OFDM Receiver Design using Adaptive Modulation and Channel Estimation based on Kalman filter Variations for Underwater Acoustic Communication

Ravi Kumar M G, Mrinal Sarvagya

Abstract*— This paper deals with enhancement of data rate in OFDM system using Adaptive modulation and Channel estimation for Underwater Acoustic Communication (UAC). The accurate knowledge of the channel aids equalization and symbol detection. Since the Kalman filter is an optimal estimator in nature, which is proposed to address the problem of channel tracking in fading environment. The random data is modulated using DPSK, QPSK and 16-QAM and transmitted over the channel. Pilot bits and cyclic prefix are used for channel estimation and to protect from the Inter symbol interference (ISI) respectively. The channels under consideration in this work are AWGN and Rayleigh. The Kalman filter operates over the data bits to estimate the channel parameters. At the receiver end demodulation and symbol detection is performed and the same model is implemented in MATLAB. The simulation results for OFDM system are compared based on the BER and MMSE for the two mentioned channels. The simulation results shows that Adaptive modulation yields better result compared to individual modulation schemes and the simulation results also prove that the Kalman filter is an excellent estimator and predictor which finds its application in channel estimation in OFDM systems.

***Index Terms*—OFDM, Underwater Acoustic Communication, Adaptive modulation, Kalman filter, Channel estimation**

I. INTRODUCTION

In recent years, Orthogonal Frequency Division Multiplexing (OFDM) based communication system has been identified as one of the key transmission method for the next generation wireless communication systems[1]. The main advantages of OFDM are handling the multi-path interference and mitigate inter-symbol interference (ISI) causing bit error rates in frequency selective fading environments[2,8]. In wireless communications, Underwater acoustic (UWA) channels are considered as some of the most challenging communication media, generally characterized by low propagation speed of sound in water (nominally 1500 m/s), limited bandwidth and randomly time-varying multipath propagation which results in frequency-selective fading [1][13].

Since OFDM system is robust to inter symbol interference, it is widely used for broadband wireless communication systems[7]. Here we use OFDM because of its high resistance to multipath fading characteristics as well as more High spectral efficiency of a large number of applications[9].

Time-varying multipath propagation and limited bandwidth are the two main constraints in achieving the high throughput of UWA communication systems [22]. In order to support high spectral efficiencies over long time intervals in such non-stationary environment, we consider communication systems employing adaptive modulation schemes [13, 22]. Here, Kalman filter based channel estimation is proposed. Distinctive feature of Kalman Filter is that its mathematical formulation is represented in the form of state-space model and also its solution is computed recursively applying without modification to stationary as well as non-stationary environments [2, 22]. In this work, we focusing more on the efficient adaptive modulation schemes, Kalman filter based Channel estimation and Equalization techniques to achieve the objectives.

The section 1 introduces the Proposed OFDM system model for the acoustic underwater channels including the Rayleigh and Ricean environment. The section 2 focuses on the techniques accomplished to achieve the goals which include Adaptive Modulation, Channel estimation using Kalman filter and Extended Kalman filter. A brief introduction to the Kalman Filter and Extended Kalman filter is made. The section 3 shows the simulation results and discussed about the simulation results and comparison table. The conclusion and future work are described later.

II. SYSTEM MODEL

2.1. OFDM Architecture over Fading Channel

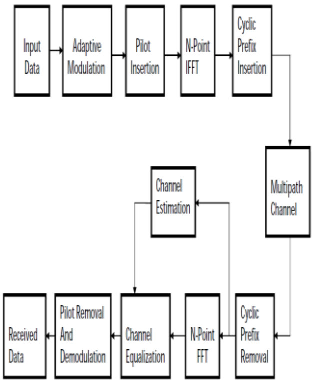

Figure 1: Proposed OFDM system

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We consider an OFDM system as in Figure 1 with *N* data subcarriers. Input data considered as random serial binary data, converted to a parallel stream and modulated with modulation techniques. The modulation is implemented by *N*-point inverse discrete Fourier transform (IDFT) for the symbol vector

$$X_n = [X_n(0)\, X_n(1) \ldots\ldots X_n(L-1)]^T \qquad (3)$$

is

$$x_n = IFFT[X_n] = \frac{1}{N}\sum_{k=0}^{N-1} X_n(k)\, e^{j2\pi kn} \qquad (4)$$

The length of N_p pilot symbols inserted to the modulated signal for supervisory, control, equalization, continuity, synchronization, or reference purposes. The Cyclic prefix of length C_p is added to the transmitted symbol before it passing through the fading channel by converting from parallel to serial data. The received data corrupted by fading channel and AWGN becomes

$$y_n = \sum_{l=0}^{L-1} h_n(l)\, x_n(l) + z_n \qquad (1)$$

In the receiver part, the demodulation removes the cyclic prefix and taking *N*-point DFT of the received vector becomes

$$Y_n = [Y_n(0)\, Y_n(1) \ldots\ldots Y_n(N-1)]^T \qquad (2)$$

At the receiver, the channel estimator is followed by frequency domain equalizer. After equalization, the estimated symbol at the k^{th} symbol becomes

$$\hat{X}_n(k) = \frac{Y_n(k)}{\hat{H}_n(k)} = \frac{X_n(k)H_n(k)}{\hat{H}_n(k)} + \frac{Z_n(k)}{\hat{H}_n(k)} \qquad (3)$$

where is $\hat{H}_n(k)$ the estimate of $H_n(k)$. The estimated symbols $\hat{X}_n(k)$ are then demapped to output bits.

2.2 OFDM UWA Communication Problems

UWA channel offers numerous hurdles to the UWA communication and distorts the signal in many ways, which is likely to be restored by channel estimation and equalization techniques. The following are few of the problems being faced specifically by OFDM UWA communication:

2.2.1 Transmission Loss:

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

$$10\log \mathrm{TL}(d_0, f_0) = k * 10\log(d_0) + d_0 * \alpha(f_0) + A \qquad (4)$$

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)

2.3.2 Acoustic Noise:

The Acoustic Noise occurred is mainly caused by shipping activities and machinery noise[2]. 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].

$$10\log N_t(f_0) = 17 - 30\log f_0 \qquad (5)$$

$$10\log N_s(f_0) = 40 + 20(s-5) + 26\log f_0 - 60\log(f_0 + 0.03) \qquad (6)$$

$$10\log N_w(f_0) = 50 + 7.5w^{0.5} + 20\log f_0 - 40\log(f_0 + 0.4) \qquad (7)$$

$$10\log N_{th}(f_0) = -15 + 20\log f_0 \qquad (8)$$

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

$$N(f_0) = N_t(f_0) + N_s(f_0) + N_w(f_0) + N_{th}(f_0) \qquad (9)$$

2.3.3 Attenuation:

Attenuation can be generally credited to absorption, due to the transformation of energy of the propagating acoustic wave into heat[2, 22]. The absorption coefficient can be calculated as

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

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

$$SNR(d_0, f_0) = \frac{P/TL(d_0, f_0)}{N(f_0)\Delta(f_0)} \qquad (12)$$

Where $\Delta(f_0)$ indicates the receiver noise bandwidth.

III. METODOLOGY

3.1 Adaptive Modulation

Adapting the transmitter to the channel characteristics has been considered in different forms, including active time-reversal and single-mode excitation [17]. In this paper we establish some efficient modulation schemes such as DPSK, QPSK and 16-QAM for Underwater Acoustic communication in order to enhance the data rate at the OFDM Receiver. Initially we assumed that the E_b/No ratio from 1 to 30 dB and we calculated the SNR values initially by using the empirical model. Thus we did the OFDM system to switch the appropriate modulation scheme which depends upon on the SNR range. By applying adaptive technique in the modulation schemes we can enhance the data rate at the OFDM receiver.

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3.2 Channel Estimation using Kalman Filter

Channel estimation is a scheme, in which the channel state information is retrieved by using the channel impulse response. Kalman filtering is an efficient technique to remove impurities in linear systems [22] [2].

3.2.1 State Space Model of Kalman Filter

A State - Space representation is a mathematical model of a physical system as a set of input, output and state variables related by first order differential equations. For a signal x(t) and noisy observation y(t), equations describing the state process model and the observation model are defined as:

$$x(t+1) = Ax(t) + W(t) \quad (13)$$
$$y(t) = Cx(t) + V(t) \quad (14)$$

Where A and C are the input matrices and W and C are the noises.

3.2.2 Kalman Filter Algorithm

Prediction for state vector and covariance:

$$\bar{x} = Ax + Bu$$
$$\bar{P} = APA^T + Q$$

Kalman gain factor:

$$K = \bar{P}\,H^T(H\bar{P}H^T + R)^{-1}$$

Correction based on Observation:

$$x = \bar{x} + K(z - H\bar{x})$$
$$P = \bar{P} - KH\bar{P}$$

A and B are the State transition matrix and Input matrix respectively. x(t) is the N-dimensional signal vector. P is the covariance of state vector estimate. z and H is the Observation vector and Observation matrix respectively.

3.3 Extended Kalman Filter

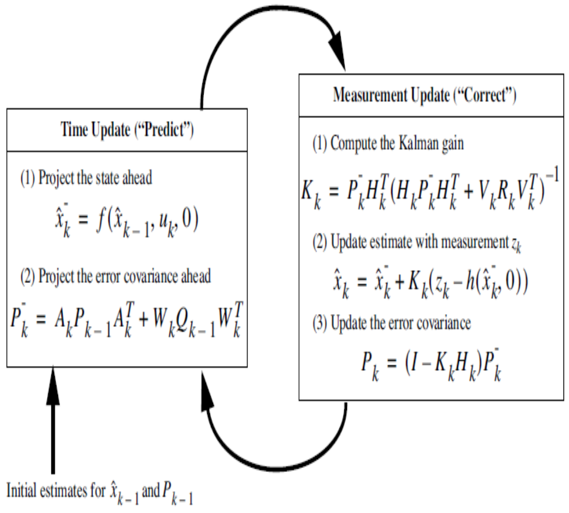

Figure 2. Extended Kalman Filter algorithm

The channel coefficients can be estimated in a recursive procedure similar to the discrete Kalman filter. As linear approximation is involved in the derivation, the filter is called the extended Kalman filter (EKF)[18]. The error in each update decreases and the estimate becomes closer to the ideal value during iterations. However it has been proved that EKF is a very useful method of obtaining good estimates of the system state. Hence it has motivated us to explore the performance of EKF in channel estimation for OFDM system. The simulation results shows that the estimation using Extended Kalman filter give better performance compare to other traditional estimation techniques.

IV. SIMULATION RESULTS AND DISCUSSION

4.1 Simulation Parameters

In this paper, for simulation we have assumed some channel parameters for OFDM system. The OFDM parameters are tabulated in table (1). The channel under consideration is Rayleigh channel.

Table (1).OFDM Parameters

No of subcarriers	256
Cyclic prefix length	16
Sampling period of channel	$1e^{-3}$
Max Doppler frequency shift	0.003
Distance	1-10km
No of OFDM symbols	1000
FFT size	256
Carrier frequency	4-8KHz
Receiver noise bandwidth	2KHz
No of pilot symbols	4
Modulation schemes	QPSK, DPSK, 16-QAM

5.2 Algorithm overview

Since underwater channel is time varying multipath channel in which achieving high data rate is challenging task. By considering this objective in mind, we designed an OFDM iterative receiver for underwater acoustic communication. The empirical model is designed to calculate the SNR by considering the channel noise, absorption coefficient and transmission loss. The calculated SNR is the main parameter for the adaptive scheme in the modulation techniques. In this work, we have considered QPSK, DPSK and 16-QAM modulation schemes. Based on the SNR values calculated using the empirical model, the modulation schemes will be switched. Thus by applying the adaptive technique in the modulation schemes the data rate of the system can be enhanced.

The effect of the channel noises and Absorption coefficient over frequency range of 1 kHz to 15 kHz is shown in figures (3) to (5). The performance of SNR over the frequency range 1 to 15kHz with distance varying from 1-10km is shown in figure(6). From the simulation results also found that the Kalman filter and the Extended Kalman filter are suitable for signal tracking using channel estimation compared to the other channel estimation techniques for UWA communication. The simulation results of channel estimation using both Kalman filter and Extended kalman filter and BER performance by considering simulation and theoretical results in Rayleigh channel are shown in figure (7) to figure (13). The simulation results are summarized in table (2) and (3).

Table (2) .Comparison of BER of OFDM system with Kalman filter and Extended Kalman filter:

Channel Estimation schemes scheme	channel	BER
Kalman filter	Rayleigh	0.0036
Extended Kalman filter		0.0010

Table (3).Comparison of BER for different Modulation Techniques and Adaptive modulation (channel estimation):

Modulation Schemes	BER Without Adaptive Modulation and channel estimation	BER With Adaptive Modulation(Channel Estimation)
DPSK	0.0008	0.0004
QPSK	0.0010	0.0002
16-QAM	0.0013	0.0005

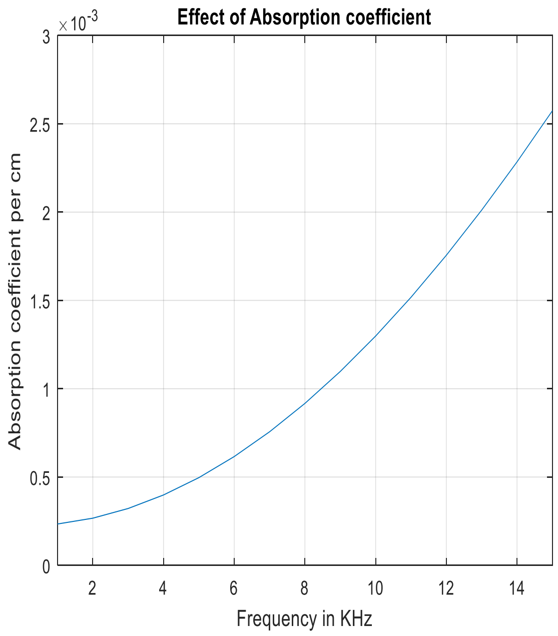

Figure 3. Effect of Absorption coefficient

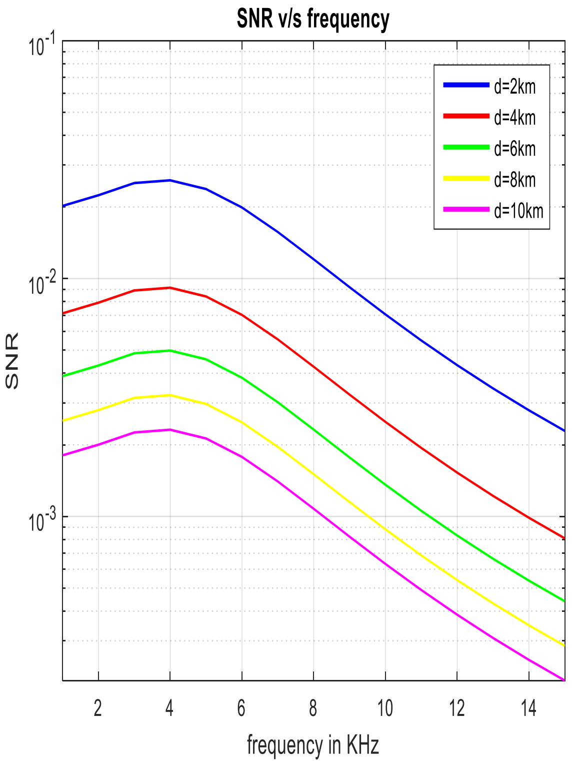

Figure 4. Performance of SNR v/s Frequency

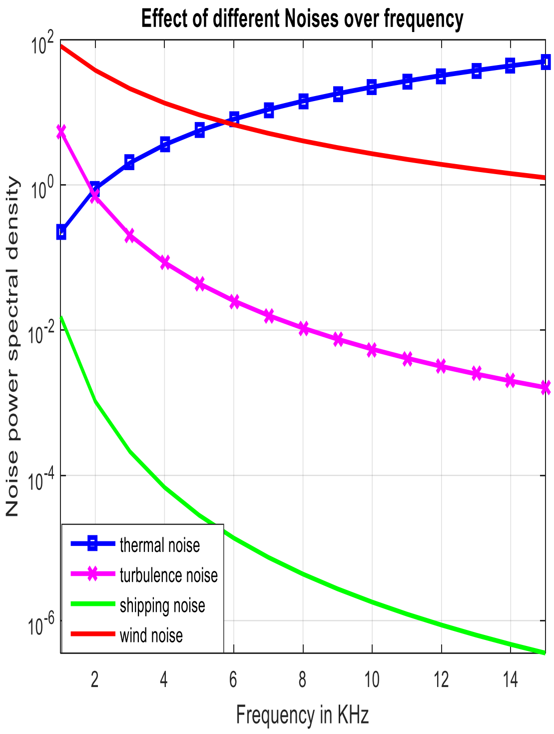

Figure 5. Effect of different Noises over frequency

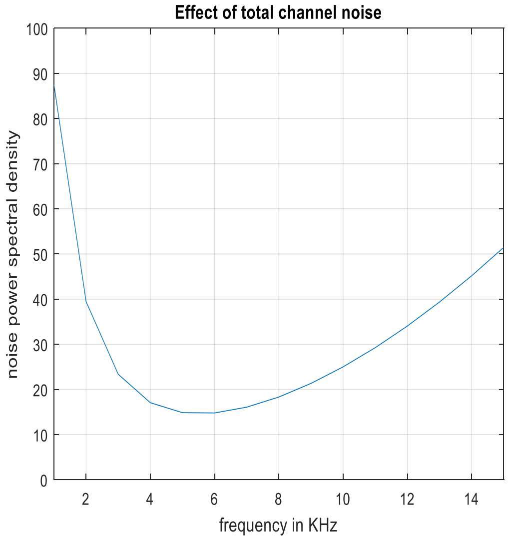

Figure 6. Effect of total channel noise

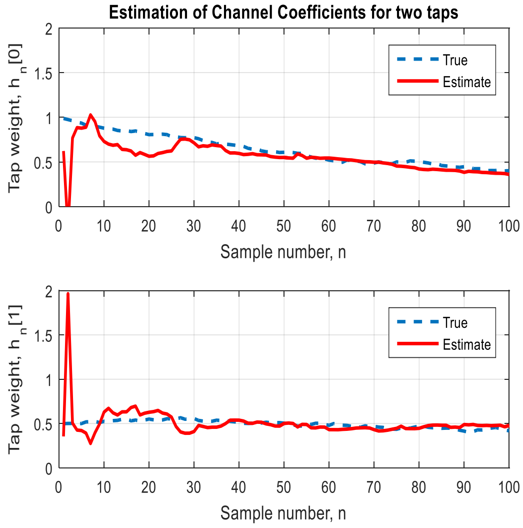

Figure 7. Channel Estimation using Kalman Filter

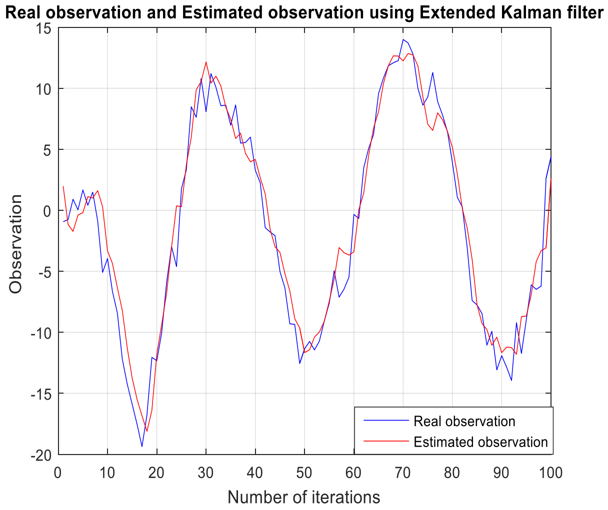

Figure 8. Channel Estimation using Extended Kalman Filter

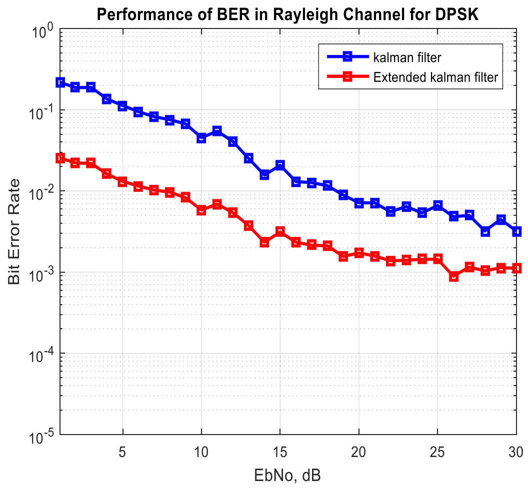

Figure 9. Comparison of Performance of Kalman filter and Extended Kalman Filter

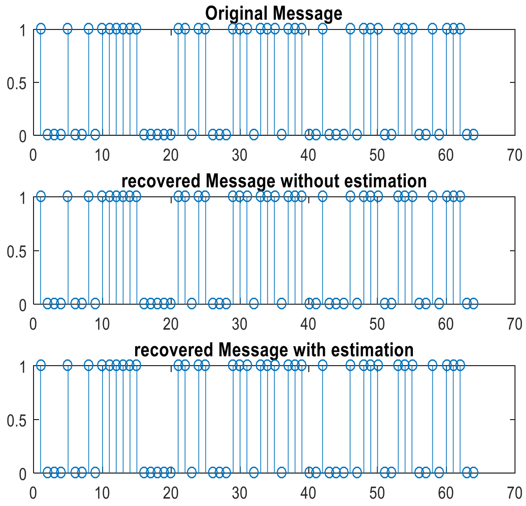

Figure 10. Comparison of channel estimation in the message recovery

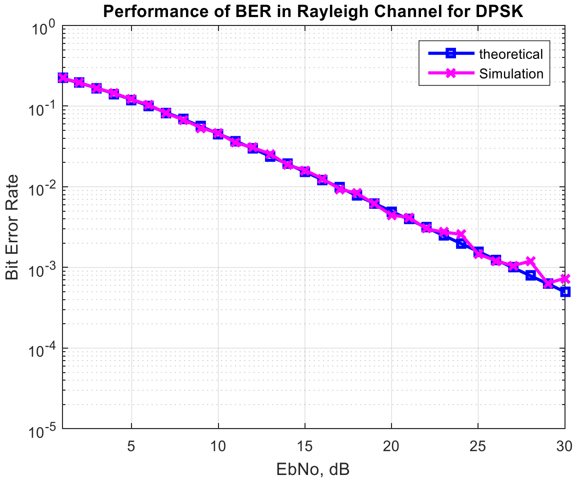

Figure 11. Performance of BER of DPSK in Rayleigh channel

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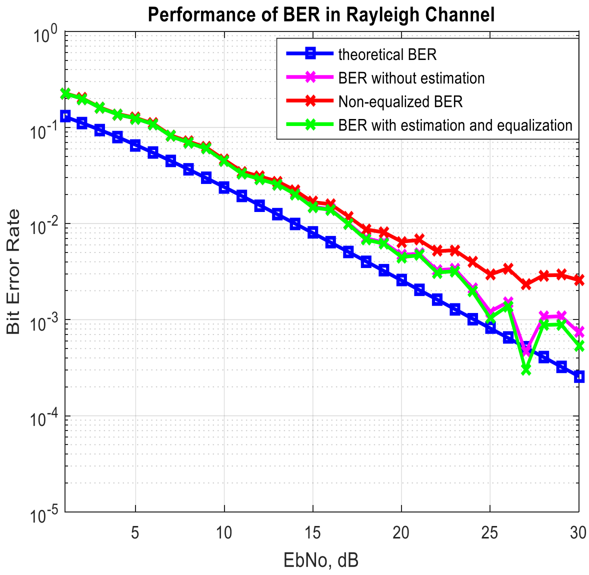

Figure 12. Performance of BER in Rayleigh channel

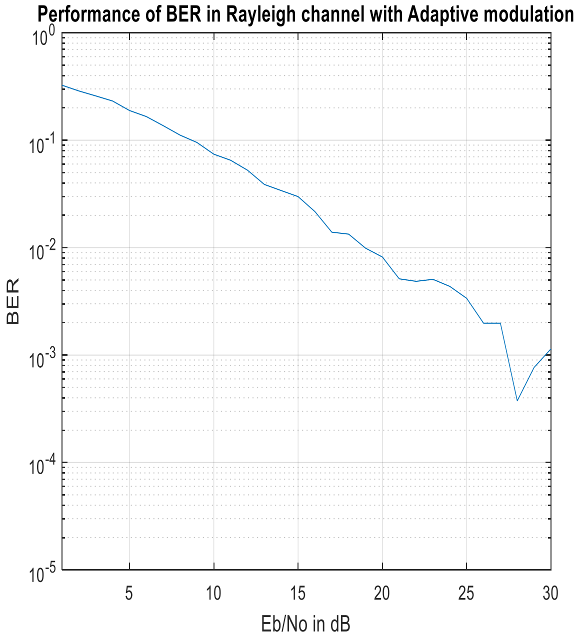

Figure 13. Performance of BER in Rayleigh channel with Adaptive modulation

V. CONCLUSION AND FUTURE WORK

Since underwater acoustic channel is time-varying multipath and highly limited in bandwidth, Obtaining high data rate, low latency and high throughput for OFDM system is a challenging task. In this work, to achieve these objectives we have used many techniques that include efficient Adaptive modulation scheme, Kalman filter based Channel estimation and channel equalization schemes with OFDM multicarrier modulation technique. Also, the simulation results show that the performance of the OFDM system with the use of Adaptive modulation is better when compared to the OFDM system without Adaptive modulation schemes. The signal tracking and estimation of the channel parameters is achieved efficiently by using the Kalman filter. Thus by using the adaptive modulation schemes based on the SNR of the channel parameters and channel estimation using Kalman filter and channel equalization techniques, we designed OFDM system which can enhance the data rate for underwater acoustic communication.

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