IJCTA, 10(07), 2017, pp. 277-286

Data Rate Enhancement in OFDM Receiver using Adaptive Modulation and Channel Estimation based on Kalman Filter for Underwater Acoustic Communication

Ravi Kumar M.G.* and Mrinal Sarvagya*

Abstract : Underwater Acoustic Communication(UWAC) techniques are an interesting area in communication research, where we can achieve a high data rate, a low latency and a high throughput which often is a very challenging task. In this paper, we design an OFDM transceiver system which is suitable for underwater acoustic communication using Adaptive modulation and Channel estimation. We have focused on the efficient modulation schemes like QPSK, DPSK and 16-QAM which is best suited for adaptive techniques based on the SNR values to enhance the data rate. Also we have used the Kalman filter for channel estimation which minimizes the mean squared error and gives us the best estimation even in the presence of noise. We have found that these modulation techniques and channel estimation methods are best suited to achieve high data rate for underwater acoustic communication.
Keywords: UWC, OFDM, Adaptive modulation techniques, Kalman filter, channel estimation.

1. INTRODUCTION

1.1. Underwater Acoustic communication

Acoustic communications is defined as method of communication from one point to another by using acoustic signals. With respect to the design and concept, the underwater acoustic network is very similar to that of a land-based network [1]. RF electromagnetic waves, acoustic waves and optical waves are the typical carriers for UWC [2]. RF waves suffer large attenuation underwater thus they require large antennas and more transmission power [3]. Therefore, usually RF waves are used for short range communication underwater (up to 10 meters) [4]. Optical waves are sometimes preferred for large data rate communications (range of a few Gb/s), but they are scattered and absorbed rapidly underwater, thus leading to short-range communications [5]. Since the acoustic waves suffer from relatively low absorption, they can be used for long range communication instead of RF waves and Optical waves. Thus leading to making the acoustic communication as the most UWC scheme [6].

1.2. Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is one of the special types of multi-carrier modulation scheme which transmit by multiple sub carriers do not have similar frequencies and they are orthogonal to each other [7],[8]. OFDM is a special type of multicarrier modulation that is generally appropriate for broadcasting over a dispersive channel[9]. OFDM is a multicarrier modulation technique used for underwater communication which improves the data transmission rates and reliability [10]. The underwater channel is highly limited in bandwidth and hence bandwidth efficient transmission techniques play a very important role.

* Research Assistant, Professor, Dept. of E&C REVA University, Bangalore, Karnataka, INDIA. *E-mail : ravimg9591@gmail.com, mrinalsarvagya@gmail.com*

2. PROPOSED WORK

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

3. SYSTEM MODEL AND DESCRIPTION

The proposed Orthogonal Frequency Division Multiplexing system for underwater acoustic communication considered in this paper is shown in figure 1. The OFDM model consists of three sections namely, Transmitter, Channel and Receiver.

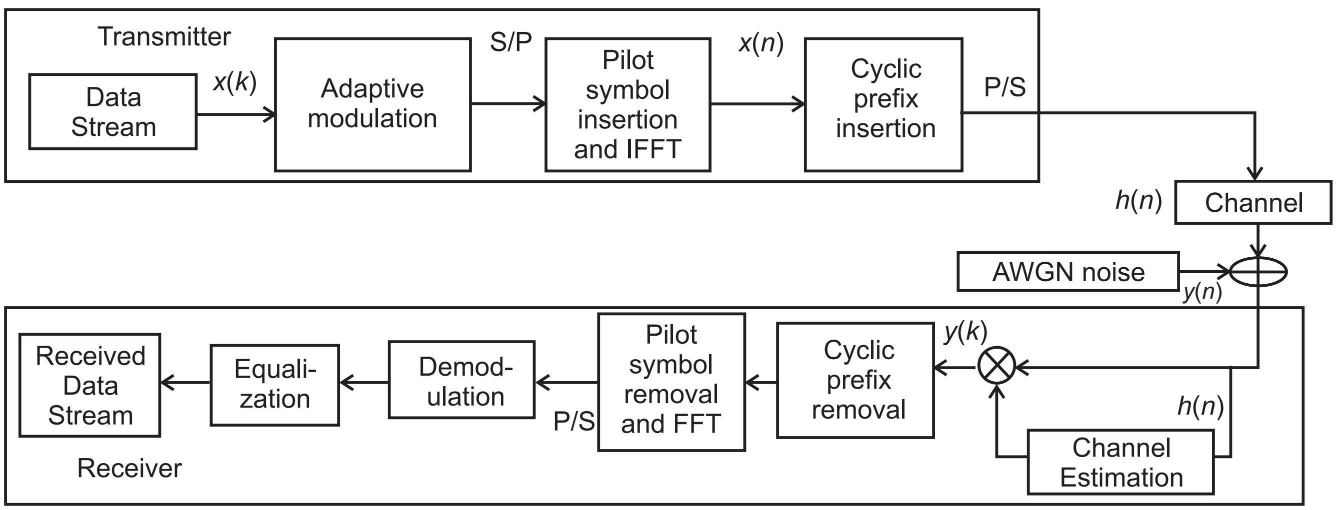

Figure 1: Proposed OFDM Transceiver system

3.1. Transmitter

The Transmitter includes of the following blocks:

3.1.1. Data stream

The Data stream '*x*' is generated by a random data generator and the data stream is the random data. The random binary signal models the raw information which would be transmitted. The serial binary signal is converted to parallel data and then fed into transmitter [11].

3.1.2. Adaptive Modulation

To enhance the data rate, we propose the use of highly efficient adaptive modulation techniques for underwater communication [9]. In this paper we establish some efficient adaptive modulation schemes such as QPSK, DPSK and 16-QAM for UWAC in order to get high data rates by considering 'N' subcarriers (256 subcarriers). In this work, 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 which depends upon on the SNR range which can be calculated at the receiver end and by applying adaptive schemes in the OFDM system where we can enhance the data rate at the receiver.

3.1.3. Pilot symbols and FFT algorithms

A pilot signal which is generally of single frequency, which is transmitted over a communications system for control, supervisory, equalization and reference purpose[12]. In this experiment we used the pilot symbols of length 4.

The capability to generate and to demodulate the signal with the use of FFT algorithm is one of the main factors for OFDM to become popular in transmission schemes [13]. By using IFFT/FFT techniques, implementation of modulation and demodulation is computationally efficient. Further the orthogonality helps us for efficient transceiver design using the inverse FFT and the FFT algorithms at the transmitter and receiver side respectively.

Let $X_0(k)$ is the input data vector to IFFT block and k varies from 0 to N–1 where N = 256. Output of IFFT block is given by

$$x_p(n) = \text{IFFT}[X_0\ (k)] = \frac{1}{2}\sum_{k=0}^{N-1} X_0(k)e^{j2\pi kn} \tag{1}$$

And the output of the FFT block is given by

$$X_0(k) = \text{FFT}[X_0\ (n)] = \frac{1}{2}\sum_{k=0}^{N-1} X_0(n)e^{j2\pi kn} \tag{2}$$

The cyclic prefix is used to defend the OFDM signals from inter symbol interference. In this experiment we used acyclic prefix of length 16.

3.2. Channel Model

3.2.1. Rayleigh fading channel

Fading is divergence of the attenuation that a carrier modulated telecommunication signal experiences over certain propagation channel. In this experiment we considered the Rayleigh fading channel as the media [2]. The Rayleigh distribution has a probability density function (PDF) given by

$$p(r) = \begin{cases} r/\sigma^2 \exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ & (0 \le r \le \infty) \end{cases} \tag{3}$$

Where denotes the RMS value of the received signal. The Doppler spread, high path loss, noise, multipath and variable propagation delay severely affect the underwater acoustic communications. The collective effect of this phenomenon causes the UW-A channel to be temporally and spatially variable. The parameters that affect UW-A communication are:

- **Transmission (path) Loss :** Transmission loss (TL) generally occurs due to two factors: attenuation and geometric spreading loss [2]. For a signal of frequency f_0 over a transmission interval d_0, the transmission loss [in dB] can be obtained by

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

Where, k = spreading factor $\alpha(f)$ is the absorption coefficient in dB/m

A = transmission anomaly in dB

f_0 = frequency of a signal (kHz)

d_0 = transmission distance (m)

- **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_0 [kHz] in dB[2].

$$10 \log N_t(f_0) = 17 - 30 \log f_0 \tag{5}$$

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

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

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

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_0 the total noise power spectral density is given by

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

The absorption coefficient can be calculated as

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

The Signal-to-Noise Ratio (SNR) can be calculated using the transmission loss TL (d_0, f_0) and the noise power spectral density N (f_0) over an interval 'd_0' when the transmitted signal has a frequency of 'f_0' and power 'P_0' is given by

$$\mathrm{SNR}(d_0, f_0) = \frac{P / \mathrm{TL}(d_0, f_0)}{N(f_0)\Delta(f_0)} \quad (11)$$

Where $\Delta(f_0)$ indicates the receiver noise bandwidth [2].

3.3. Receiver

The receiver includes the following subsections.

3.3.1. Channel Estimation

In any communication system, the basic objective is to reconstruct the data transmitted at the transmitter side, at the receiver. In doing this there are so many Estimation / Equalization techniques and they need knowledge of the channel behavior in order to recover the transmitted data. Therefore the development of an efficient scheme of approximating the transmission channel between the transmitter and the receiver is a necessary requirement of the Transceiver design [14]. The general block diagram of the channel estimation is shown in the figure (2). In figure (2), $e(n)$ represents the estimation error or innovation error. The goal of the most channel estimation techniques is to reduce the mean squared error (MSE), $E[e^2(n)]$.

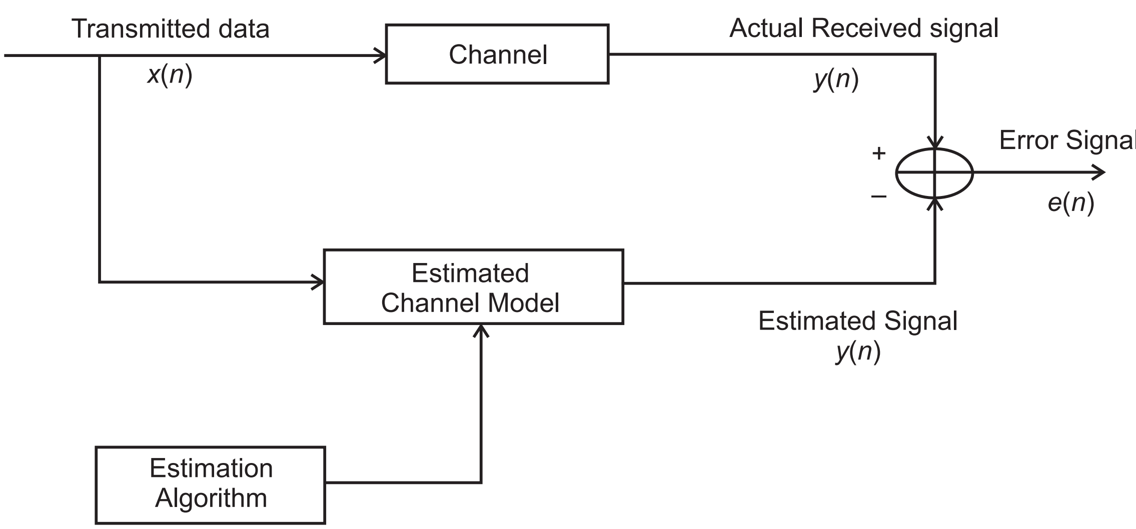

Figure 2: Block diagram of the channel estimation

4. CHANNEL ESTIMATION BASED ON KALMAN FILTER

4.1. System model

The Kalman filter is a recursive filter that is based on the use of state space methods and recursive algorithms [8] and in turn reduces the mean square error [12]. The Kalman filter algorithm consists of two steps:

- **Prediction :** It refers to projecting forward the current state to gain the estimates for next step. It is therefore known as time update step.
- **Correction :** It is the feedback stage that incorporates new measurements into the estimates. It is therefore known as measurement step.

This process is repeated for each state with value from previous state as initial value. Therefore, Kalman filter is called a recursive filter. The Kalman filter is represented in state-space model and the state-space model consists of two equations:

$$x_k = \mathrm{A}x_{k-1} + w_{k-1} \tag{12}$$

$$y_k = \mathrm{C}x_k + v_k \tag{13}$$

xk is the N-dimensional state vector at $k = 1, 2, 3, \ldots n$. Process noise '*w*' is the N-dimensional uncorrelated input vector of state equation. y_k is the M-dimensional noisy observation vector and the measurement noise is a zero mean white Gaussian noise. 'A' is the state transition matrix which can be calculated using the Yule-Walker equations (AR process) and 'C' is the output matrix.

The algorithm of the Kalman filter is explained in this section: At the k-1[th] iteration, the state vector is considered as zero vectors and the state transition matrix is calculated using the Yule Walker AR process. There is a consideration of two ideal equations: Time Update (*prediction*) and Measurement Update (*correction*). Both the equation sets are applied at each kth state. The Kalman filter principle is detailed as the following set of estimations below[10].

Time update :

1. $x_k^- = \mathrm{A}\hat{x}_{k-1} + \mathrm{B}u_k$ 2. $\overline{\mathrm{P}}_k = \mathrm{AP}_{k-1}\mathrm{A}^{\mathrm{T}} + \mathrm{Q}$

Measurement update:

1. $\mathrm{K}_k = \overline{\mathrm{P}}_k\mathrm{C}^{\mathrm{T}}(\mathrm{C}\overline{\mathrm{P}}_k\mathrm{C}^{\mathrm{T}} + \mathrm{R})^{-1}$ 2. $\hat{x}_k = \hat{x}_k^- + \mathrm{K}_k(zk - \mathrm{C}\hat{x}_k^-)$

3. $\mathrm{P}_k = (\mathrm{I} - \mathrm{K}_k\mathrm{C})\overline{\mathrm{P}}_k$

Where K is the Kalman gain and P is the Error covariance update. The Covariance matrix of system noise 'Q' and Covariance matrix of measurement noise 'R' assumed initially for the computation. is the state update which contains the channel parameters.

5. SIMULATION RESULTS AND DISCUSSION

5.1. Simulation Parameters

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

5.2. Algorithm overview

In this experiment, our main objective is to design an OFDM receiver with high data rate for underwater acoustic communication. There are multiple ways To achieve our objective but in this article we focus on finding the efficient adaptive modulation techniques, channel estimation technique and channel equalization schemes which are suitable for the underwater environment even in the presence of AWGN noise and channel noise. The effect of the channel noises over frequency range of 1 kHz to 15 kHz is shown in figures (3). In this experiment, we have considered efficient modulation schemes like QPSK, DPSK and 16-QAM and verified the BER performance individually. These schemes typically give a better performance compared to other modulation techniques. Using the equation (11) we calculated the SNR based on the E_b/N_0 or BER values and we experimented which modulation scheme will give better performance with respect to Bit Error Rate (BER) performance. Thus by applying the adaptive method in the modulation process the BER or SNR performance were optimized and the efficient data rate was achieved. From the simulation result also found that the Kalman filter is suitable for signal tracking using channel estimation compared to the other channel estimation techniques for UWA communication. The LMS and MMSE equalization techniques used for signal reconstruction by minimizing the mean squared error. The simulation results of effect of channel noises and BER performance for every modulation schemes by considering simulation and theoretical results are shown in figure (3) to figure (6) and the simulation results are summarized in table (2). The results for signal tracking using Kalman filter in AWGN channel and Rayleigh channel are shown in figure (7) to figure (8).

Table 1
OFDM Parameters

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

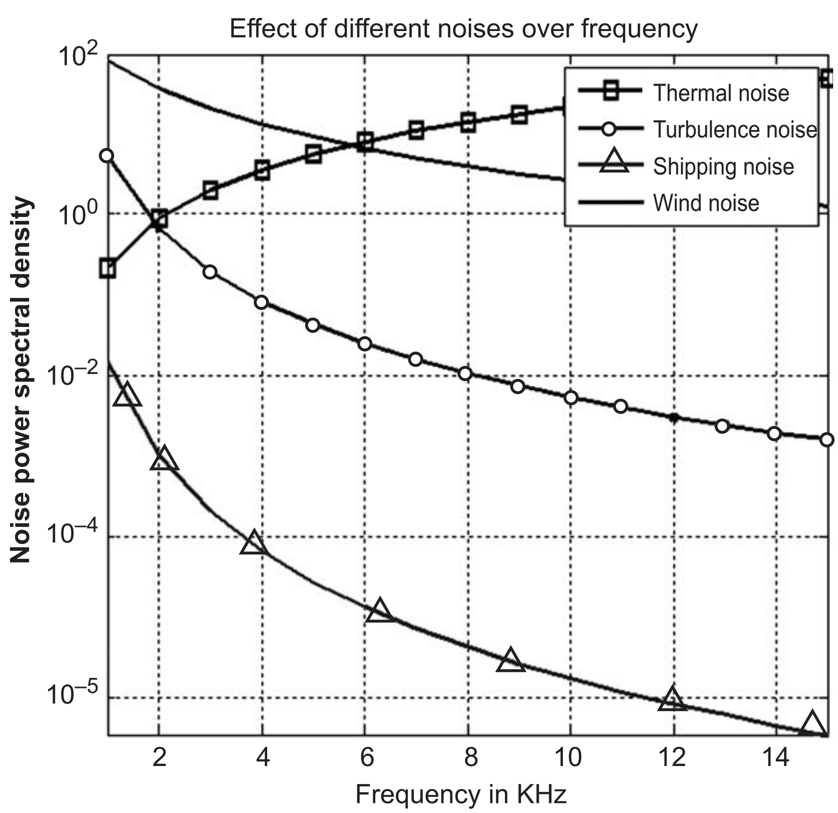

Figure 3: Effect of Thermal Noise, Turbulence noise, Shipping Noise and Wind noise over frequency 1 kHz to 15 kHz

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

5.3. Simulation Results

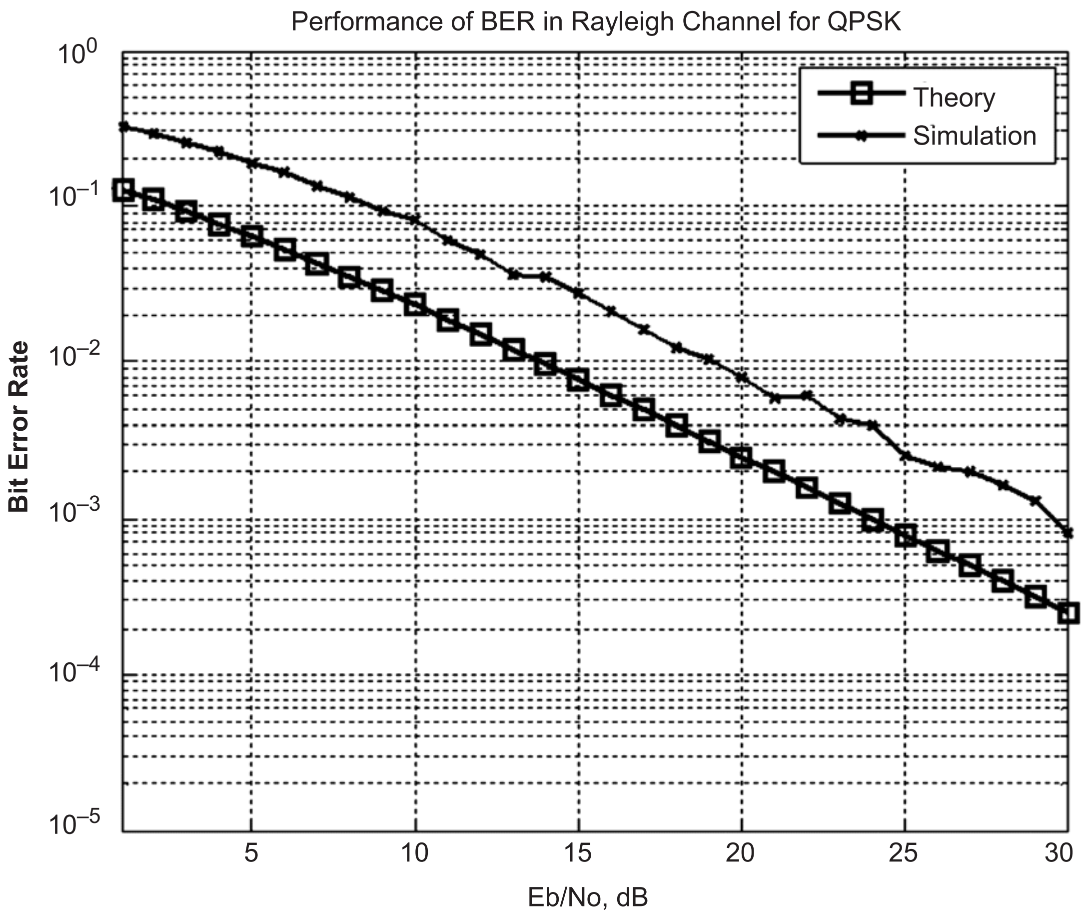

Figure 4: BER performance in Rayleigh channel for QPSK

6. CONCLUSION AND FUTURE WORK

In Underwater Acoustic (UWC) Communication achieving high data rate, low latency and high throughput is a very challenging task. To achieve these we have tried many techniques that include efficient modulation schemes, Channel estimation using Kalman filter and channel equalization schemes with OFDM multicarrier modulation technique. From the simulation results we found that some modulation schemes like QPSK, DPSK and 16-QAM are the best adaptive modulation schemes for underwater communication for highly limited bandwidth even in the presence of channel noise. The Kalman filter is used for channel estimation and the signal tracking is achieved efficiently by using the Kalman filter. Thus by using the adaptive modulation schemes based on the SNR values, channel estimation techniques like Kalman filter and channel equalization techniques like LMS, MMSE, we can design OFDM receiver which has high data rate for underwater communication. In future we can achieve high data rate in the receiver in the other ways with the use of channel coding techniques and adaptive channel estimation schemes, etc. We can design the receiver and verify the performance using numerical simulation and Mathematical model.

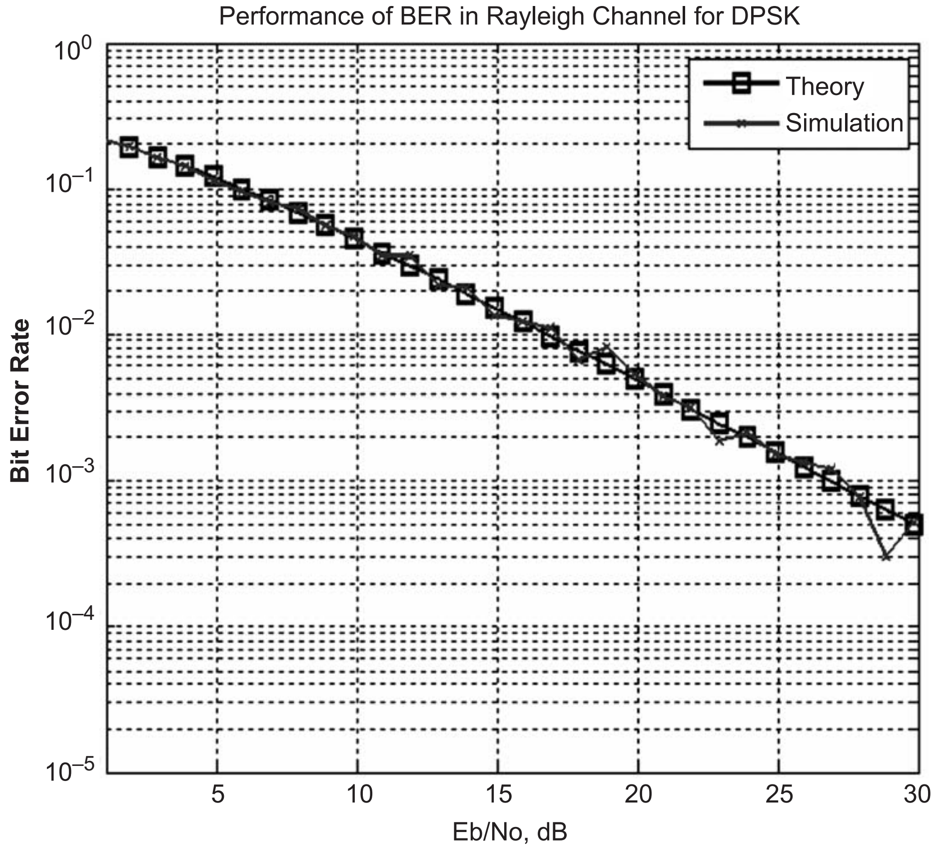

Figure 5: BER performance in Rayleigh channel for DPSK

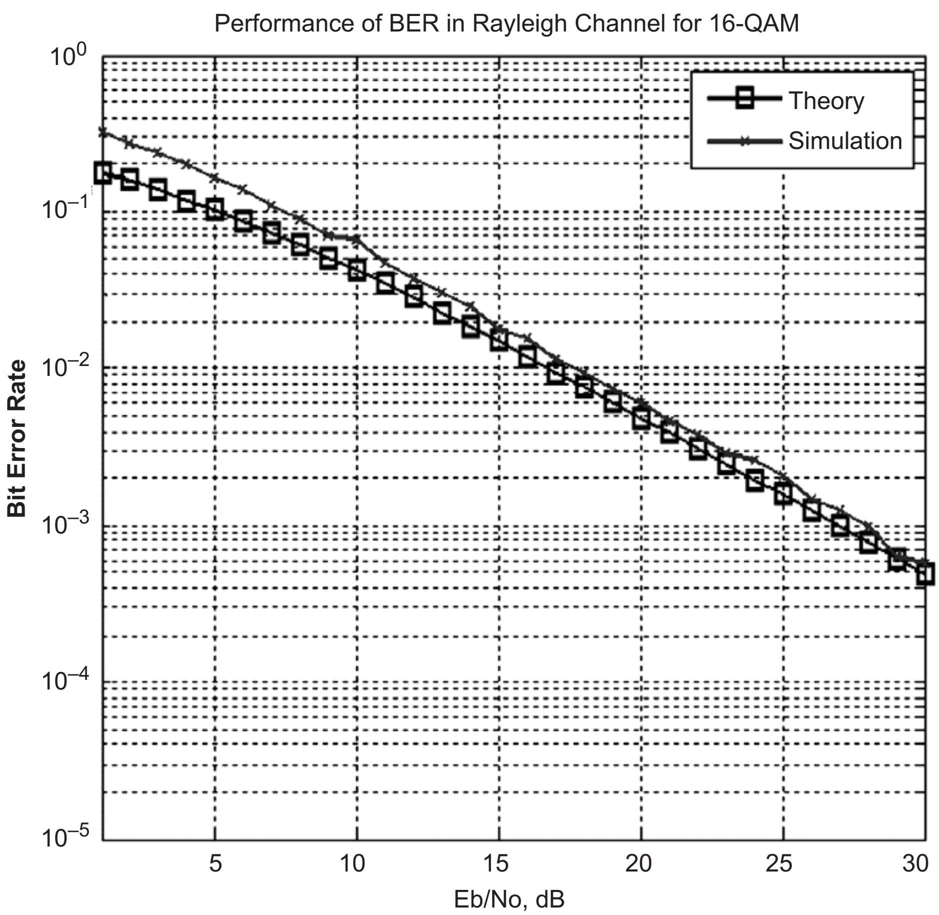

Figure 6: BER performance in Rayleigh channel for 16-QAM

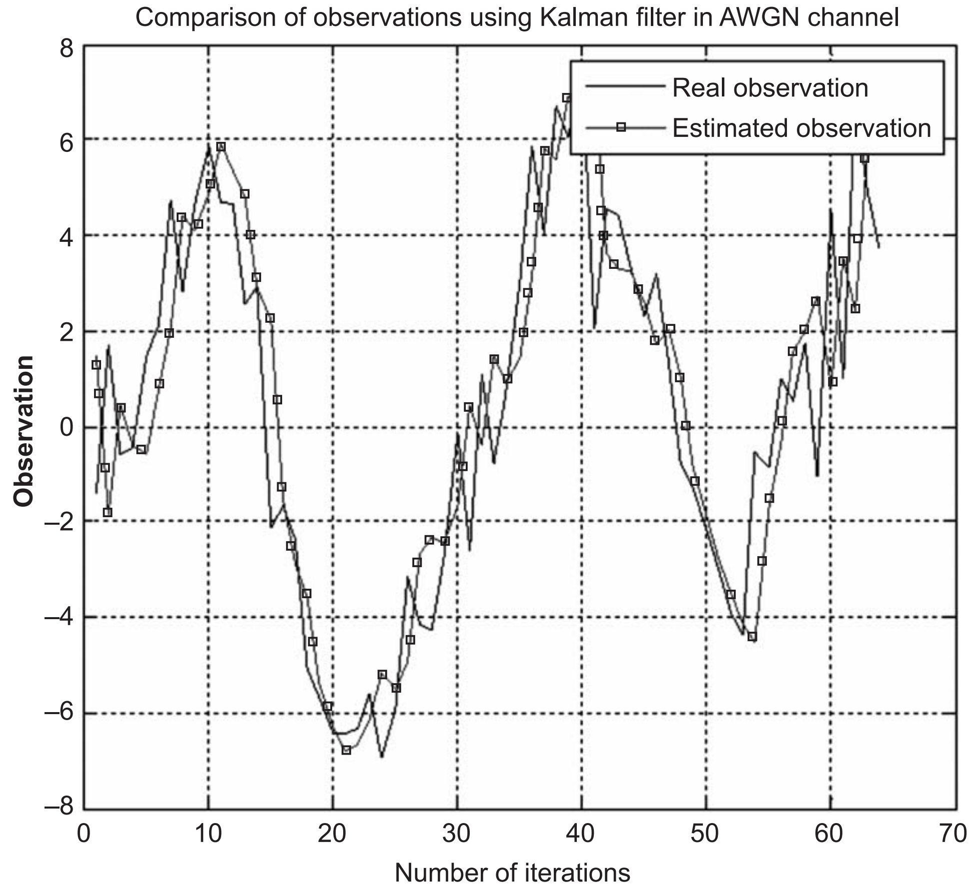

Figure 7: Comparison of Observations using Kalman filter in AWGN channel

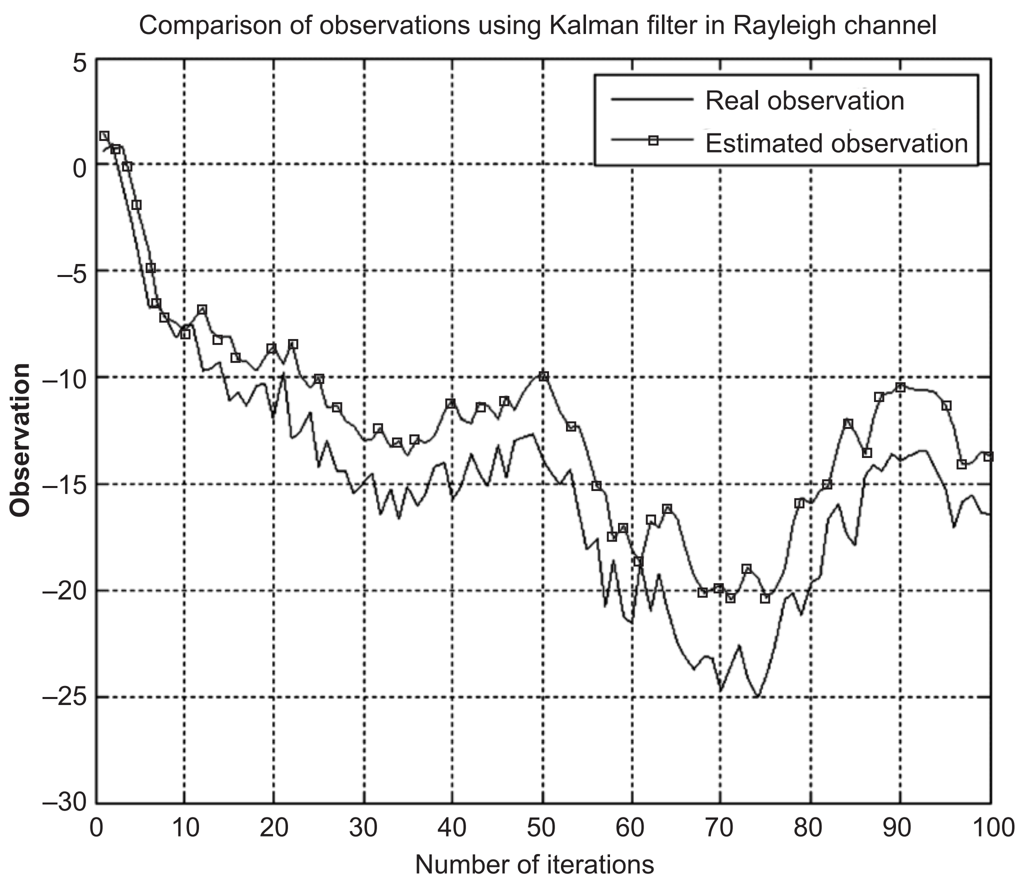

Figure 8: Comparison of Observations using Kalman filter in Rayleigh channel

7. ACKNOWLEDGEMENTS

The authors wish to thank Navel Research Board (NRB), Delhi, INDIA, for funding the part of the project under NRB Research Scheme, Grant No. NRB/4003/PG/365 Dated 21st September 2015.

8. REFERENCES

1. Baosheng li, jiehuang, shenglizhou, keenan ball and milicastojanovic, "MIMO-OFDM for high rate underwater acoustic Communications", IEEE Journal of Oceanic Engineering, ©2009 IEEE.
2. Tommasomelodia, hovanneskulhandjian, li-chungkuo, emrecanDemirors, Text book of "Advances in Underwater Acoustic Networking", Chapter 23, *First Edition.* By TommasoMelodia, Copyright ©2012 John Wiley & Sons, Inc.
3. I. F Akyildiz, T. Melodia, and K. R. Chowdhury, " A Survey on Wireless Multimedia Sensor Networks", Computer Networks (Elsevier), 51(4):921–960, March 2007.
4. M. U. Cella, R. Johnstone, and N. Shuley, "Electromagnetic wave wireless communication in shallow water coastal environment: Theoretical analysis and experimental results", In ACM International Workshop on UnderWater Networks (WUWNet'09), pages 9:1–9:8, Berkeley, California, USA, 2009.
5. N. Farr, A. Bowen, J. Ware, C. Pontbriand, and M.Tivey,"An integrated, underwater optical/acoustic communications system. In Proc. of IEEE OCEANS, pages 1–6, 2010.
6. I. F. Akyildiz, D. Pompili, and T. Melodia, "Challenges for Efficient Communication in Underwater Acoustic Sensor Networks", ACM Sigbed Review, July 2004.
7. NaincyValdaya, MukeshKumawat, "A Novel Algorithm for Efficient channel estimation using MMSE-Kalman estimator and Median filtering", International journal of computer applications(0975-8887),volume 100, No-13, august 2014.
8. AmitKapoor and IshanKhurana, "Channel Estimation based on Kalman filtering with BER reduction in MIMO-OFDM syatems", International journal of computer applications (0975-8887), volume 97, No-1, July 2014.
9. J.Faezah and K.Sabira, "Adaptive Modulation for OFDM Systems", International Journal of Communication Networks and Information Security (IJCNIS) Vol. 1, No. 2, August 2009.
10. Chin-Feng Lin, Wen-ChinWu, and Jenny Chih-Yu Lee, "Underwater Acoustic Multimedia Communication Based on MIMO–OFDM", Wireless PersCommun (2013) 71:1231–1245,DOI:10.1007/s11277-012-0871-4,©Springer, Science+Business Media ,New York ,2012.
11. Megha Gupta, Rajesh nema, Ravi Shankar mishra, "Bit error rate performance in OFDM system using MMSE and MLSE Equalizer over Rayleigh fading channel through the BPSK, QPSK, 4QAM and 16 QAM Modulation technique", IJERA, ISSN:2248-9622, volume 1, Issue 3, pp:1005-1011
12. Kala Praveen Bagadi and Susmita Das, "MIMO-OFDM Channel Estimation using Pilot Carries", International Journal of Computer Applications (0975 – 8887) Volume 2 – No.3, May 2010.
13. Marius Oltean, "An Introduction to Orthogonal Frequency Division Multiplexing",Universitatea "Politehnica"Timişoara.
14. Rashi Jain, "Kalman filter based Channel Estimation", International journal of Research and technology (IJERT), ISSN: 2278-0181, Volume 3, Issue 4, April 2014.
15. N. K. Noordin, b. M. Ali, n. Ismail, and s.s. Jamuar, "Adaptive techniques in Orthogonal frequency division Multiplexing in mobile radio Environment", International Journal of Engineering and technology, Vol.1,no.2,2004,pp.115-123.
16. Md. Golam Sadeque, "Bit Error Rate (BER) Comparison of AWGN Channels for Different Type's Digital Modulation Using MATLAB Simulink", ASRJETS, ISSN (Print) 2313-4410, ISSN (Online) 2313-4402 © Global Society of Scientific Research and Researchers.
17. Brijesh Kumar Patel and Jatin Agarwal, "Comparative Study of Bit Error Rate with Channel Estimation in OFDM System for M-ary Different Modulation Techniques", International Journal of Computer Applications (0975 – 8887) Volume 95– No.8, June 2014.