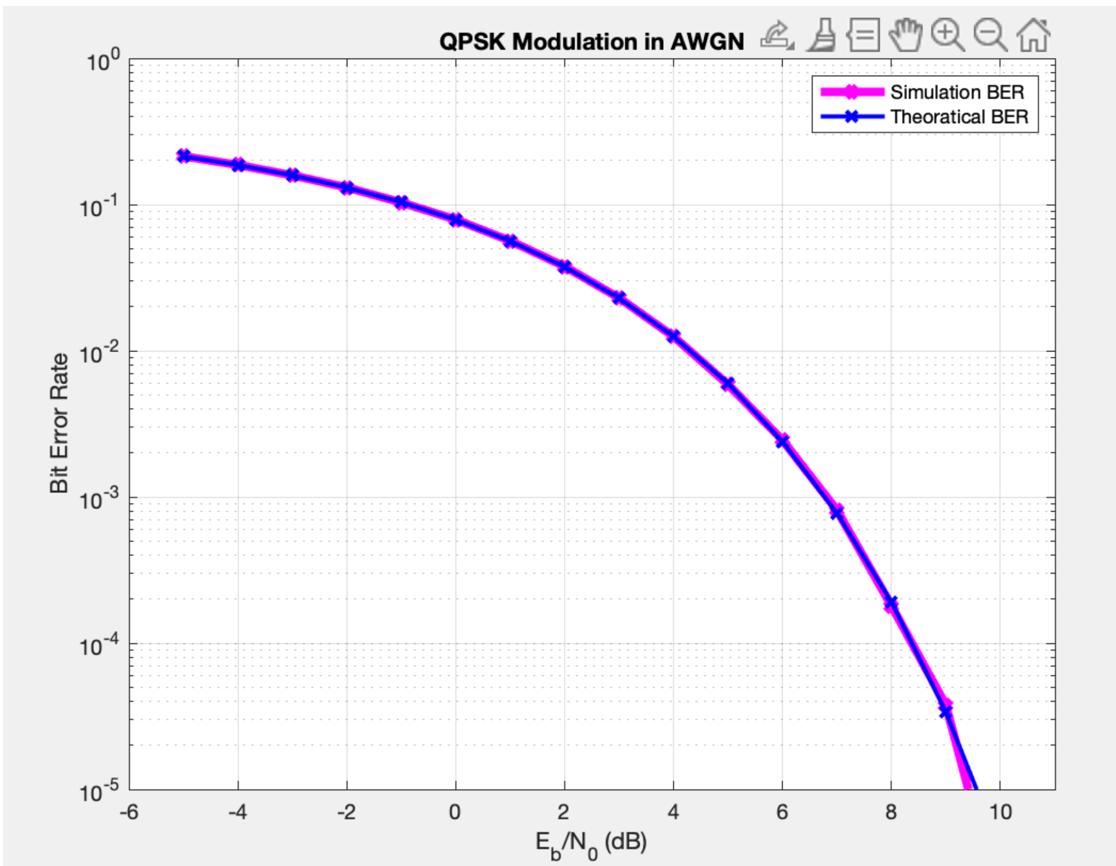
```
%Commited 12/7 arno li guiwecgdiu@gmail.com

% Simulated QPSK and theoritical QPSK
```

```

%initialize the random data transmitted(used in
    simulation)
N=10^6; % Numbers of Bits to be processed
M=4; %Modulation Order
k=log2(M); %Numbers of bits per symbol
nSymbols=N/k; %Numbers of symbols
generatedata= randi([0 1],N,1); % Generate bits as 0
    & 1
```

```

%initialzie the QPSK modulator
Modulator = comm.QPSKModulator; % Define modulator
    for QPSK
Demodulator = comm.QPSKDemodulator;   % Define
    demodulator for QPSK

%Data modulation
modulatedata = step(Modulator,generatedata);  %
    Modulate bits using QPSK
E_bN_0=-5:10;   % Define range of Eb/N0
SNR = E_bN_0 + 10*log10(k); %Conversion into SNR

%Demodulation
for j=1:length(SNR)
receivedSig(:,j)= awgn(modulatedata,SNR(j),'measured'
    );    % Add AWGN noise to modulated Data
Demodulatedata = step(Demodulator,receivedSig(:,j));
   % Demodulate noisy data
[numerr(j),errrate(j)] = biterr(generatedata,
    Demodulatedata); %Find number of Error Bits and
    Error Rate
end

%Plot BER of Simulated Data
semilogy(E_bN_0,errrate,'mx-','linewidth',4)
hold on
```

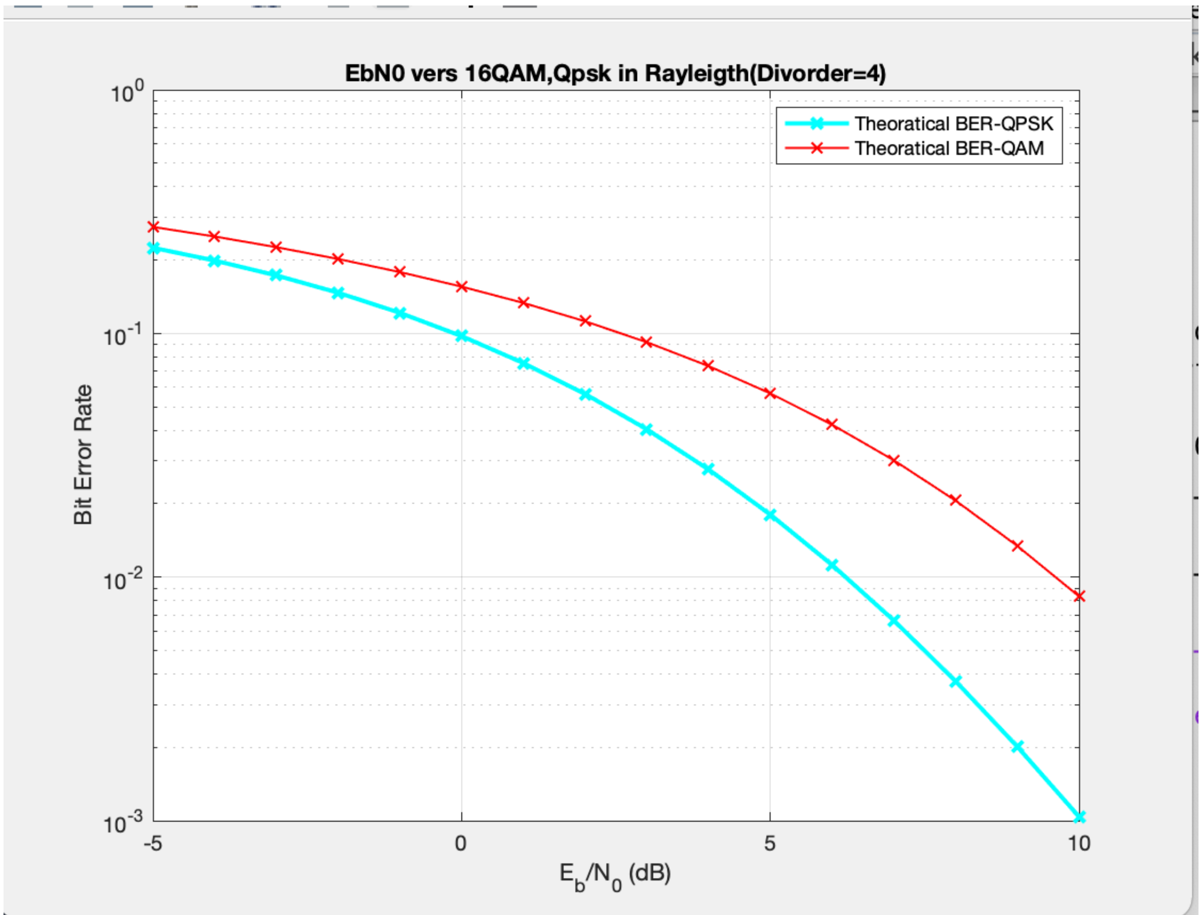
Theortical part:

```

%Theoretical BER OF QPSK IN AWGN CHANNEL
E_bN_0=-5:10;   % Define range of Eb/N0
tber = berawgn(E_bN_0,'psk',4,'nondiff');   % Theoretical BER of QPSK in AWGN Channel
semilogy(E_bN_0,tber,'b-x','linewidth',2) %Plot Theoretical BER in AWGN
```



c.Plot the theoretical error probability for QPSK and 16QAM in Rayleigh fading. Discuss Rayleigh fading and the key concepts of fast fading. Describe what is the difference between Rayleigh and Ricial fading.

Answer:



My understanding is that Rayleigth Fading is to produce a decline in the amplitude of the signal, the fading coefficient follows a Rayleigth distribution.

Because In the wireless communication channel, the amplitude the signal at receiving point comes from different propagation paths, the delay time of each path is different, and the superposition of component waves in each direction produces the standing wave, thus forming a signal fast fading. The time that the multiple signal reaches the receiver is preceded by a relative time (between) delays (delays). If these relative delays are much smaller than the time of a symbol, it can be considered that the multiple signal reaches the receiver almost simultaneously. In this case, multiple paths do not cause interference between symbols.

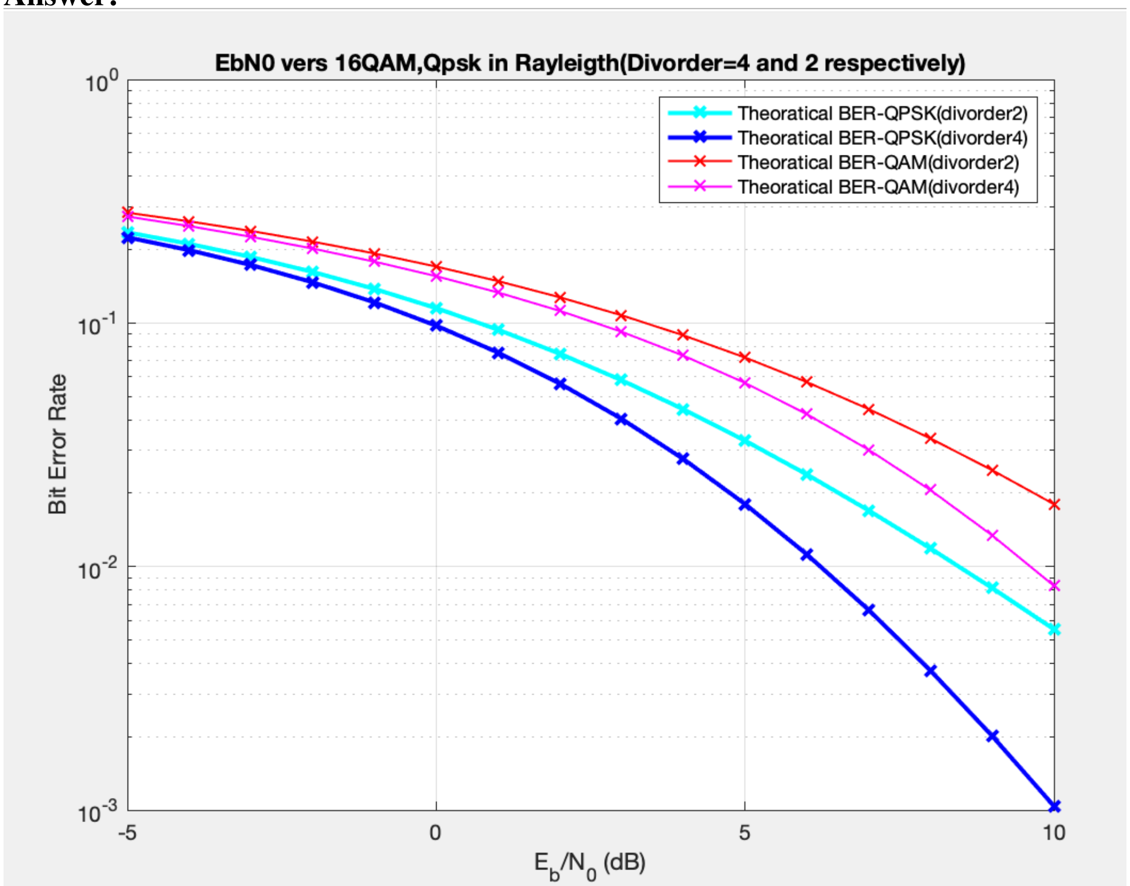
FastFast fading and slow fading, usually refers to the speed at which a signal changes relative to time of one symbol. Roughly speaking, if there is little change in a symbol's time, it is considered to be slow fading. Conversely, if there is a significant change in the time of a symbol, it is considered to be a fast fading.

Rayleigh fading can effectively describe a wireless propagation environment where there are obstacles that can scatter radio signals in large quantities. If there is enough scattering in the propagation environment, the signal arrives at the receiver and appears as a superposition of a large number of independent random variables, its envelope of distribution follows a Raylegith Distribution. Generally, there is no LOS. When the channel exist a main component, such as, LOSthe envelope should follow the Ricial Distribution. The corresponding channel model is a Ricial fading channel.

d.Use diversity to improve performance in Rayleigh fading. Plot the error probability for QPSK and 16QAM in Rayleigh fading with diversity orders of 2 and 4 using ber = berfading(EbNo,'pam',M,divorder)

Discuss and compare different types of diversity and how they can improve performance of communication systems in fading channels.

Answer:



e.Discuss your results and suggest other methods to improve the performance in AWGN or Rayleigh fading environments.

Answer:

2.2 Q2.2 Celluar planning(10 marks)

A digital cellular system has 20MHz of available spectrum and operates with a cluster size of 7. Each channel requires 200 kHz of spectrum. The radio system uses TDMA with 8 calls per channel. Assume that each user represents a traffic load of 0.02 Erlangs. The cell radius is 2km, and the network comprises 20 basestations.

- a.What is the channel bandwidth?
- b.What is the maximum number of calls that can be supported in a cell?
- c.How many subscribers can we have per cell?
- d.What is the maximum number of calls that can be supported in a cluster group?
- e.What is the cluster area?
- f.Determine the total capacity in terms of calls per MHz per kilometre square.
- g.Determine the subscriber capacity in terms of subscribers per MHz per kilometre square.
- h.What is the total subscriber capacity of the network?
- i.What is the total coverage area?
- j.What is the basic concept behind cellular systems?

Answer:
a) Channel bandwidth $Bw_C = 200kHz$
b) Total bandwidth $Bw_T = 20MHz$
TotalChannels = $\frac{Bw_T}{BW_C} = \frac{2\times10^7}{2\times10^5} = 100 \quad channels$
ChannelsPerCell = $\frac{TotalChannels}{ClsuterSize} = \frac{100}{7}$
MaximumCallsPerCell= ChannelsPerCell * callsPerChannel = $\frac{100}{7} \times 8 = 114.2857 \quad calls$
c) SubsceiberPerCell=$\frac{114.2857}{0.02} = 5.7143 \times 10^3$
d) maximum number of calls in a cluster group=ClusterSize* MaximumCallsPerCell=7 $\times \frac{100}{7} \times 8 = 800$ calls
e) clusterArea=$7 * \pi R^2 = 7 * \pi * 2^2 = 87.97 \quad km^2$
f) totalCapacity=TotalCalls/(ClusterSize*TotalBandwdith) =$800/(20*87.92) = 0.455$ calls/MHz/km^2
g) subscriberCapacity=$0.455/0.02 = 22.75$ subscribers/MHz/ km^2
h) totalSubscriberCapacity = subscriberPerCell*NumOfBasestations= $5.7143 \times 10^3 \times 20 =$ 114288
i)Total coverage area =πR^2 * NumOfBasestations= $12.5664 \times 20 = 251.2km^2$

j) Answer:

The basic principle behind cellular systmes is to explore the power fall off with distance of signal propagation in order to reuse the same channel at spatially separated locations.

An area is divided in non overlapping cells.Each cell is assumed to cover and ideal hexagon. Hexagons are used.Adjacent cells cannot use the same set of frequencies.

A set of procedure between the cell towers ensures that a moving device can always and seamlessly connect to the nearest of best positioned tower(seamlessly handover).
The main reason for using the cellular systems are higher capacity , higher number of users - cellular systems can reuse spectrum according to different patterns . Each cell can support a maximum number of users and less transmission power needed.

2.3 Q2.3 System Design(10 marks)

a) With the aid of the graph given in the figure below, indicating the performance of various digital modulation schemes operating in an (AWGN) channel with an error rate of 10^{-5}, select suitable modulation schemes in order to meet the following criteria.

	System A	System B
Data Rate at BER < 10^{-5}	20Mbit/s	40Mbit/s
Channel Bandwidth	20MHz	20MHz
E_b/N_o	<10dB	<16dB

Fig. 1. 2.3.1

Answer:
We assume the bandwidth efficiency is denoted as EB, where EB=Data rate(bits)/Bandwidth.

For system A,with the given requirements in fig 2.3.1, $EB_A = \frac{2\times10^7}{2\times10^7}$=1 (bits/Sec/Hz). Then bandwidth efficiency of A is required to be 1, by the figure 2.3.2, we can choose PSK(M=2) and DPSK(M=2), then the Eb/N0 is required to be less than 10dB.

So the digital modulation schemes system A is BPSK(M=2).

For system B,with the given requirements in fig 2.3.1, $EB_B = \frac{4\times10^7}{2\times10^7}$=2 (bits/Sec/Hz). Then bandwidth efficiency of B is required to be 2, by the figure 2.3.2, we can choose from PSK(M=4) and DPSK(M=4), then the Eb/N0 is required to be less than 16dB.

For a better performance, a less Eb/N0 is more suitable. So we choose PSK(M=4).

b) With the aid of the same graph explain why QPSK can offer a throughput enhancement compared to BPSK without either a bandwidth expansion or an increase in transmission power? In addition discuss why the noise performance of QPSK is superior to 8PSK and 16QAM is superior to 16PSK.

Answer:
Q1: Because in QPSK,it is possible to transmit orthogonal signals on the same transmission link, without one set of signal affecting the detection of the other. Two pairs of phase symbol states in QPSK have orthogonal properties,$+/-A.cos(w_ct) and +/-, A.sin(w_ct)$,cos and sin waves of the same frequency are orthogonal to each other.

Q2: The performance of QPSK is superior to 8PSK is because QPSK(M=4) has less symbol states, hence it is easier to be corrected detected at the receiver. For 16QAM versus 16PSK, 16QAM is a higher-order modulation. The minimum Euclidean distance between two adjacent symbols is greater than 16PSK. Large distances are easier to identify and have better noise immunity. When M¿4 time, QAM modulation is significantly better than PSK modulation.

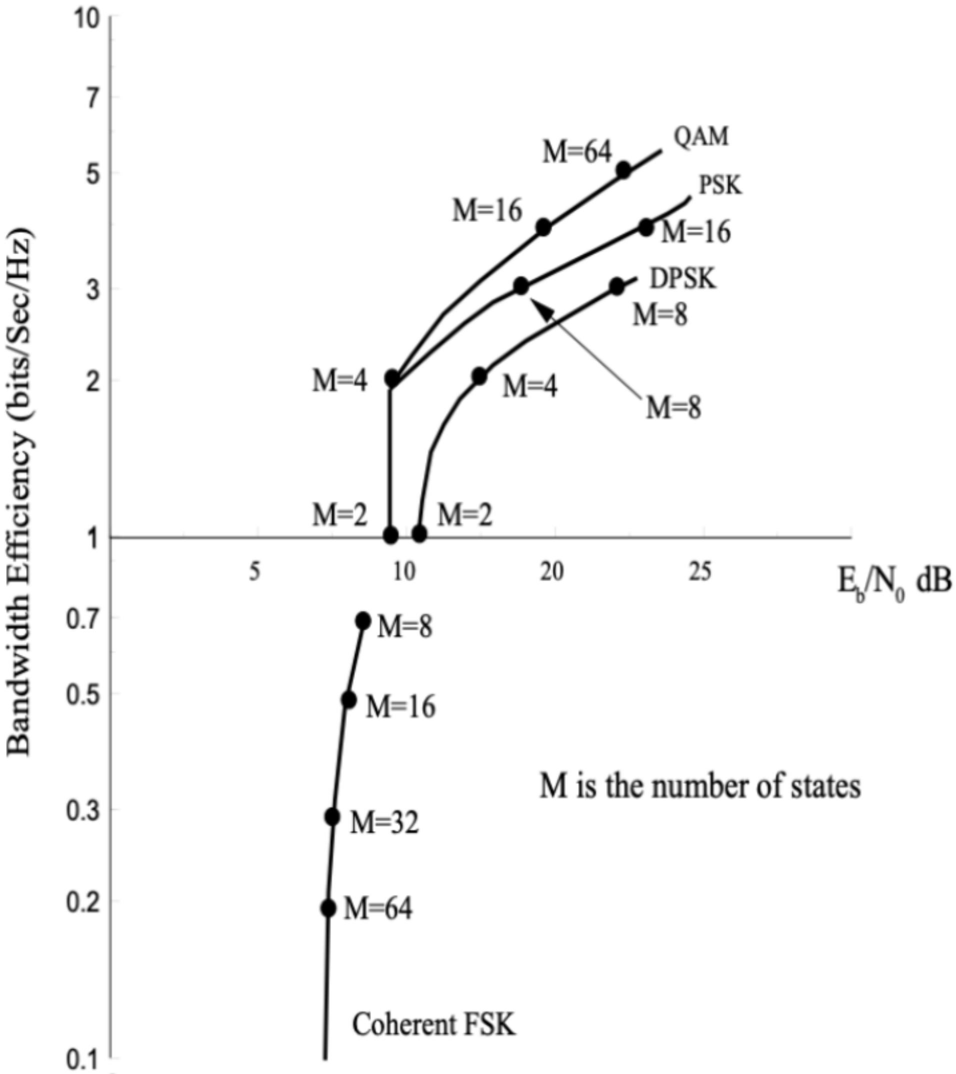


Fig. 2. 2.3.2

References