A MATLAB SIMULATION STUDY ON THE IMAGE TRANSMISSION THROUGH THE UNDERWATER ACOUSTIC OFDM SYSTEM WITH DIFFERENT DIGITAL MODULATIONS

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Abstract: *An image transmission underwater communications system has been researched and developed during the past years due to its potential applications in life, military, oil exploitation, and transportation. In this brief report, a study on the effect of the modulation method on the image communication through the underwater acoustic channel was performed. Based on the MATLAB simulator by Alamgir Mohammed, a simple multipath OFDM channel model was used in the transmission of the UTC-logo image. From obtained results, the performance parameters of the underwater OFDM channel with different digital modulation schemes of PSK (Phase-Shift Key), QAM (Quadrature amplitude modulation) were evaluated. As the consequences, the utilization of QAM-4 or PSK-4 at SNR=30dB can provide the best communication performance with the similarity values between the transmitted and received images are 0.786 and 0.595, respectively. Such simulation data can be used as theoretical guidelines in choosing appropriate transmission modulation parameters for image transmission underwater.*

Keywords: *underwater acoustic communication, image transmission, Matlab simulation, similarity.*

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I. INTRODUCTION

Underwater wireless communication (UWC) is a technique of sending and receiving data such as messages, voices, data, and images below water [1-11]. Since about 71% of the surface of Earth is water-covered, and the oceans hold about 96.5% of all water on Earth [12], the UWC has many important applications in life, military, and transportation such as underwater sports, diving purposes, navigation, autonomous underwater vehicles, remotely operated vehicles.

Compared to terrestrial communication, UWC seems more difficult and complicated owing to factors including time variations of the channel, strong signal attenuation, and multi-path propagation. So far, electromagnetic waves, optical beams and acoustic communication links have been used for UWC [11]. Among them, UAC (underwater acoustic communication) has been considered as the most potential method in the UWC because it brings about the great factors of power and communication distance. However, in UAC, the multipath propagation results from the fact that several replicas of the transmitted signal reach the receiver after traveling through different paths, with different attenuations and delays, which is the reason for the severe inter-symbol interference problem. In order to overcome that, OFDM (orthogonal frequency-division multiplexing) has been used in UAC since it can help to suppress inter-symbol interference and brings about higher spectral efficiency than a single carrier system [11]. As a survey for this study, Table 1 presents typically recent studies on the underwater OFDM based-communications links in the most active domestic and international researches where the audio, data, pseudorandom, and image are used as the source signal in simulations [1-10]. In particular, image is the one of the import information sources in modern life. It is more significant in the UWC because a received image exhibits many visual aspects of the objects inside a lake, a river, or undersea rather than other signal types. So far, there are a few studies of image transmission through water using an acoustic link with OFDM, thus many aspects of this topic might not be explored yet.

In this brief report, a very general study on the impart of modulation method on the image transmission through the underwater acoustic channel with different modulation factors was performed. Based on the MATLAB simulator by Alamgir Mohammed [12], a simple multipath OFDM channel was used in the transmission of the UTC-logo image. Two modulation techniques of QAM and PSK with different number of phases were examined. From obtained results, the performance parameter of the channel link including was evaluated and discussed in order to find out the optimal channel modulation.

Table 1. *Recent studies on underwater OFDM based-communications links*

Source signal	**Communication links**	**Modulation type**	**Published Year**	**Reference number**
Audio	Acoustic	BPSK	2016	[1]
Pseudorandom	Acoustic	QPSK	2018	[2]
Pseudorandom	Acoustic	QAM	2013	[3]
Pseudorandom	Acoustic	PSK, QAM	2014	[4]
Pseudorandom	Acoustic	PSK	2020	[5]
Pseudorandom	Optical	QAM	2016	[6]
Data	Acoustic	OQPSK	2015	[7]
Data	Optical	QAM	2017	[11]
Image	Acoustic	QAM	2019	[9]
Image	Acoustic	QAM	2013	[10]

II. AWC MATLAB SIMULATION FOR THE IMAGE TRANSMISSION

An illustrative scheme of the underwater OFDM communication for this study is presented in Fig. 1 developed from the MATLAB simulation created by Alamgir Mohammed [12]. In short, as a basic telecommunication channel, an input signal of a 256×256 UTC-logo image is encoded and converted to parallel, following by modulation and IFFT (Inverse Fast Fourier Transform) processes. The binary signal is inserted in the interval for noise suppression after its parallel-to-serial conversion. Then, the digital signal is converted to analog to provide to the acoustic actuator. The image is traveled underwater by the acoustic signal. At the receiver side, the acoustic signal is received and converted it to digital. The data stream is converted to parallel from serial after interval removal. Subsequently, after FFT (Fast Fourier Transform) step, demodulation and parallel to serial operations are performed. The UTC-logo image is reconstructed thanks to the encoder. The QAM and PSK methods with different the number of phases were used to modulate/demodulate each subcarrier in the OFDM system.

Regarding the channel modeling, a widely-used simple multipath system was used in this simulation [11,12]. It is well-know that the underwater multipath phenomenon is mainly original from reflection when acoustic waves bounce either at the surface or the bottom of the sea and reach the receiver side as shown in Fig. 2. It is worth noting that the number of received paths, attenuations, and delays should be random. In MATLAB, those important factors are simply represented as the "two-ray Rayleigh Fading" model with several factors of the power of paths, delays of the paths which are randomly generated by a computer. On the other hand, the path gain is a Rayleigh variable but does not change over time. The S/N (Signal-to-noise ratio) values and the phase parameters were manually inserted.

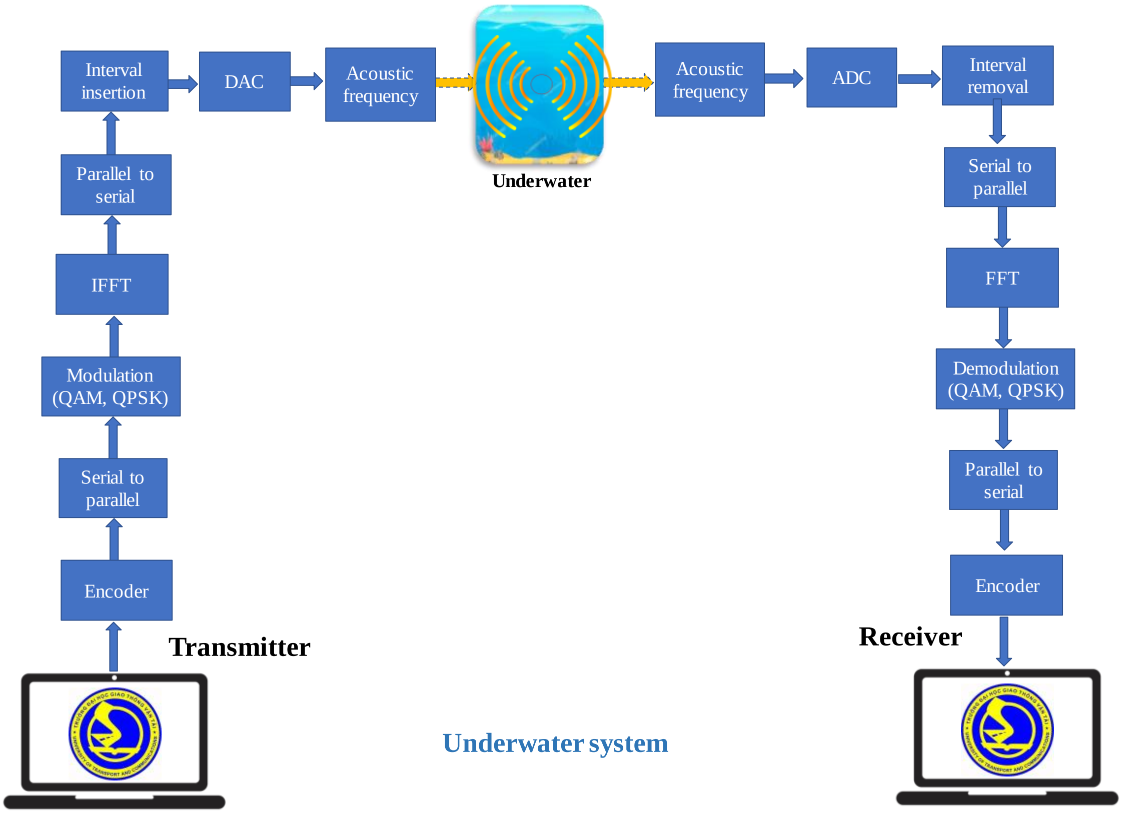

Figure 1. *Block diagram OFDM-based channel model in this simulation*

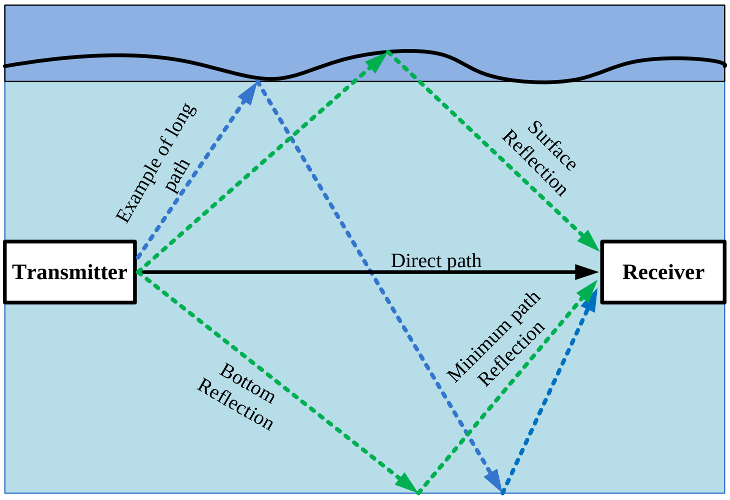

Figure 2. *Diagram of simple multipath channel used in this MATLAB simulator [13]*

On the other hand, figure 3 shows a typical photo taken during the simulation operation. A desktop computer configuration of Intel® Core ™ i5-4440 CPU @3.10GHz, 16.0 GB RAM, 64-Bit Operating System was used to run MATLAB simulator.

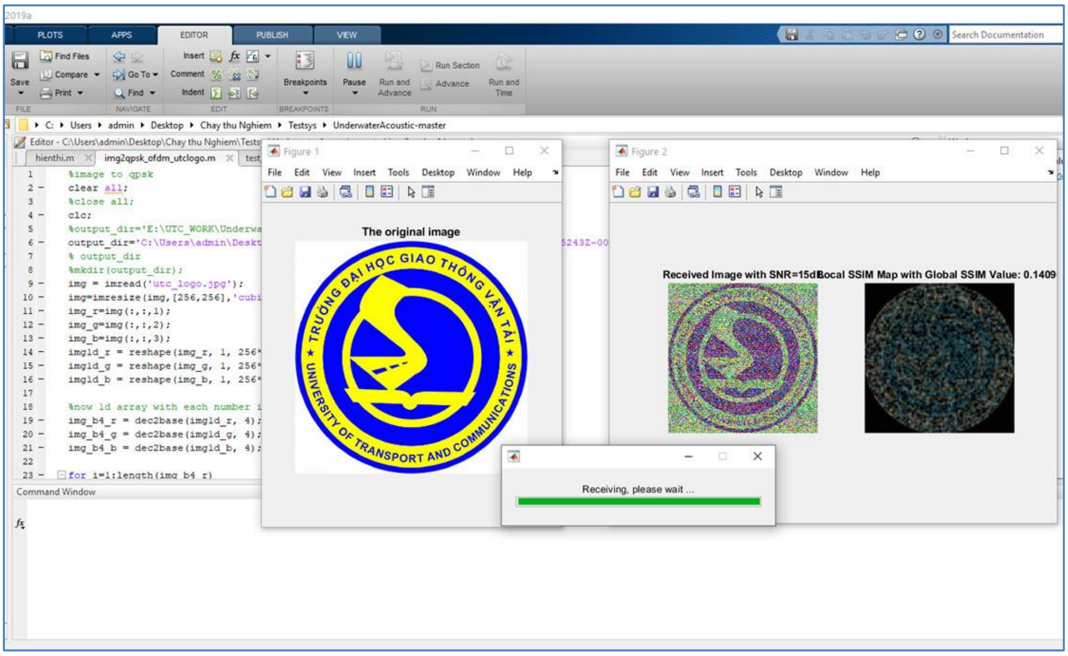

Figure 3. *Photo of simulation interface on MATLAB*

III. RESULTS AND DISCUSSION

After each simulation, the reconstructed image was collected and analytically compared with its transmitted image. Figure 4 shows some received UTC-logo images at the receiver side at different modulation methods under different SNR varied from 10 to 30 dB. To assess the quantitative performance of the system, firstly, the image processing aspect is considered. c. In the first method, MSE value is defined based on the differences between the corresponding pixels in the two images, as follows:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i,j) - K(i,j)\right]^2, \qquad (1)$$

where:

- $I(i,j)$ and $K(i,j)$ are the intensities at the location of the pixel (i,j) in image I and K, respectively.
- m and n are the width and height of each image, respectively.

From equation (1), it can be realized that a value of 0 for MSE indicates a perfect similarity. However, large distances between pixel intensities do not mean the contents of the two images are dramatically different. This is the drawback of this method, MSE value does not show the local differences between the two images. Therefore, in this study, the SSIM technique is employed to assess the similarity between the transmitted and received images. SSIM is defined as a loss function based on three features including luminance, contrast, and structure which is presented below equation [15]:

$$SSIM(x,y) = \frac{\left(2\mu_x\mu_y + c_1\right)\left(2\sigma_{xy} + c_2\right)}{\left(\mu_x^2 + \mu_y^2 + c_1\right)\left(\sigma_x^2 + \sigma_y^2 + c_2\right)}, \qquad (2)$$

where,

- μ_x, μ_y are the average of x, y, respectively;
- σ_x, σ_y are the variances of x and y, respectively;
- σ_{xy} is the covariance of x and y.
- $c_1=(k_1L)^2$; $c_2=(k_2L)^2$ are the two variables to stabilize the division with weak denominator
- L is the dynamic range of the pixel-values
- $k_1=0.01$ and $k_2=0.03$ by default

The SSIM value varies in range from 0 to 1. The higher SSIM value is, the more similar the two images will be. These features are the most important signature to represent a given image. The method in equation (2) was individually coded in a Matlab program to calculate the similarity between received and transmitted images. Table 2 shows the similarity between transmitted and received images at SNR=10 with a different number of phases in QAM-n or PSK-n. The similarity value decreased as increasing the bit number which can be explained that in UAC the increase of channel delay spread and intersymbol interference [11,16]. From Table 2, one can realize that the QAM-4 or PSK-4 in OFDM channel can help to achieve the best results.

Table 2. *Similarity between transmitted and received images in UAC with different number of phases at SNR=10*

QAM-n/PSK-n	4	8	16	32	64	128	256	512	1024
Similarity from QAM	0.371	0.192	0.148	0.444	0.019	0.032	0.017	0.015	0.022
Similarity from PSK	0.262	0.095	0.013	0.008	0.008	0.009	0.007	0.01	0.008

Table 3 presents similarities between the transmitted and received images under different modulation methods in three cases of SNR (10, 20, and 30 dB). By observing Table 3, the larger the number of phases, the lower the similarity is in both cases of using QAM and PSK modulation techniques. The higher similarity indicates the better quality of the received image as can be seen in Fig. 4. It is obvious that when SNR increases, the performance of the UWC system is improved. For example, when applying 4-QAM modulation method, SSIM is increased from 0.371 to 0.786 when increasing SNR from 10dB to 30dB. Additionally, in a comparison between QAM and PSK methods, QAM seems to be better than the other in all of the considered cases. The best results in each case of modulation methods are indicated in bold.

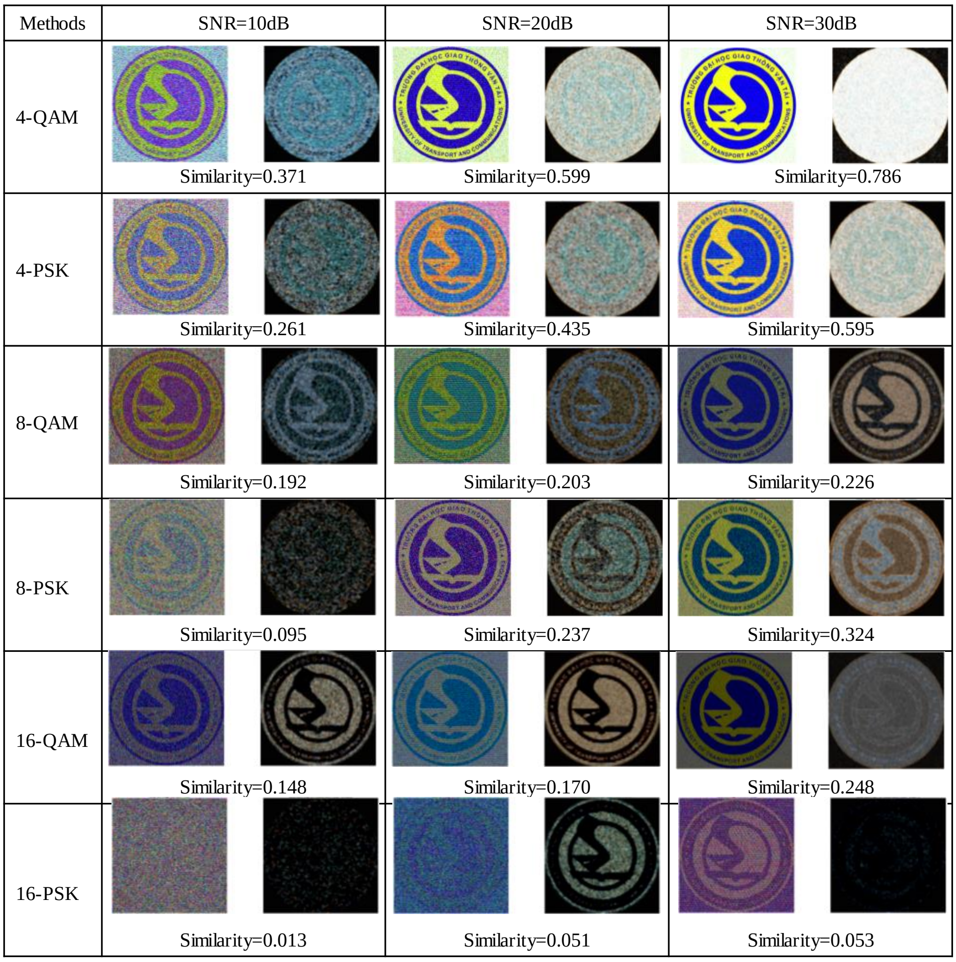

Figure 4*. Some examples for received images and SSIM map when applying different modulation methods under different SNR. In each column, the received images are in the left side and the SSIM maps are in the right side*

***Table 3**. The similarity between the transmitted and received images with different number of phases in QAM technique and SNR=10, 20, and 30dB*

The number of phases	**QAM**			**PSK**		
	SNR=10	SNR=20	SNR=30	SNR=10	SNR=20	SNR=30
4	0.371	0.599	**0.786**	0.262	0.435	**0.595**
8	0.192	0.203	0.226	0.095	0.237	0.324
16	0.148	0.170	0.248	0.013	0.051	0.053
32	0.444	0.372	0.367	0.008	0.023	0.027
64	0.019	0.039	0.092	0.008	0.026	0.037
128	0.032	0.032	0.033	0.009	0.020	0.044
256	0.017	0.026	0.026	0.007	0.027	0.042
512	0.015	0.014	0.032	0.010	0.025	0.044

On the other hand, besides computing SSIM value, Symbol Error Rate (SER) is estimated to explore another corner of the performance of the examined UWC system. Figure 5 shows the relationships between SER and Eb/No for QAM-4, QAM-8, and QAM-16. As can be seen, the SER tends to decrease as increasing Eb/No. Also, the SER increases as increasing the bit number of modulation. That is because when the number of modulation levels is higher, it is very difficult to perform demodulation at the receiver side due to the inherent characteristics of underwater [11]. This observation is in line that in UAC literature [6-11]. From the data in Fig. 5, the modulation scheme of QAM-4 is the most optimal which results in a similar meaning obtained from the similarity calculation in Table 3.

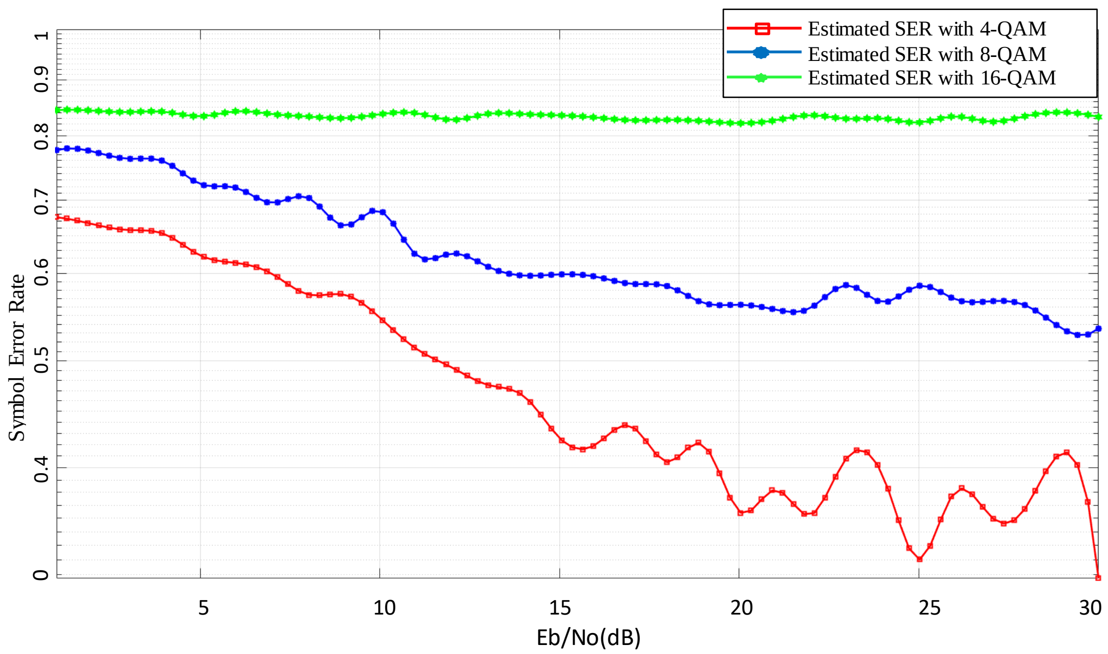

***Figure 5.** Symbol Error Rate vs. Eb/No*

IV. CONCLUSIONS

A study on the effect of the modulation method on image transmission through the underwater acoustic channel has been demonstrated. Based on the Alamgir Mohammed MATLAB simulation, a simple multipath channel OFDM model with the modulation schemes of PSK, QAM was used in the transmission of the UTC-logo image. The performance parameters of the channel including similarity and SER with different digital modulation schemes of PSK or QAM were calculated. Based on the obtained data, the utilization of QAM-4 and PSK-4 at SNR=30dB can provide the best communication performance with the similarity values between transmitted and received images are 0.786 and 0.595, respectively. Such simulation data may be used as theoretical references in choosing the suitable modulation parameters for image transmission underwater in some practical applications of military, oil exploitation, or transportation.

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