

EENGM30010: Mobile Communication Systems 2021

Mobile Communication System Course Work

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Program: Network Communication and Signal Processing(MSc)

Semester 1

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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

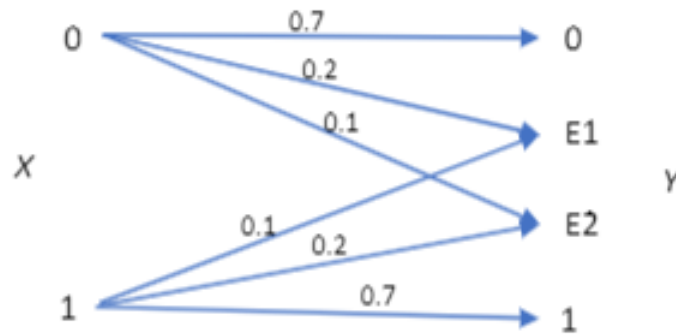


Figure 1.1: Binary Double Erasure Channel.

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 $P(x=1)=1-p$

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

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

By $P(x,y)$:

$$P(Y=0) = 0.7p \quad P(Y=e_1) = 0.1(1+p)$$

$$P(Y=e_2) = 0.2 - 0.1p \quad P(Y=1) = 0.7(1-p)$$

$$H(Y) = \sum_i^n p(y_i) \log_2 \frac{1}{P(y_i)} \quad (5)$$

$$H(Y|X) = \sum_{x,y} p(x,y) \log_2 \frac{1}{p(y|x)}$$

$$H(Y) = 0.7p * \log_2 \frac{1}{0.7p} + 0.1(1+p) * \log_2 \frac{1}{0.1(1+p)} \\ + (0.2 - 0.1p) * \log_2 \frac{1}{0.2 - 0.1p} + 0.7(1-p) * \log_2 \frac{1}{0.7(1-p)} \quad (6)$$

$$H(Y|X) = 0.7p * \log_2 \frac{1}{0.7} + 0.2p * \log_2 \frac{1}{0.2} \\ + 0.1p * \log_2 \frac{1}{0.1} + 0.1(1-p) * \log_2 \frac{1}{0.1} \\ + 0.2(1-p) * \log_2 \frac{1}{0.2} + 0.7(1-p) * \log_2 \frac{1}{0.7}$$

The Capacity of channel will be:

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

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

$$X(Y) = 1.881 \quad (p = 0.5) \quad (8)$$

$$H(Y|X) = 1.157 \quad (p = 0.5)$$

The channel capacity is

$$C = H(Y) - H(Y|X) \\ = 0.724 \quad (9)$$

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

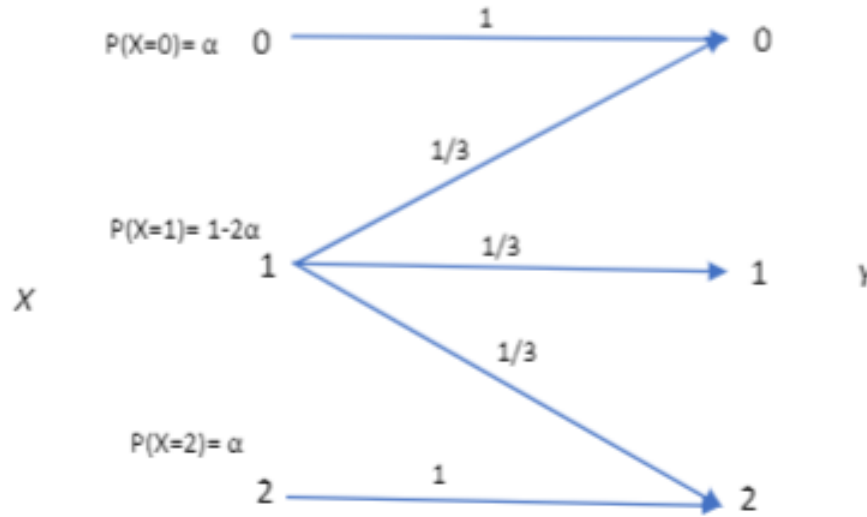


Figure 1.2: Binary Non-Symmetric Channel.

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):

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

Assign the value:

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

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 graph when 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:

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

The value of $H(X|Y)$ will be:

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

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

where,

$$H_2(p) = H(0, 1-p) = -p \log_2 p - (1-p) \log_2 (1-p) \tag{22}$$

1.3 Question 1.3(20 Marks)

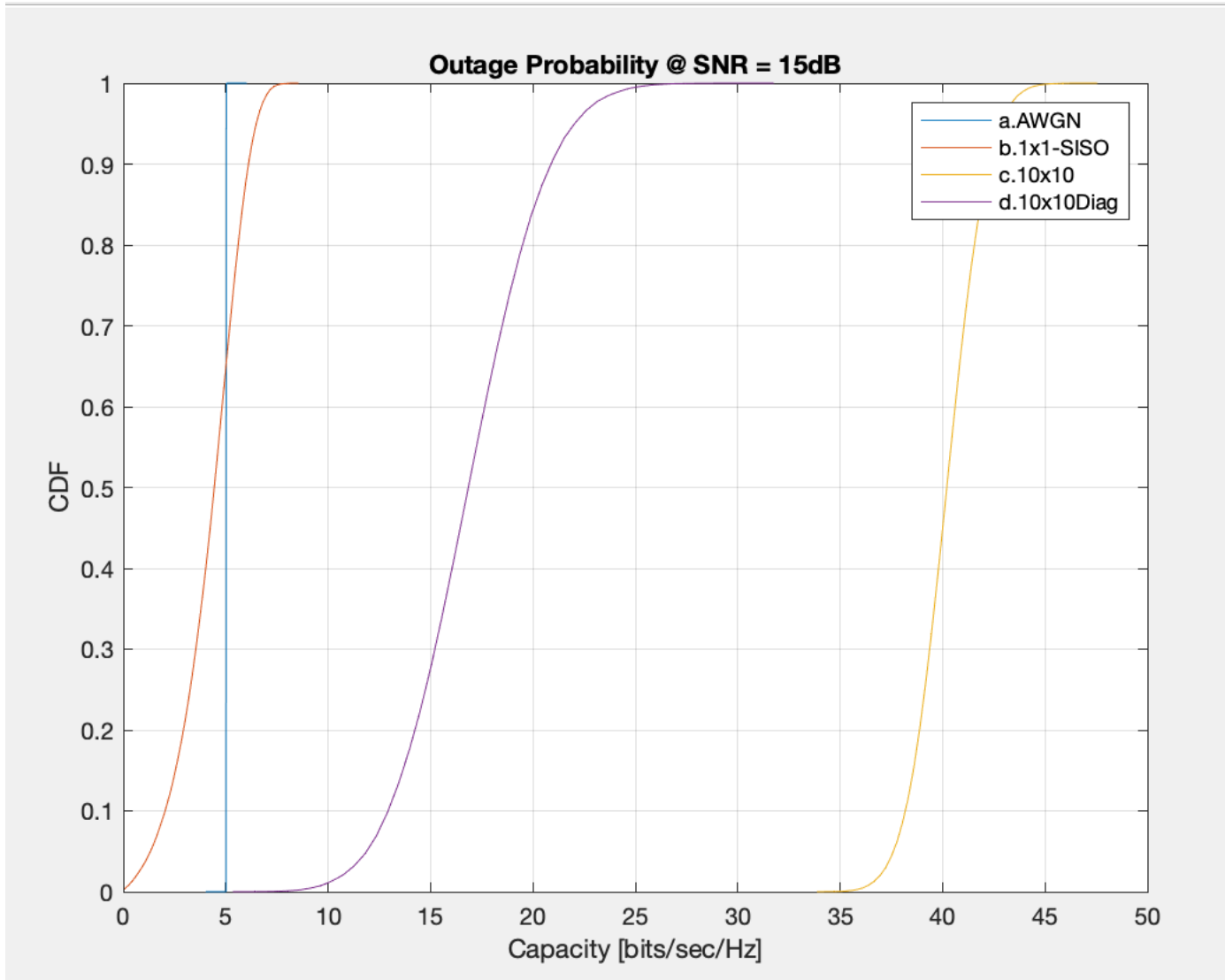
Compute and plot on the same graph the outage capacity for the following cases: a) AWGN channel; b) SISO Rayleigh fading channel; c) MIMO wireless channel where the individual channels in the wireless MIMO system are all independent and *iid* complex circular symmetric Gaussian $h_{i,j} \mathcal{CN}(0, 1)$; 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. $h_{i,j} \mathcal{CN}(0, 1)$ and $h_{i,j \neq i} = 0$. An example of such (3×3) channel is below:

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

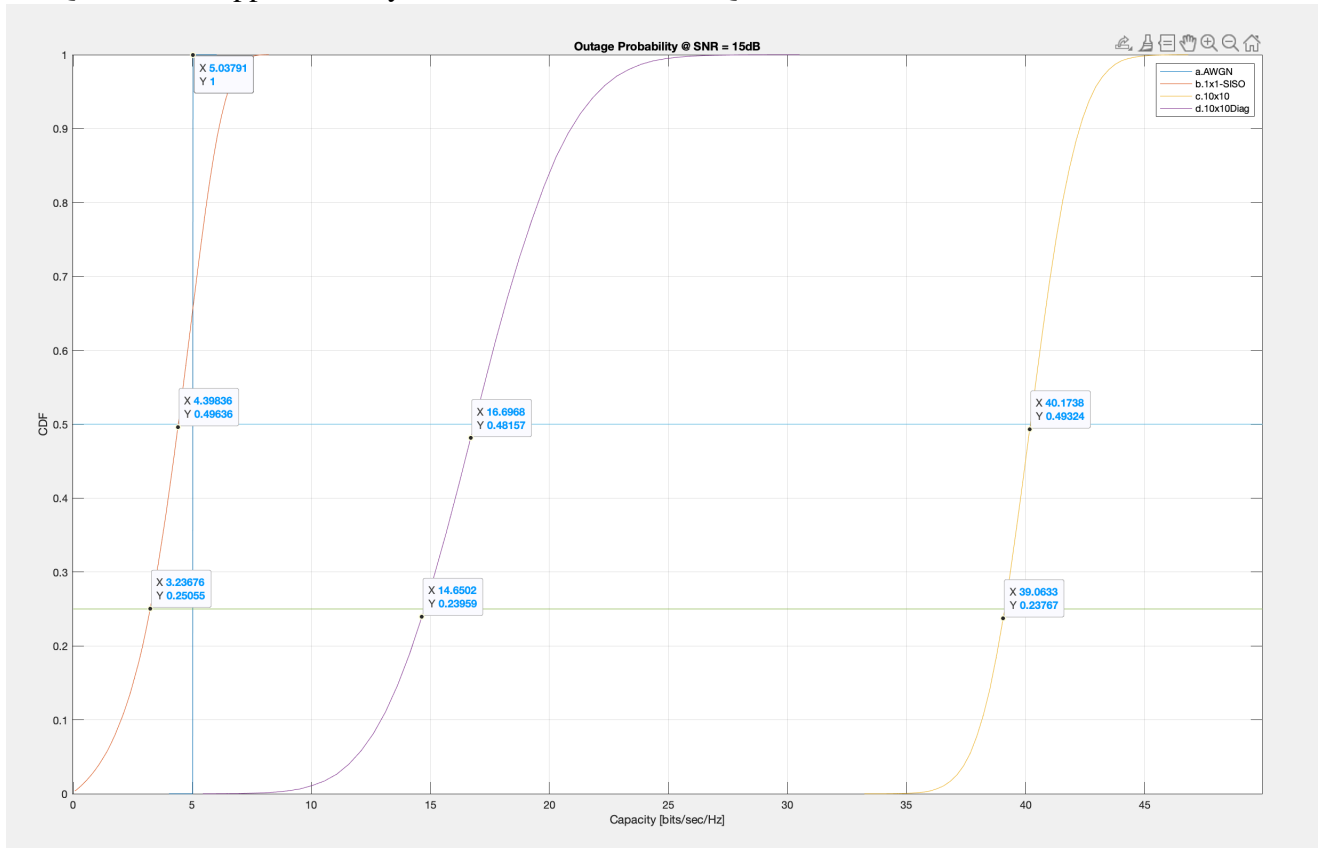
Assume Gaussian signalling input \mathbf{X} , and Addictive White Gaussian Noise $N \mathcal{CN}(0, \theta_N^2 \mathbf{I})$.

- 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 3×3 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:



CDF\Capacity	Awgn	SISO	10x10	10x10 diag-matrix
25%	5	3.23	39.06	14.65
50%	5	4.39	40.17	16.69

The unit of capacity is bits/sec/Hz

⋮ Type '/' for commands

2. Mobile Communications Systems – Part 2

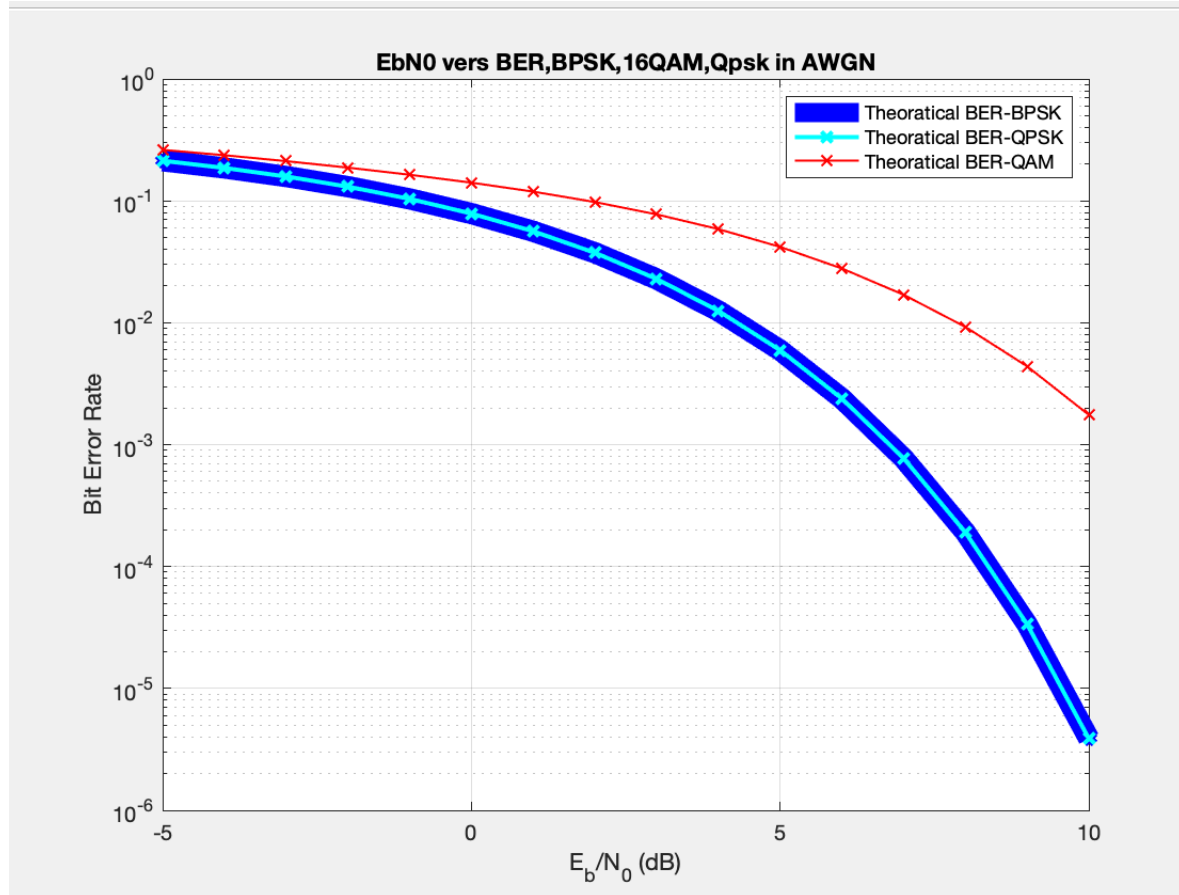
2.1 Q2.1 Course work assignment using Matlab(30 marks)

a. Plot the theoretical error probability for BPSK, QPSK and 16QAM in AWGN for different E_b/N_0 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:

```
1 %Committed 12/7 arno li guiwecgdiu@gmail.com
```

```

2
3 % Simulated QPSK and theoritical QPSK
4
5 %initialize the random data transmitted(used in
  simulation)
6 N=10^6; % Numbers of Bits to be processed
7 M=4; %Modulation Order
8 k=log2(M); %Numbers of bits per symbol
9 nSymbols=N/k; %Numbers of symbols
10 generatedata= randi([0 1],N,1); % Generate bits as 0
  & 1

```

```

1
2 %initialzie the QPSK modulator
3 Modulator = comm.QPSKModulator; % Define modulator
  for QPSK
4 Demodulator = comm.QPSKDemodulator; % Define
  demodulator for QPSK
5
6 %Data modulation
7 modulatedata = step(Modulator,generatedata); %
  Modulate bits using QPSK
8 E_bN_0=-5:10; % Define range of Eb/N0
9 SNR = E_bN_0 + 10*log10(k); %Conversion into SNR
10
11 %Demodulation
12 for j=1:length(SNR)
13 receivedSig(:,j)= awgn(modulatedata,SNR(j),'measured'
  ); % Add AWGN noise to modulated Data
14 Demodulatedata = step(Demodulator,receivedSig(:,j));
  % Demodulate noisy data
15 [numerr(j),errrate(j)] = biterr(generatedata,
  Demodulatedata); %Find number of Error Bits and
  Error Rate
16 end
17
18 %Plot BER of Simulated Data
19 semilogy(E_bN_0,errrate,'mx-','linewidth',4)
20 hold on

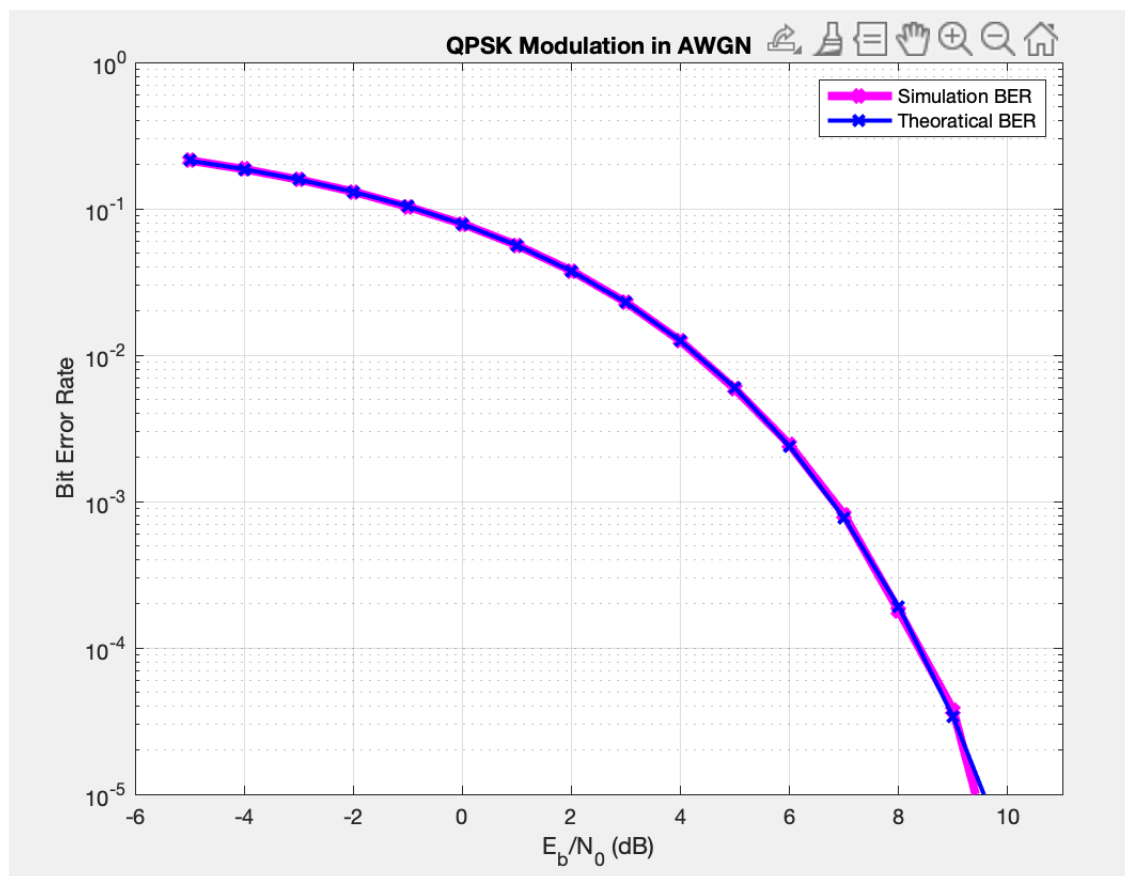
```

Theoretical part:

```

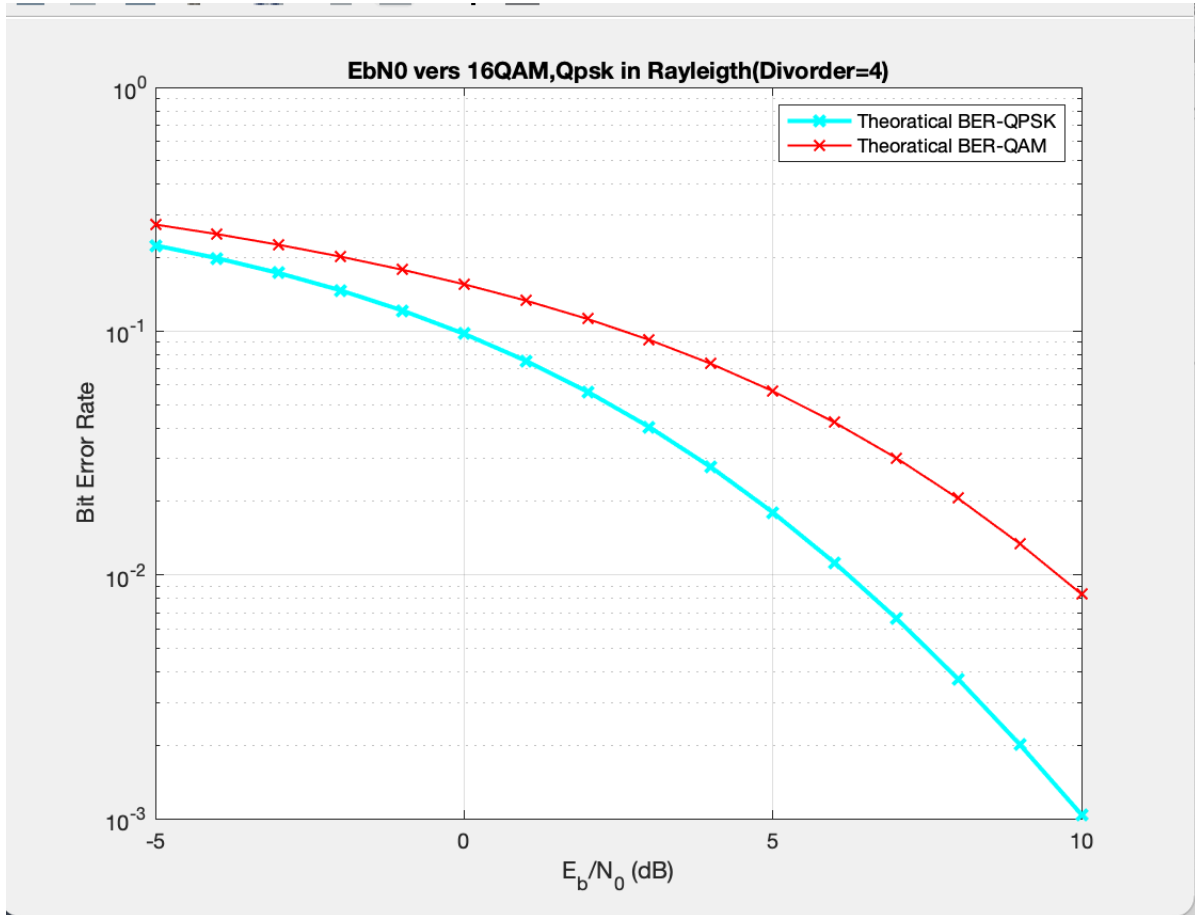
1
2 %Theoretical BER OF QPSK IN AWGN CHANNEL
3 E_bN_0=-5:10; % Define range of Eb/N0
4 tber = berawgn(E_bN_0,'psk',4,'nondiff'); %
    Theoretical BER of QPSK in AWGN Channel
5 semilogy(E_bN_0,tber,'b-x','linewidth',2) %Plot
    Theoretical BER in AWGN

```



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 Rician fading.

Answer:



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

Difference between Rayleigh fading and Ricial fading is "if the LOS component

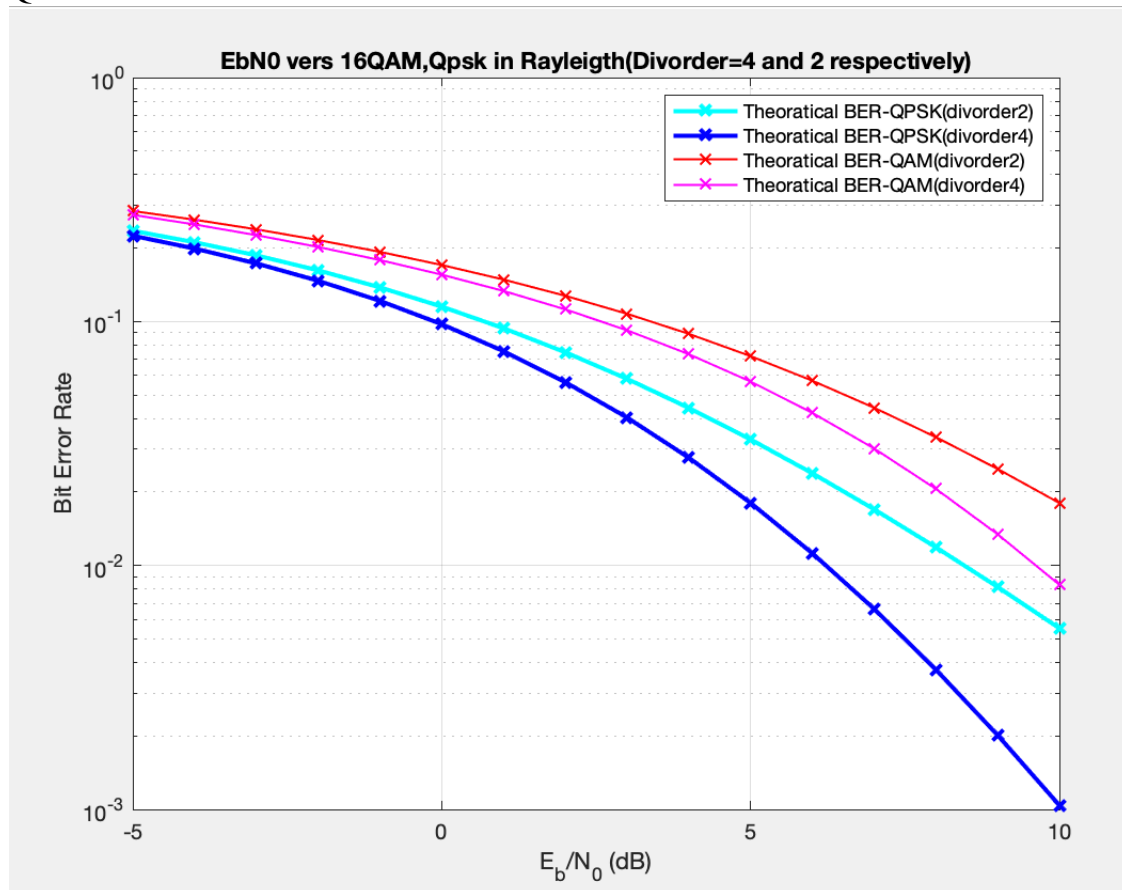
mainly exist. Rayleigh fading can effectively describe a wireless propagation environment where there are obstacles that can scatter radio signals in large quantities. If there is enough scattering in the propagation environment, the signal arrives at the receiver and appears as a superposition of a large number of independent random variables, its envelope of distribution follows a Rayleigh Distribution. Generally, there is no LOS. When the channel exist a main component, such as, LOS the envelope should follow the Rician Distribution. The corresponding channel model is a Rician 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 = berfad- ing(EbNo,'pam',M,divorder)`

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

Answer:

Q1:



Q2:

1.Space Diversity, which the transmitted signal is received via a number of different anten-

nas. Space diversity reception is to set up several antennas at different vertical heights in space, receive microwave signals from one transmitting antenna at the same time, and then synthesize or select one of the strong signal receiving end antennas. The distance between the antennas should be greater than half the wavelength to ensure the receiving antenna. The fading characteristics of the output signal are independent of each other, that is, when the output signal of a receiving antenna is very low, the output of the other receiving antennas may not have a low amplitude at the same time. The corresponding combination circuit selects the one with the larger signal amplitude and the best signal-to-noise ratio to obtain a total receiving antenna output signal. This reduces the influence of channel fading and improves the reliability of transmission.

2.Angle diversity. Signals arriving from different directions are uncorrelated. So, directive antennas can be used to produce the required independently faded diversity signals. Directive antennas restrict angles over which rays may be received. So the effects of Doppler spread and time delay spread are reduced.

3.Frequency diversity is the use of two or more microwave frequencies with a certain frequency interval to send and receive the same information at the same time, and then synthesize or select, and use the statistically uncorrelated characteristics of signals located in different frequency bands after passing through the fading channel, that is, different. The difference in the statistical characteristics of frequency band fading is used to realize the function of anti-frequency selective fading. When implemented, the information to be sent can be modulated separately on frequency-independent carrier waves for transmission.

4.Time diversity is the resumption of the same signal multiple times in different time intervals, as long as each send interval is large enough, the decline of each send down will be independent of each other. Time diversity is to take advantage of these declines in statistically unrelated characteristics, that is, the differences in the statistical characteristics of time decline to achieve the function of resisting selective decline of time.

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

Answer:

Machine learning or deep learning may be helpful on the detection of the channel and prevention the noise.

According to *Detection of Gaussian Noise and Its Level using Deep Convolutional Neural Network*(2017, Joon Huang Chua & Hui Ying Khaw), a deep learning algorithm may be applied in the AWGN and Rician channel detection. The essay illustrates the feasibility of application of deep learning in the AWGN detection, it presents methods for detecting Gaussian noise and classifying its level using CNN. Then by the output model and statistical technique optimization using data adapting, filters generation in solving.

With the trained model, an adopted filter that could accurately identify multiple classes and finally contribute to the performance of an mobile system.

2.2 Q2.2 Cellular 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 $Bw_T = 20MHz$

$$\text{TotalChannels} = \frac{Bw_T}{Bw_C} = \frac{2 \times 10^7}{2 \times 10^5} = 100 \text{ channels}$$

$$\text{ChannelsPerCell} = \frac{\text{TotalChannels}}{\text{ClusterSize}} = \frac{100}{7}$$

$$\text{MaximumCallsPerCell} = \text{ChannelsPerCell} * \text{callsPerChannel} = \frac{100}{7} \times 8 = 114.2857 \text{ calls}$$

$$\text{c) SubscriberPerCell} = \frac{114.2857}{0.02} = 5.7143 \times 10^3$$

$$\text{d) maximum number of calls in a cluster group} = \text{ClusterSize} * \text{MaximumCallsPerCell} = 7 \times \frac{100}{7} \times 8 = 800 \text{ calls}$$

$$\text{e) clusterArea} = 7 * \pi R^2 = 7 * \pi * 2^2 = 87.97 \text{ km}^2$$

$$\text{f) totalCapacity} = \text{TotalCalls} / (\text{ClusterSize} * \text{TotalBandwidth}) = 800 / (20 * 87.92) = 0.455 \text{ calls/MHz/km}^2$$

$$\text{g) subscriberCapacity} = 0.455 / 0.02 = 22.75 \text{ subscribers/MHz/ km}^2$$

$$\text{h) totalSubscriberCapacity} = \text{subscriberPerCell} * \text{NumOfBasestations} = 5.7143 \times 10^3 \times 20 =$$

114288

i) Total coverage area $= \pi R^2 * \text{NumOfBasestations} = 12.5664 \times 20 = 251.2 \text{ km}^2$

j) Answer:

The basic principle behind cellular systems 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 an 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 $EB = \text{Data rate(bits)}/\text{Bandwidth}$.

For system A, with the given requirements in fig 2.3.1, $EB_A = \frac{2 \times 10^7}{2 \times 10^7} = 1$ (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 E_b/N_0 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, $EB_B = \frac{4 \times 10^7}{2 \times 10^7} = 2$ (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 E_b/N_0 is required to be less than 16dB.

For a better performance, a less E_b/N_0 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, $+/- A \cos(w_c t)$ and $+/- A \sin(w_c t)$, 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 is larger than 4, QAM modulation starts being significantly better than PSK modulation.

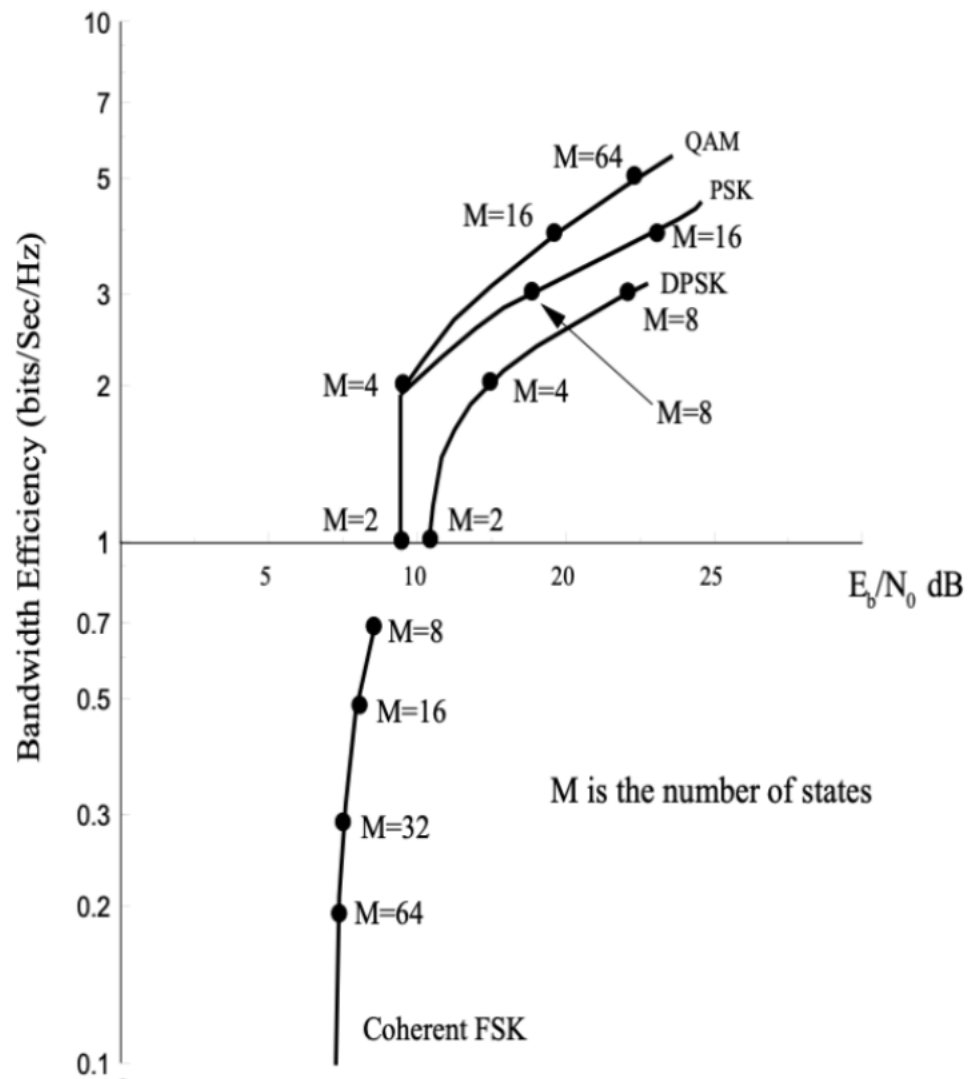


Fig. 2. 2.3.2

Code List

The code attachment includes files: q1-3.m,q2-1a.m,q2-1b.m,q2-1c.m,q2-1d.m. They can be run at Matlab environment.

Reference

- Joon, H. C., et al. "Detection of Gaussian noise and its level using deep convolutonal neural network." (2017): 1-4.