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OFDM-Receiver Design using Efficient Adaptive Modulation Techniques for Underwater Acoustic Communication

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ABSTRACT

Underwater Acoustic (UWC) Communication techniques are an interesting area of communication research, in which achieving high data rate, low latency and high throughput is challenging task. In this paper, we used the OFDM multicarrier modulation technique which is suitable for underwater acoustic communication for highly limited bandwidth to enhance the data rate at the receiver. We used efficient techniques which includes efficient adaptive modulation schemes and channel equalization to achieve high data rate in the receiver using OFDM scheme for UWC in the presence of channel noise (ambient noise). We focused on the efficient modulation schemes that suits for adaptive techniques based on the SNR values to enhance the data rate. Also we found some efficient modulation techniques like QPSK, DPSK and 16-QAM for underwater channel communication which are best in achieving high data rate by considering more subcarriers.

Key words: UWA, OFDM, Modulation schemes, Adaptive techniques, Channel noise.

I. INTRODUCTION

1.1. Underwater Acoustic communication

Acoustic communications is defined as communication methods from one point to another by using acoustic signals for communication. With respect to the design concept the underwater acoustic networks are very alike to land-based networks [1]. RF electromagnetic waves, acoustic waves and optical waves are the typical physical carriers for UWC [3]. RF waves are suffered by high attenuation in underwater thus they requires huge antennas and more transmission power [4]. Therefore, usually RF waves are used for short range communication in underwater (up to 10 meters) [5]. Optical waves are sometimes preferred for large data rate communications (in the range of a few Gb/s), but they are absorbed and scattered rapidly in underwater, this again leads to limited range communications [6]. Since the acoustic signals suffered from relatively low absorption, they can be used for long range communication instead of RF waves and Optical waves. This leads to making acoustic communication is the most UWC scheme [7].

Since, underwater channel is a time varying multipath channel it causes Inter Carrier Interference (ICI), Inter Symbol Interference (ISI) and channel fading [8]. Because of the detrimental effect of frequency spreading and time spreading, obtaining high data rate in UWAC is challenging [9].The frequency spreading of the underwater channel caused by the time varying dynamic motion of the medium and the movement between the transmitter block and receiver block.

1.2. Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is the multicarrier modulation technique for underwater communication which improves the data transmission rates and reliability [10]. The effective UWAC is usually affected by the parameters like large

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transmission delays, Doppler Effect, multipath channel fading and high power consumption. The underwater channel is highly limited in bandwidth and bandwidth efficient transmission techniques play an important role.

1.3. Bit Error Rate (BER)

Generally the BER is the number of bit errors occurred per unit time. In other way it is defined as the ratio of number of bit errors occurred to the total number of bits sent. The BER can be expressed mathematically as:

$$\mathrm{BER} = \frac{\text{Number of errors occurred}}{\text{Total number of bits sent}}$$

$$\mathrm{BER(dB)}=20\log_{10}(\mathrm{BER}) \quad (1)$$

We have seen that by considering the energy per bit to noise power spectral density (E_b/No) ratio, the BER might be affected by various parameters [11]. We can see that by changing the controllable variable, it is possible to achieve the performance which is required for our system.

II. PROPOSED WORK

There are so many ways to achieve the efficient data rate at the receiver in underwater communication namely, efficient adaptive modulation techniques, adaptive channel coding and equalization techniques, etc. There are so many digital modulation techniques which are well flourished in the communication field, choice of a suitable modulation technique for an application depends on many parameters such as data rate, bit error rate and design complexity etc. This paper includes so many techniques to achieve the efficient data rate by using the different modulation techniques, channel estimation and channel equalization techniques.

III. METHODOLOGY

OFDM in the form of Multi-carrier modulation technique finds its application in highly dispersive channel and is suitable for achieving high data rate in frequency selective underwater channels. The frequency-selective wide-band channel is transformed into flat frequency narrowband channels, leading to robust communication in large delay spread channels. OFDM allows overlapping between the subcarriers and hence the available limited channel bandwidth can be efficiently utilized. The proposed OFDM system is shown in figure (1).

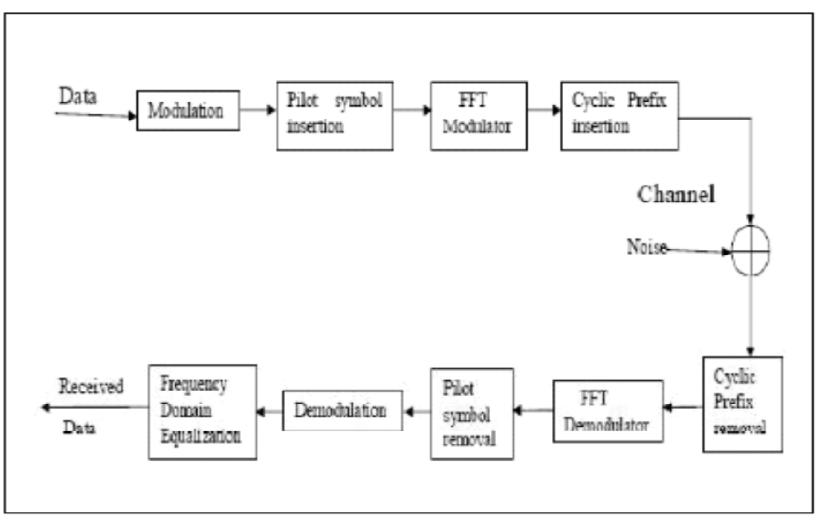

Figure 1: Block diagram of proposed OFDM system

3.1. Adaptive Modulation Techniques

The main objective of this article to design the efficient Transceiver is to enhance the data rate. To achieve this objective we proposed highly efficient adaptive modulation techniques for underwater communication [2]. In this paper we established some efficient adaptive modulation schemes such as QPSK, DPSK and 16-QAM for underwater acoustic communication in order to get high data rates by considering more subcarriers (256 subcarriers). In this experiment we experimented and analyzed individual modulation scheme results with OFDM for underwater communication. Initially we assumed the Eb/No ratio from 1 to 30 and using the Eb/No values we calculated the SNR values initially. Thus we made the OFDM system to switch the appropriate modulation scheme depends upon the SNR range and by applying such adaptive schemes in the OFDM system we can enhance the data rate at the receiver.

3.2. Cyclic Prefix and Pilot Symbol

By using the cyclic prefix, it enables the OFDM signal to operate reliably. The OFDM signals are defended from ICI by using the cyclic prefix. In this experiment we used the cyclic prefix of length 16 to avoid the OFDM signals from inter symbol interference. A pilot signal is a signal that transmitted over a communications system for control, equalization and supervisory or reference purposes[14]. In this experiment we insert the pilot symbols of length 4 for each frame in the transmitter side and after FFT algorithm we removing the pilot symbols at the receiver side.

3.3. FFT Algorithm and Orthogonality of subcarriers

The capability to generate and to demodulate the signal with the use of FFT algorithm [12] is one of the main factors for OFDM to become popular in transmission schemes. By using IFFT/FFT techniques, implementation of modulation and demodulation is computationally efficient. The orthogonality helps for efficient transceiver design using the inverse FFT on the transmitter side the FFT algorithm on the receiver side.

OFDM transmitter transmits more number of narrowband sub channels. The frequency range should be chosen very carefully in order to make the carrier signals to be orthogonal each other. We assumed that the distance between the sub-carriers is $1/T_o$, where T_o is the interval of an OFDM symbol. In figure 2, the frequency spectrum of an OFDM transmission is shown. At the central frequencies, the ICI is cancelled, although the individual spectra of subcarriers overlap. By using the correlation techniques we can separate the orthogonal signals at the receiver side.

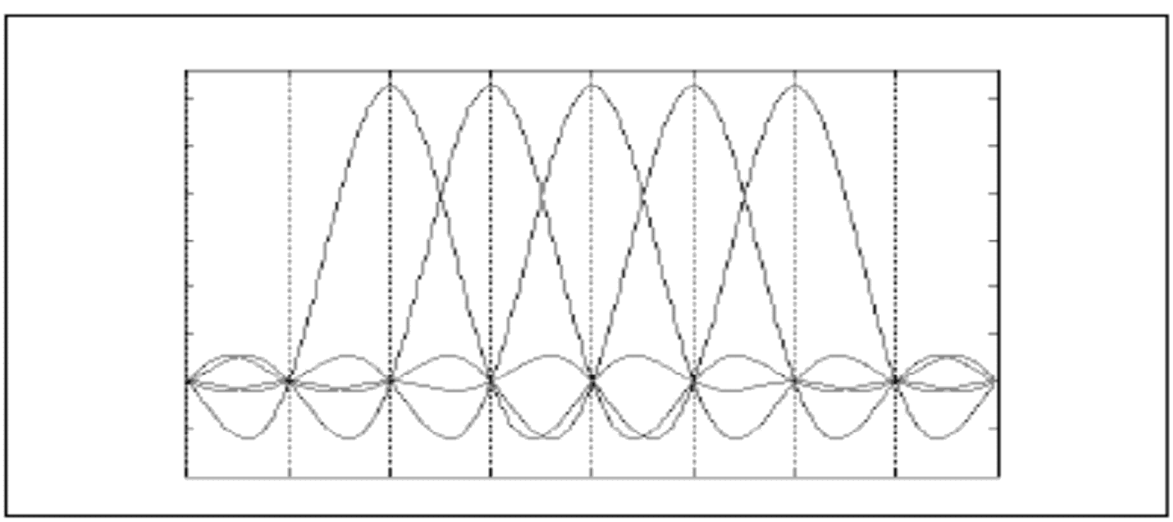

Figure 2: OFDM transmission spectrum

3.4. Transmission Loss

Transmission loss (TL) is generally occurred due to two factors: attenuation and geometric spreading loss. For a signal of frequency f_o over a transmission interval $d_{o,}$ the transmission loss [in dB] can be obtained by

$$10\log TL(d_0, f_0) = k * 10\log(d_0) + d_0 * \alpha(f_0) + A \tag{2}$$

Where, k= spreading factor

$\alpha(f)$ is the absorption coefficient in dB/m

A=transmission anomaly in dB

f_o = frequency of a signal (kHz)

d_o= transmission distance (m)

3.5. Acoustic Noise

The Acoustic Noise occurred is mainly caused by shipping activities and machinery noise. The assistance of the major noise sources can be expressed by equations (3) to (6) that give PSD's of each noise source with respect to frequency f_o [kHz] in [dB].

$$10\log N_t(f_0) = 17 - 30\log f_0 \tag{3}$$

$$10\log N_s(f_0) = 40 + 20(s - 5) + 26\log f_0 - 60\log(f_0 + 0.03) \tag{4}$$

$$10\log N_w(f_0) = 50 + 7.5w^{0.5} + 20\log f_0 - 40\log(f_0 + 0.4) \tag{5}$$

$$10\log N_{th}(f_0) = -15 + 20\log f_0 \tag{6}$$

Where N_t, N_s, N_w and N_{th} represents turbulence noise, shipping noise, wind noise and thermal noise respectively. For a given frequency f_o the total noise power spectral density is given by

$$N(f_0) = N_t(f_0) + N_s(f_0) + N_w(f_0) + N_{th}(f_0) \tag{7}$$

3.6. Attenuation

Attenuation can be generally attributed to absorption, due to the translation of energy of the propagating acoustic wave into heat. The absorption coefficient can be calculated as

$$\alpha(f_0) = \left(0.002 + 0.11\frac{{f_0}^2}{{f_0}^2+1} + 0.011{f_0}^2\right) * 10^{-3} \tag{8}$$

The Signal-to-Noise Ratio (SNR) can be calculated using the transmission loss TL (d_o, f_o) and the noise power spectral density N (f_o) over an interval 'd_o' when the transmitted signal has a frequency of 'f_o' and power 'P_o' is given by

$$SNR(d_0, f_0) = \frac{P/TL(d_0,f_0)}{N(f_0)\Delta(f_0)} \tag{9}$$

Where $\Delta(f_0)$ indicates the receiver noise bandwidth. The parameters we considered for this experiment are listed in the table 1.

IV. RESULTS AND DISCUSSIONS

In this paper our main objective is to achieve high data rate at the receiver for underwater acoustic communication channel using OFDM technique. To achieve this objective so many ways are there but in this paper we focused only on finding the efficient adaptive modulation techniques which are suitable in the underwater channel even in the presence of AWGN noise and channel noise that includes Thermal noise, Turbulence noise, Wind noise and Shift noise. The effect of these noises and the absorption coefficient over frequency range of 1 kHz to 10 kHz is shown in figures (3) and (4). We concentrated more on the

Table 1
OFDM Parameters

No of subcarriers	*256*
Cyclic prefix length	16
Sampling period of channel	$1e^{-3}$
Max Doppler frequency shift	0
Distance , d_o	10m
No of OFDM frames	1000
FFT size	256
Carrier frequency, f_o	8KHz
Receiver noise bandwidth	2KHz
No of pilot symbols	4
Modulation schemes	**QPSK, DPSK, 16-QAM**

modulation schemes like QPSK, DPSK and 16-QAM. These schemes will give better performance compare to other modulation techniques. Using the equation (9) we calculated the SNR. Based on the Eb/No or SNR values, we experimented which modulation scheme will give better performance with respect to Bit Error Rate (BER) performance. During this experiment observed that the QAM, DPSK and QPSK modulation schemes are suitable for high range, medium range and low rang SNR respectively. The simulation results of comparison of transmitted signal and received signal for every modulation techniques and BER performance for every modulation schemes by considering simulation and theoretical results are shown in figure (5) to figure (10) and the simulation results are summarized in table 2.

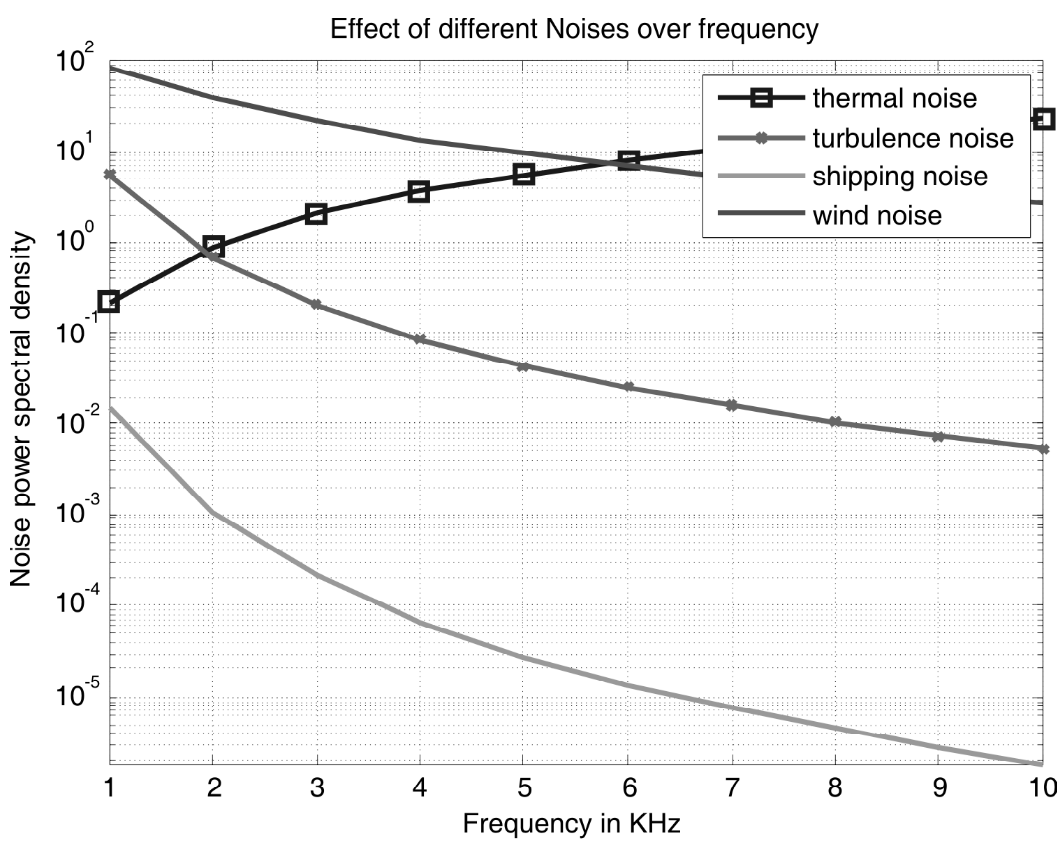

Figure 3: Effect of Thermal Noise, Turbulence noise, Shipping Noise and Wind noise over frequency 1 kHz to 10 kHz

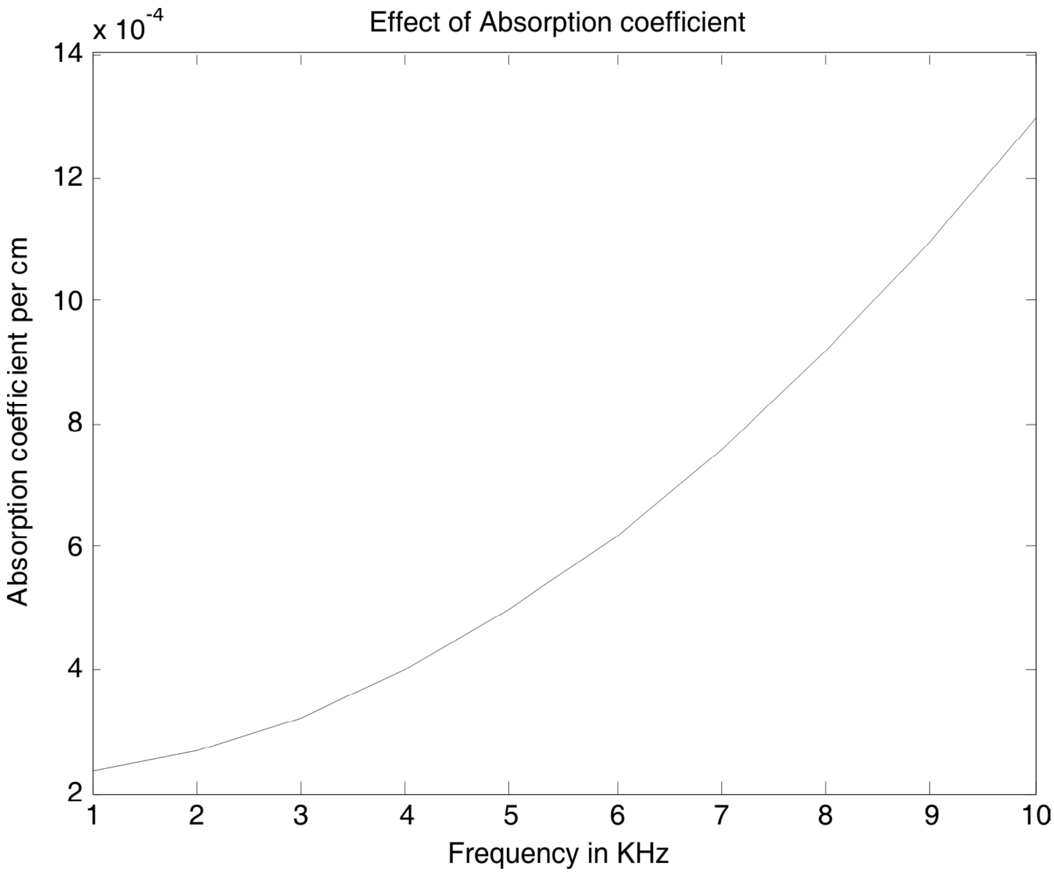

Figure 4: Effect of Absorption coefficient over the frequency range 1 kHz-10 kHz

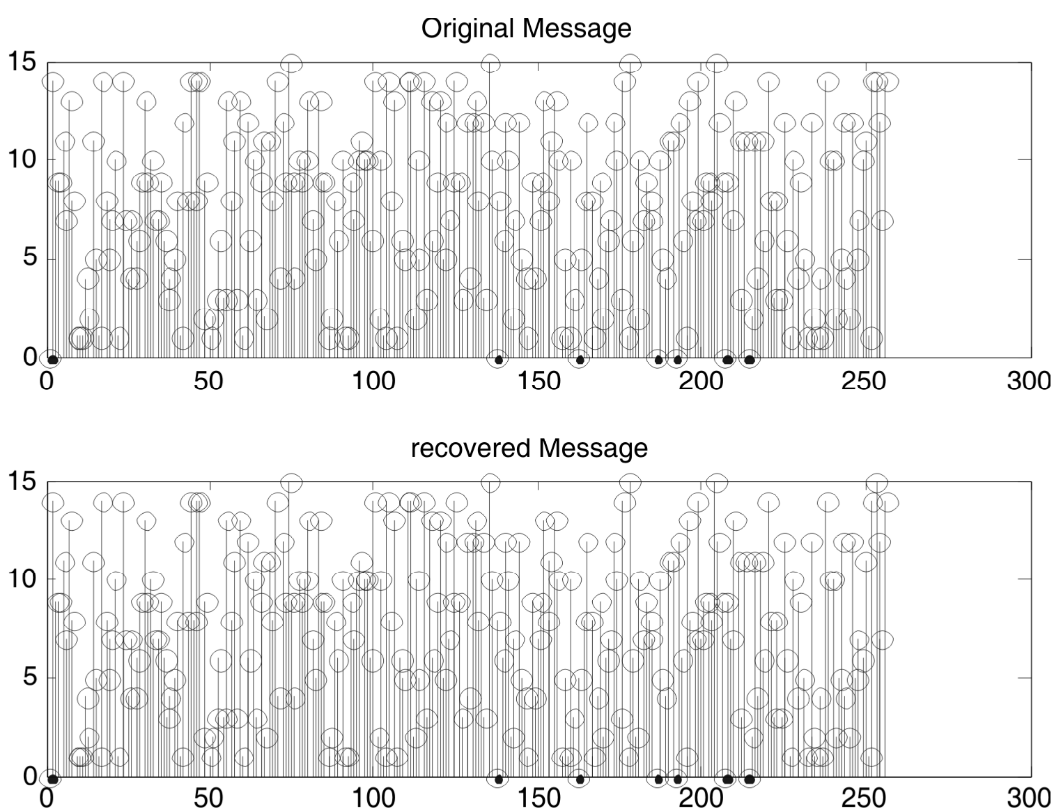

Figure 5: Comparison of transmitted and received message using 16-QAM modulation

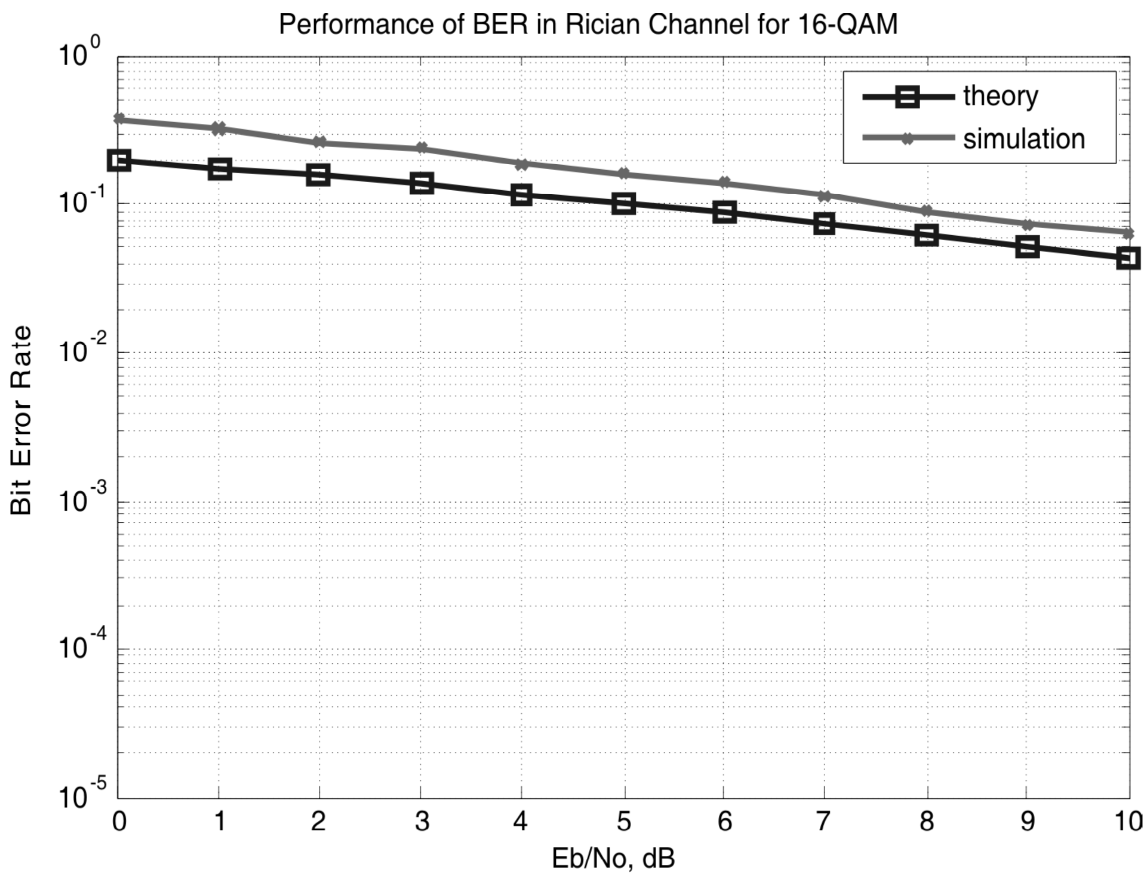

Figure 6: BER performance in Rician channel for 16-QAM

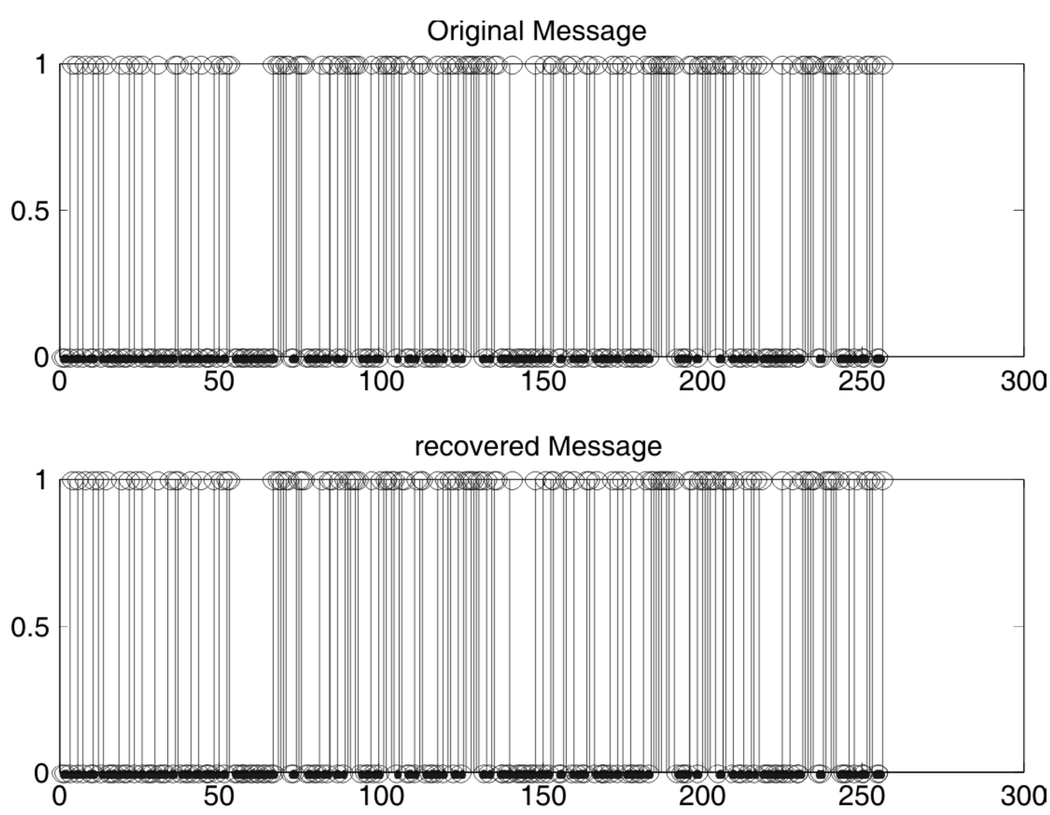

Figure 7: Comparison of transmitted and received message using DPSK modulation

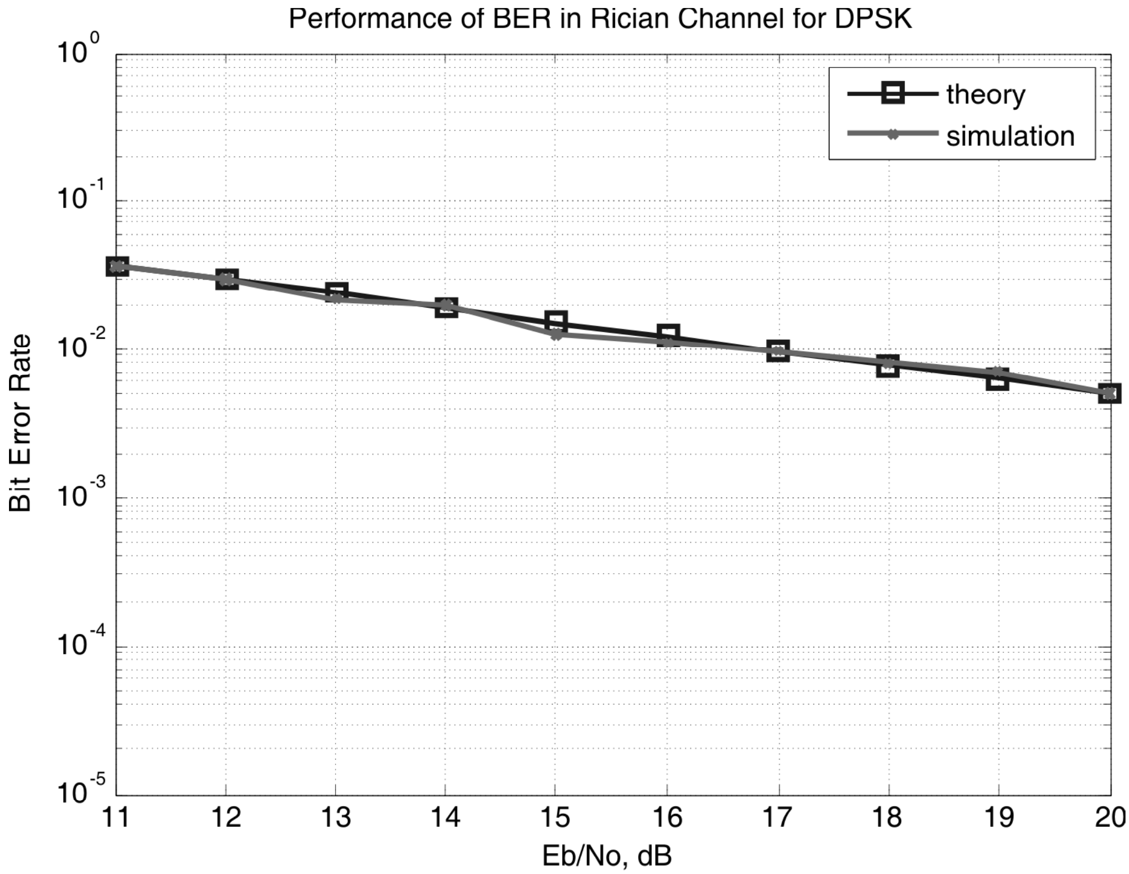

Figure 8: BER performance in Rician channel for DPSK

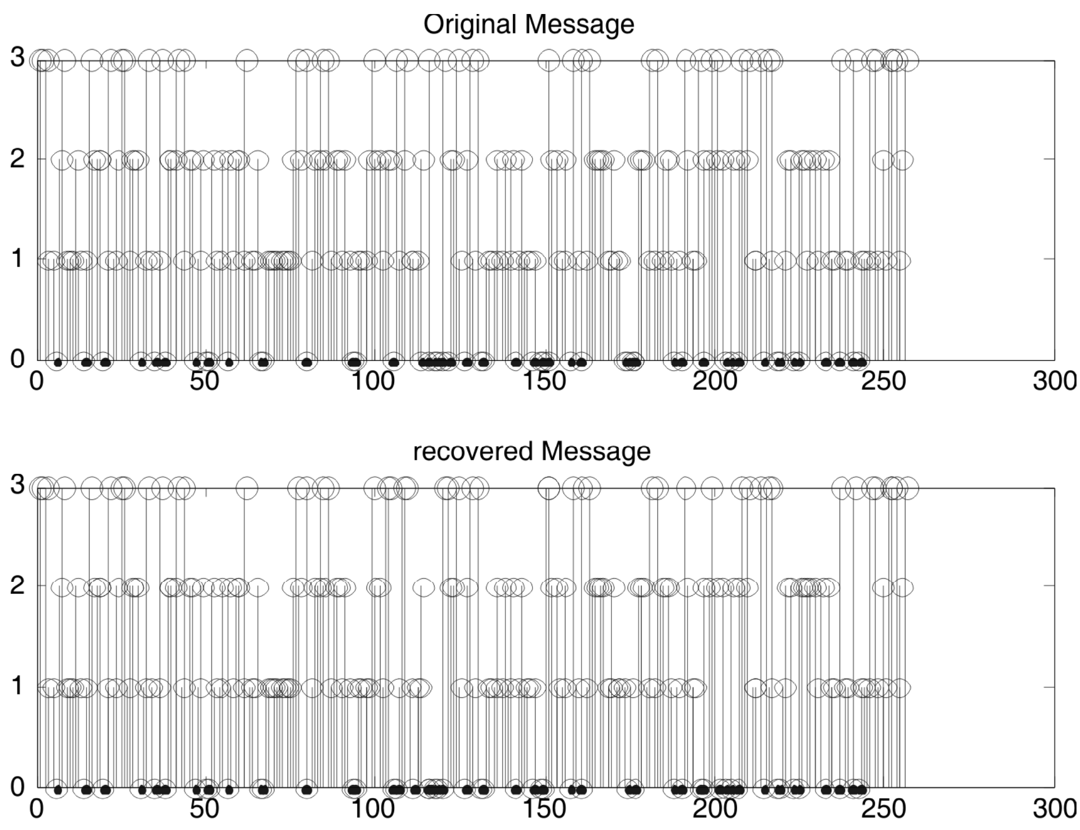

Figure 9: Comparison of transmitted and received message using QPSK modulation

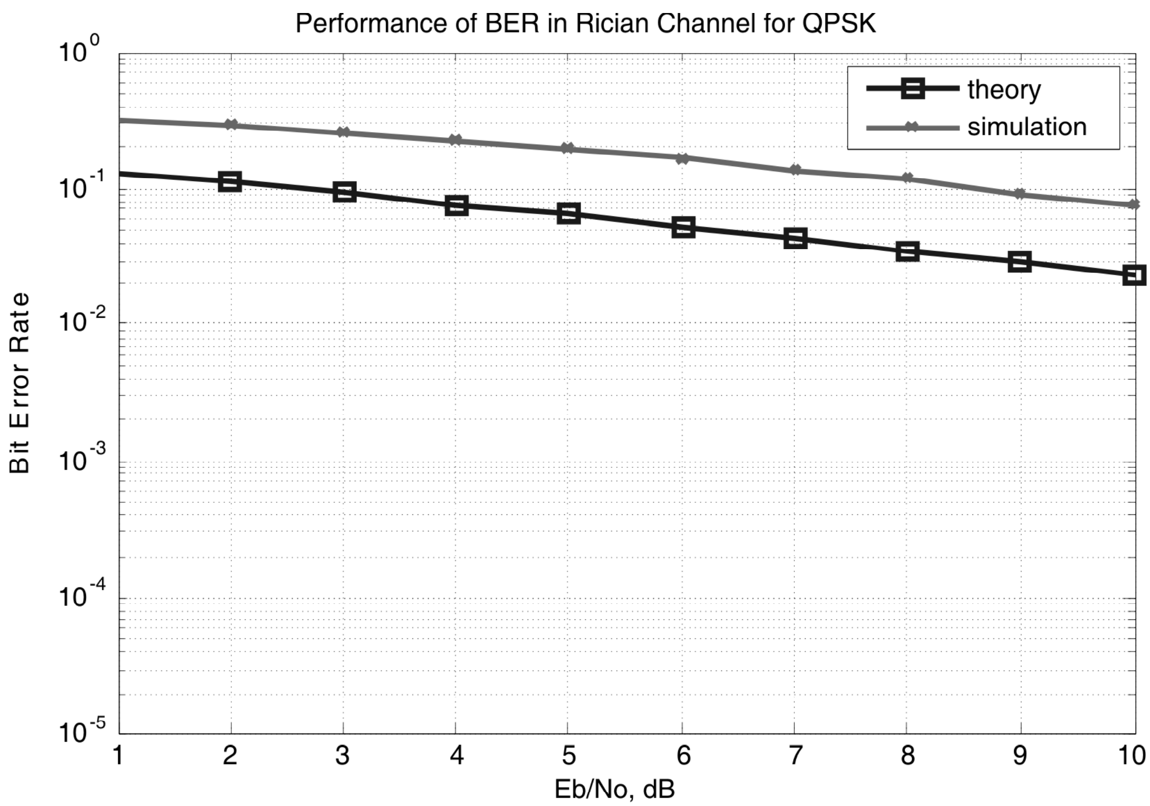

Figure 10: BER performance in Rician channel for QPSK

Table 2
Simulation results of different OFDM modulation schemes

Modulation Technique	*Range of Eb/No in dB*	*Theoretical BER*	*BER from simulation*
16-QAM	1-10	0.1200	0.1732
DPSK	11-20	0.0166	0.0162
QPSK	21-30	0.0726	0.2012

5. CONCLUSION AND FUTURE WORK

Underwater Acoustic (UWC) Communication techniques are an interesting area of communication research. Achieving high data rate, low latency and high throughput is challenging task in UWC. To achieve these issues we tried the techniques that include Adaptive modulation schemes and equalization schemes with OFDM multicarrier modulation technique. From the simulation results we observed that some modulation schemes like QPSK, DPSK and 16-QAM are the best adaptive modulation schemes for underwater acoustic communication for highly limited bandwidth even in the presence of channel noise. Thus by using the adaptive technique in the modulation schemes based on the SNR values, we can achieve high data rate and design efficient OFDM Receiver. In future we can achieve high data rate in the receiver in the other way like channel estimation and channel coding, etc. for limited bandwidth, low latency and high throughput. We can design the receiver and verify the performance using numerical simulation and Mathematical model.

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