Hanoi University of Science and Technology
School of Electronics and Telecommunication Engineering

REPORT

Wireless Communications

Topic:

Simulation of a SISO Wireless Communication System Using 16-QAM Modulation Scheme

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Chapter 0. Contributions to this project

Name	Theory	Workflow design	Matlab implementation	Report
Nguyen Anh Minh		x	x	x
Hoang Minh Tam	x	x		x
Ngo Duc Anh	x	x		x

Bảng 0.1 Contributions of each member to this project

Chapter 1. Introduction

The Information Age which began in the latter half of the 20th century has brought about major impacts in modern society, accompanied by powers of digital computing and communication technology. Consequently, studying and conducting research in the field of information theory, and in digital communication particularly has always been prioritized. The sole purpose of studying information theory is to understand how information is quantified, stored, and most importantly, communicated through different environments. Therefore, designing a decent system for the information, which is represented as sequences of binary digits, to be propagated thoroughly and error-free be-tween transmitter and receiver could be considered as the most fundamental task of digital communication.

Chapter 2: Theoretical Background

2.1 Quadrature amplitude modulation

2.1.1 Introduction

Quadrature amplitude modulation (QAM) is the name of a family of digital modulation methods and a related family of analog modulation methods widely used in modern telecommunications to transmit information. It conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves of the same frequency are out of phase with each other by 90°, a condition known as orthogonality or quadrature. The transmitted signal is created by adding the two carrier waves together. At the receiver, the two waves can be coherently separated (demodulated) because of their orthogonality property. Another key property is that the modulations are low-frequency/low-bandwidth waveforms compared to the carrier frequency, which is known as the narrowband assumption.

QAM is used extensively as a modulation scheme for digital telecommunication systems, such as in 802.11 Wi-Fi standards. Arbitrarily high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, limited only by the noise level and linearity of the communications channel.QAM is being used in optical fiber systems as bit rates increase; QAM16 and QAM64 can be optically emulated with a 3-path interferometer.

2.1.2 Digital 16-QAM Modulation

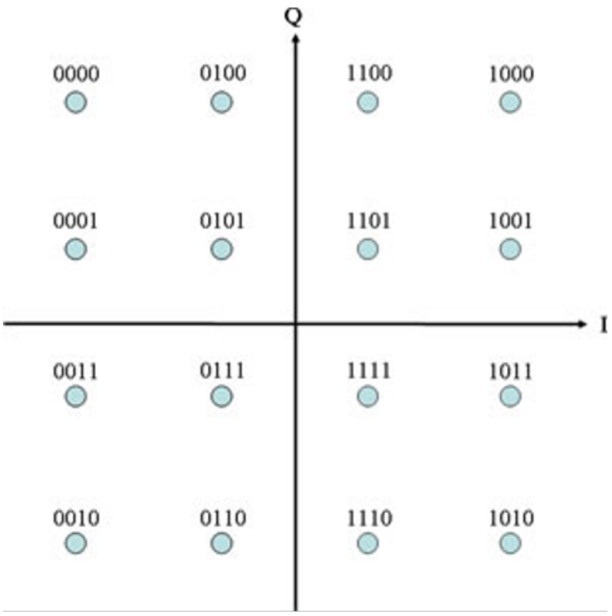
As in many digital modulation schemes, the constellation diagram is useful for QAM. In QAM, the constellation points are usually arranged in a square grid with equal vertical and horizontal spacing, although other configurations are possible (e.g. a hexagonal or triangular grid). In digital telecommunications the data is usually binary, so the number of points in the grid is typically a power of 2 (2, 4, 8, . . .), corresponding to the number of bits per symbol. The simplest and most commonly used QAM constellations consist of points arranged in a square, i.e. 16-QAM, 64-QAM and 256-QAM (even powers of two). Non-square constellations, such as Cross-QAM, can offer greater efficiency but are rarely used because of the cost of increased modem complexity.

By moving to a higher-order constellation, it is possible to transmit more bits per symbol. However, if the mean energy of the constellation is to remain the same (by way of making a fair comparison), the points must be closer together and are thus more susceptible to noise and other corruption; this results in a higher bit error rate and so higher-order QAM can deliver more data less reliably than lower-order QAM, for constant mean constellation energy. Using higher-order QAM without increasing the bit error rate requires a higher signal-to-noise ratio (SNR) by increasing signal energy, reducing noise, or both.

If data-rates beyond those offered by 8-PSK are required, it is more usual to move to QAM since it achieves a greater distance between adjacent points in the I-Q plane by distributing the points more evenly. The complicating factor is that the points are no longer all the same amplitude and so the demodulator must now correctly detect both phase and amplitude, rather than just phase. The constellation diagrams show the various positions for the states within different forms of QAM, quadrature amplitude modulation. As the order of the modulation increases, so does the number of points on the QAM constellation diagram.

2.1.3 Constellation Diagram

It can be seen from these few QAM constellation diagrams, that as the modulation order increases, so the distance between the points on the constellation decreases. Accordingly small amounts of noise can cause greater issues. The constellation for 16 QAM is shown in Figure 2.1



Hình 2.1 16 QAM Constellation Diagram

As the level of noise increases due to low signal strengths, so the area covered by a point on the constellation increases. If it becomes too large, then the receiver is unable to determine which position on the constellation the transmitted signal was meant to be, and this results in errors.

It is also found that the higher the order of modulation for the QAM signal, the greater the amount of amplitude variation is present on the transmitted signal. For transmitter RF amplifiers for everything from Wi-Fi to cellular and more, it means that linear amplifiers are required. As linear amplifiers are less efficient than those that can be run in saturation, it means that techniques like Doherty amplifiers and envelope tracking may be needed.

2.2 Error Correcting Code for Digital Communication

2.2.1 Binary Coding

A binary code represents text, computer processor instructions, or any other data using a two-symbol system. The two-symbol system used is often "0" and "1" from the binary number system. The binary code assigns a pattern of binary digits, also known as bits, to each character, instruction, etc. For example, a binary string of eight bits can represent any of 256 possible values and can, therefore, represent a wide variety of different items.

In computing and telecommunications, binary codes are used for various methods of encoding data, such as character strings, into bit strings. Those methods may use fixed-width or variable-width strings. In a fixed-width binary code, each letter, digit, or other character is represented by a bit string of the same length; that bit string, interpreted as a binary number, is usually displayed in code tables in octal, decimal or hexadecimal notation. There are many character sets and many character encodings for them.

A bit string, interpreted as a binary number, can be translated into a decimal number. For example, the lower case a, if represented by the bit string 01100001 (as it is in the standard ASCII code), can also be represented as the decimal number "97".

2.2.2 Gray Coding

The reflected binary code (RBC), also known just as reflected binary (RB) or Gray code after Frank Gray, is an ordering of the binary numeral system such that two successive values differ in only one bit (binary digit). For example, the representation of the decimal value "1" in binary would normally be "001" and "2" would be "010". In Gray code, these values are represented as "001" and "011". That way, incrementing a value from 1 to 2 requires only one bit to change, instead of two.

Gray codes are widely used to prevent spurious output from electromechanical switches and to facilitate error correction in digital communications such as digital terrestrial television and some cable TV systems.

Many devices indicate position by closing and opening switches. If that device uses natural binary codes, positions 3 and 4 are next to each other but all three bits of the binary representation differ:

The four-bit version of this is shown below:

Decimal	Binary	Gray	Gray Decimal
0	0000	0000	0
1	0001	0001	1
2	0010	0011	3
3	0011	0010	2
4	0100	0110	6
5	0101	0111	7
6	0110	0101	5
7	0111	0100	4
8	1000	1100	12
9	1001	1101	13
10	1010	1111	15
11	1011	1110	14
12	1100	1010	10
13	1101	1011	11
14	1110	1001	9
15	1111	1000	8

Hình 2.2 Comparison between gray coding and binary coding

For decimal 15 the code rolls over to decimal 0 with only one switch change. This is called the cyclic or adjacency property of the code.In modern digital communications, Gray codes play an important role in error correction. For example, in a digital modulation scheme such as QAM where data is typically transmitted in symbols of 4 bits or more, the signal's constellation diagram is arranged so that the bit patterns conveyed by adjacent constellation points differ by only one bit. By combining this with forward error correction capable of correcting single-bit errors, it is possible for a receiver to correct any transmission errors that cause a constellation point to deviate into the area of an adjacent point. This makes the transmission system less susceptible to noise.

2.3 Transmission Medium

2.3.1 AWGN Channel

Additive white Gaussian noise (AWGN) is a basic noise model used in information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

- Additive because it is added to any noise that might be intrinsic to the information system.
- White refers to the idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.

- Gaussian because it has a normal distribution in the time domain with an average time domain value of zero.

AWGN is often used as a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude. The model does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. However, it produces simple and tractable mathematical models which are useful for gaining insight into the underlying behavior of a system before these other phenomena are considered.

The AWGN channel is a good model for many satellite and deep space communication links. It is not a good model for most terrestrial links because of multipath, terrain blocking, interference, etc. However, for terrestrial path modeling, AWGN is commonly used to simulate background noise of the channel under study, in addition to multipath, terrain blocking, interference, ground clutter and self interference that modern radio systems encounter in terrestrial operation.

The probability density function p of a Gaussian random variable z is given by:

$$p_G(z) = \frac{1}{\sigma\sqrt{2\pi}}\varepsilon^{-\frac{(z-\mu)^2}{2\sigma^2}} \tag{2.1}$$

where,

$$\sigma = \frac{1}{10^{\frac{SNR}{10}}} \tag{2.2}$$

2.3.2 Rayleigh Fading Channel

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices.

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communication channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable. Rayleigh fading is a special case of two-wave with diffuse power (TWDP) fading.

Calling this random variable R, it will have a probability density function:

$$p_R(z) = \frac{2r}{\Omega}\varepsilon^{-\frac{r^2}{\Omega}}, r >= 0 \tag{2.3}$$

where $\Omega = E(R^2)$ To generate Rayleigh fading, we can use differnet methods, including Jake's method or Filtered White Noise.

2.4 Important Metrics for Evaluation of communication system

2.4.1 Signal-to-noise ratio

Since AWGN is represented by a Gaussian distribution, the standard deviation μ, in this case the signal-to-noise ratio (SNR) is taken into account, used as a reference for error measurement in wireless communication. In terms of definition, SNR or signal-to-noise ratio is the ratio between the desired information or the power of a signal and the undesired signal or the power of the background noise.

Also, SNR is a measurement parameter in use in the fields of science and engineering that compares the level of the desired signal to the level of background noise. In other words, SNR is the ratio of signal power to the noise power, and its unit of expression is typically decibels (dB). Also, a ratio greater than 0 dB or higher than 1:1, signifies more signal than noise.

To calculate SNR, divide the value of the main signal by the value of the noise, and then take the common logarithm of the result:

$$SNR = log(N/S)(dB) \tag{2.4}$$

For power:

$$SNR = 20log(N/S)(dB) \tag{2.5}$$

For voltage:

$$SNR = 10log(N/S)(dB) \tag{2.6}$$

2.4.2 Bit Error rate

The bit error rate (BER) is the number of bit errors per unit time. The bit error ratio (also BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. Bit error ratio is a unitless performance measure, often expressed as a percentage.

The bit error probability is the expected value of the bit error ratio. The bit error ratio can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long-time interval and a high number of bit errors.

Theoretically, for AWGN channel, one can use the following equation 2.7 to calculate BER with respect to SNR.

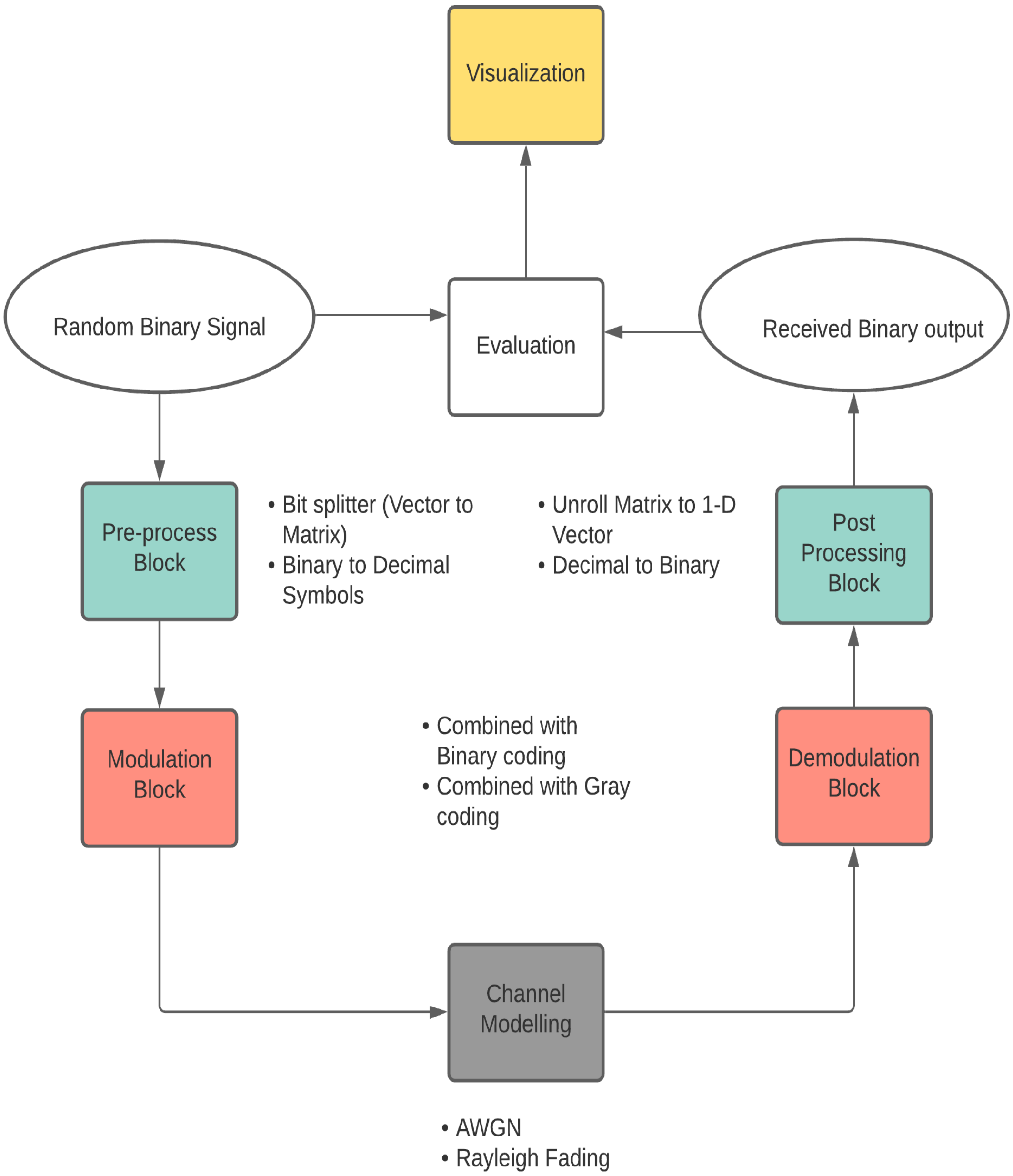
$$p_B = \frac{4}{n}(1 - \frac{1}{\sqrt{M}})Q(\sqrt{\frac{3n}{M-1}\frac{E_E}{N_0}}) \tag{2.7}$$

Plotting of BER versus SNR is frequently used in measuring the perfomance of different wireless communication systems, determining if they are proned to noise.

Chapter 3: Simulation

3.1 Workflow

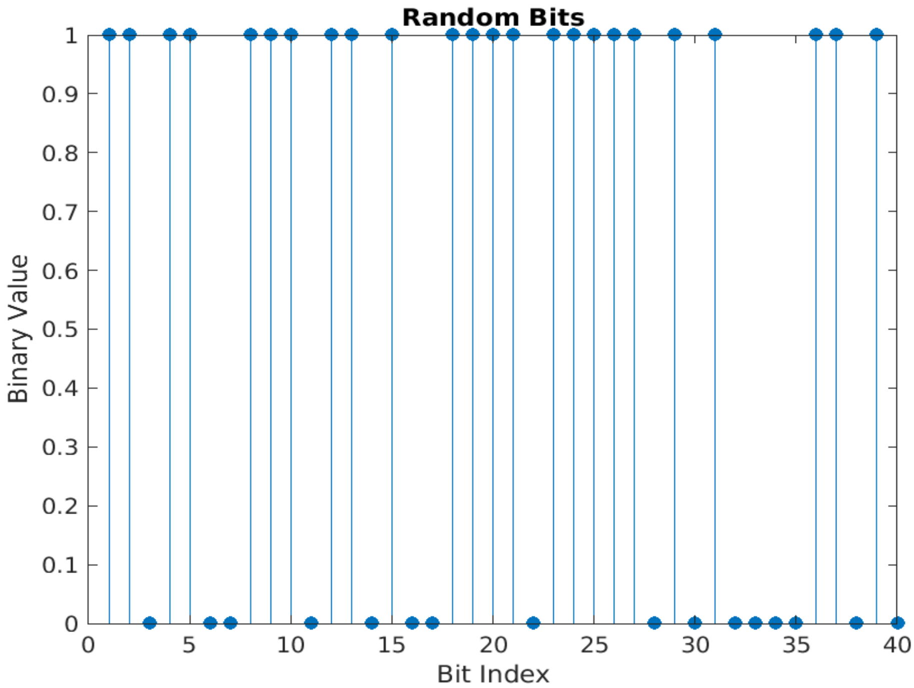
In order to design a system that can perfectly demonstrate SISO communication, we decided to choose MATLAB [1] as our programming platform. The whole simulation process is performed by compiling and running multiple MATLAB source code file which, each of which represents a respective block in Figure 3.1. We will then describe each block and their MATLAB implementation in the following sections.



Hình 3.1 Block diagram representing the workflow of our system

3.2 Preprocess and Postprocess blocks

First a vector of length 30000, containing random-generated binary input data is created using the *randi* function. Since QAM uses 4 bits to describe a symbol, it is necessary that the generated data be transformed into a shape of 7500x4, with each row represents a single symbol. After that, we use *bi2de* function, so as to convert each binary row to their decimal form counterpart.



Hình 3.2 A sample of randomly generated bits

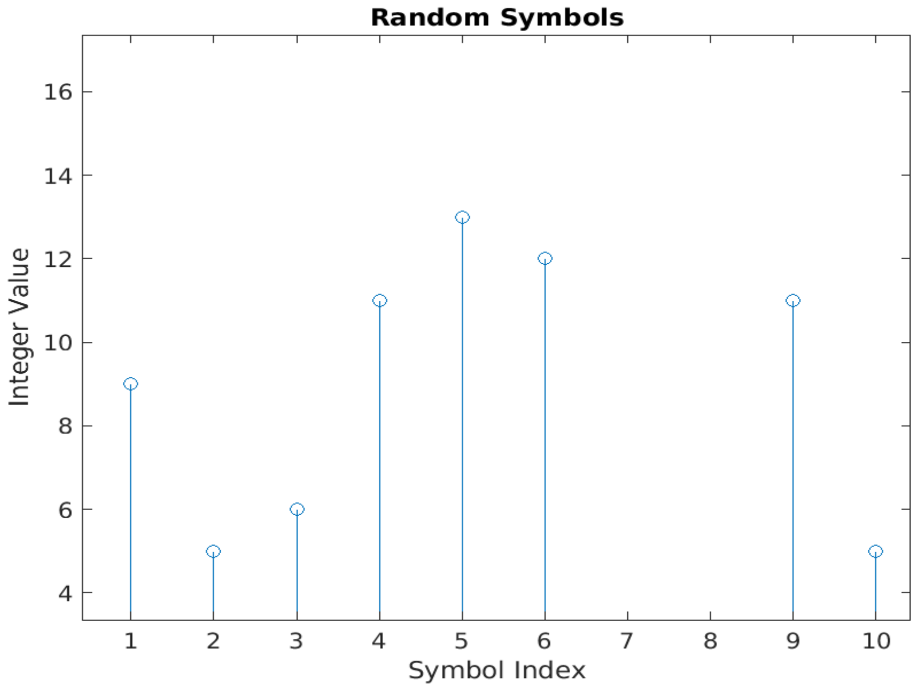
A reverse process is performed in the Post-Process block, where the demodulated decimal symbols is transformed back into 7500x4 binary matrix, using *de2bi* function, before being flattened as one-column vector. Both of the source files of pre and post-process blocks can be found on our GITHUB [] repository, named *preprocess.m* and *postprocess.m*

3.3 Modulation and Demodulation blocks

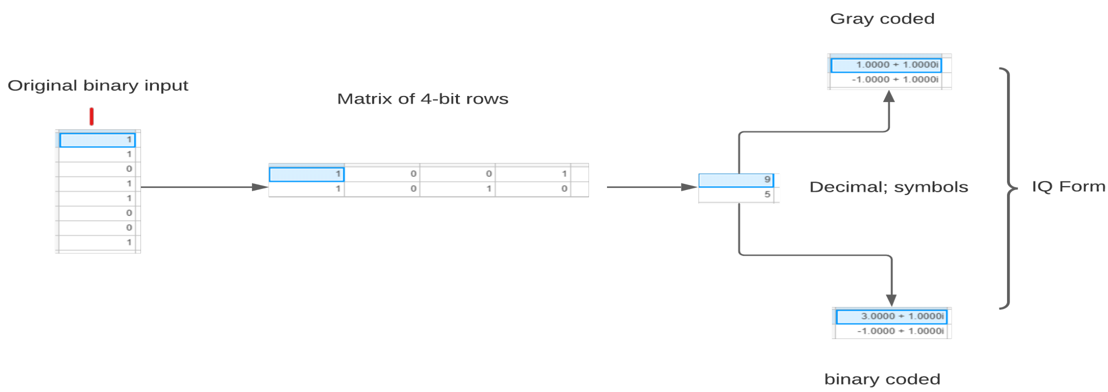
For both modulation and demodulation tasks, we use the *qammod.m* and *qamdemod.m* in Communication Toolbox of MATLAB. We change the *M* paramters to 16 for 16-QAM, and adding 'bin' and 'gray' configuration to compare the impact of both binary coding and gray coding; therefore, two streams of modulated signals are used for further transmission task. An IQ form of the modulated signals can be seen in Figure 3.5

3.4 Channel modelling

For both AWGN and Rayleigh Fading Channel, we applied the pre-configured system objects from Communication Toolbox. The standard deviation of Gaussian distri-

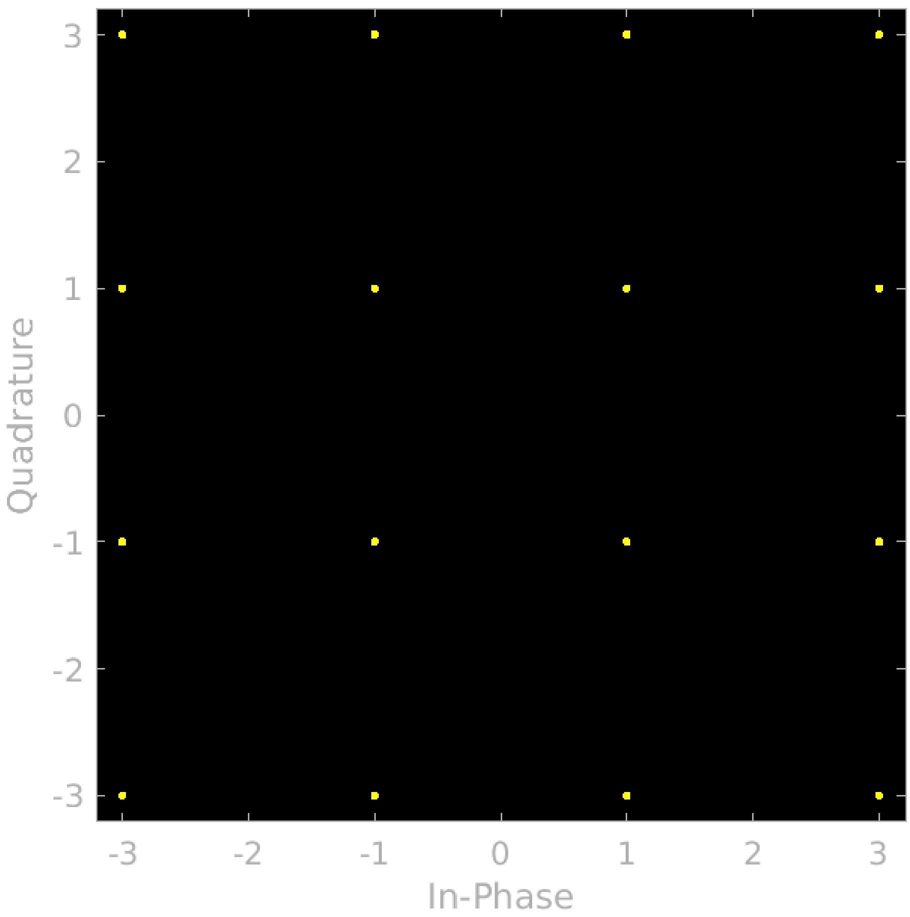


Hình 3.3 A sample of converted decimal symbols sequence, with the maximum value in the vector equals 16

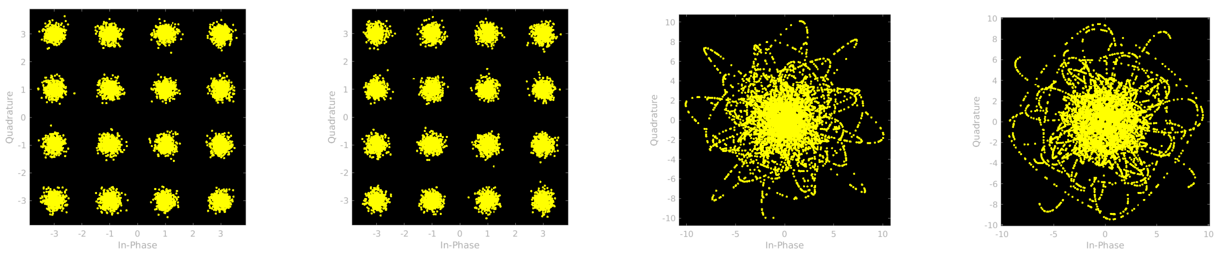


Hình 3.4 Flowchart describes how the data is processed

bution representing the AWGN channel changes for every element in a pre-defined *snr* array, with each σ is calculated using 2.2 The Rayleigh Fading channel is generated using Filtered-White-Noise technique. We passed both modulated, binary coded and gray-coded to each channel. Hence, 4 vectors of transmitted data are acquired at the receiver. Figure 3.6 suggests that the signals that passed through AWGN channel can retain more property of its original constellation form at the the transmitter's side. This implies that Rayleigh Fading Channel has more impact on the transmitted signals.



Hình 3.5 Constellation visualization of the modulated signals



(a) Binary coded-AWGN **(b) Gray coded-AWGN** **(c) Binary coded - Rayleigh Fading** **(d) Gray coded - Rayleigh Fading**

Hình 3.6 Constellation diagram of received signals

3.5 Evaluation block

For evaluating the BER between the received signals and their respective original counterparts, we calculate the total number of wrong bits in the received data, divide to the length of input vector. This can be done easily using *textitbiterr.m* function. For each value of SNR, we save four values of BER into four different arrays, due to the fact that we are dealing with 4 streams of data at the receiver. The stored BER values are then fed into the visualization block for further analyzing tasks.

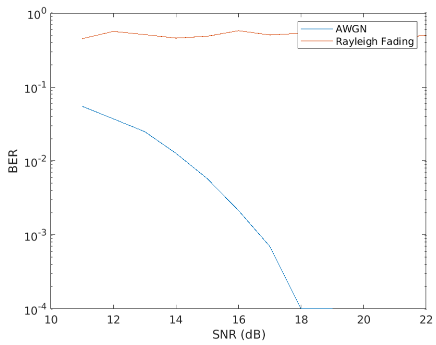
3.6 Visualization

Once we had acquired the BER between 4 couples of signals, plots would be generated, measuring the following metrics:

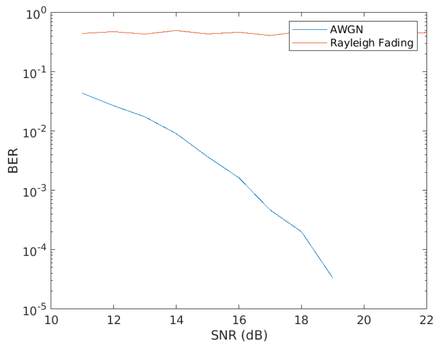
- BER versus SNR of AWGN-passed binary-decoded signals and Rayleigh-passed binary-decoded signals
- BER versus SNR of AWGN-passed gray-decoded signals and Rayleigh-passed gray-decoded signals

Chapter 4: Simulation result

As can be derived from Figure 4.1a and **??**, the BER of systems that used AWGN as transmission medium decrease as the SNR increase. This result perfectly fits to Equation 2.7. Also, it is notable that the BER of systems that use Rayleigh Fading Channel does not experience sufficient changes as the SNR increases, staying around the probability of 0.4 and 0.5, far greater than ones in AWGN cases. This result confirms that Rayleigh Fading Channel affects the transmitted signal at a far greater extend. Another thing worth mentioning in the blue lines is the fact that the system using binary-coded signal needs only an SNR value of 18 to reaches zero, which could not be observed in the case of gray-coded signal,



(a) Binary decoded signals



(b) Gray decoded signals

Hình 4.1 Compare BER versus SNR of systems that use different transmission medium. Figure 4.1a calculates BER in the received binary-decoded signals, while figure 4.1b calculates BER for received gray-decoded signals

The source code for this block can be found in file *visualization.m* in out Github repository, along with the code used to visualize Figure 3.1, 3.2, 3.3, 3.5, 3.6

Conclusion

The implementation with SISO communication using 16-QAM modulation has been shown in this project. Thanks to the guidance and support of Prof. Vu Van Yem, we managed to run the simulation of SISO system with 16-QAM modulation scheme.

Due to limited time and our incomplete knowledge, the project, undoubtedly, has several mistakes that need to be worked on more. Our group sincerely look forward to the lecturer's comments.

REFERENCES

[1] MATLAB, *version 7.10.0 (R2010a)*. Natick, Massachusetts: The MathWorks Inc., 2010.

The detailed version of our source code for this project could be found on this link https://github.com/minhna1112/16QAM-MATLAB