Available online at: www.mbai.org.in doi: 10.6024/jmbai.2016.58.2.1935-09

Bit error rate performance of underwater channels for OFDM data

N. Sabna* and P. R. Saseendran Pillai
Department of Electronics, Cochin University of Science and Technology, Kochi-682 022, Kerala, India.
*Correspondence e-mail: sabnan@yahoo.com

Received: 03 Sep 2016, Accepted: 30 Dec 2016, Published: 10 Jan 2017

Original Article

Abstract

In underwater acoustic communication, the energy received is a combination of energies contributed by different rays traversing through different paths due to multiple reflections of the waves at the boundaries, which results in Inter Symbol Interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM), which is a multicarrier modulation technique, is widely employed nowadays. Its advantages include resilience to Inter Symbol Interference, immunity to selective fading, simpler channel equalization, etc. Sea trials being very expensive, underwater acoustic communication scenario can be simulated with any of the available toolboxes. In the simulation studies, Bellhop has been used for generating the channel impulse response based on the assumed environmental conditions. In this paper, OFDM performance has been simulated in underwater communication scenario using 16-QAM and 16-PSK modulation methods. From the simulation studies, it has been observed that 16-QAM based OFDM offers lower bit error rates than that for the 16-PSK based OFDM.

Keywords: *Bellhop, bit error rate performance, modulation, sound speed profile.*

Introduction

Acoustic signals are widely used in ocean exploration, oceanographic data collection, underwater communication, etc. Optical waves and electromagnetic waves do not propagate over long distances in underwater environment. The underwater channel is too complex due to various phenomena (Urick,1975) like multipath propagation, time stretching, ambient noise, Doppler effects, etc. The sound speed is typically 1500 m/s, but varies with depth, climatic conditions etc. Sea trials are expensive as well as time consuming and hence various toolboxes available for simulating underwater acoustic communication has been used for investigating the behaviour of underwater channels. Bellhop is an effective toolbox for the analysis and study of acoustic communication in the ocean. Bellhop (Porter, 2011; Rodriguez, 2008) is also an efficient toolbox for modeling acoustic propagation underwater based on description of the environment provided by the user.

Material and methods

In this paper, Orthogonal Frequency Division Multiplexing (OFDM) has been simulated in underwater communication scenario using Quadrature Amplitude Modulation (QAM) and Phase Shift Keying (PSK) modulation methods and the corresponding bit error rates for various Signal-to-Noise Ratio values have been computed. In QAM based OFDM methods, the number of points in the constellation are also varied to learn the trend of bit error rate performances.

Sound speed profile has been computed with the help of Leroy's formula (Leroy, 1969) using the Conductivity, Temperature, Depth (CTD) data collected. For a given CTD data and environmental conditions like frequency of operation, number of transceivers and their depths specified by the user, ray trace, eigen ray plot and channel impulse response can be generated with the Bellhop model.

Orthogonal Frequency Division Multiplexing

OFDM, which is a multicarrier modulation technique, is widely employed in broadband wireless communication standards such as IEEE 802.11 (Wi-Fi). In OFDM (Ghorpade, 2013; Patidar *et al.*, 2011) the entire frequency band is divided into a number of orthogonal sub bands. The data stream is also divided into several parallel data streams of lower rate and the individual subcarriers are modulated by individual low rate data streams and the resultant signals are added up and transmitted. OFDM eliminates intersymbolinterference (ISI) with a guard band, which is zero padding (ZP) or cyclic prefix (CP).

The general block diagram of an OFDM System is given in Fig. 1. The binary input undergoes modulation after serial to parallel conversion which is followed by IFFT. Guard band insertion has been carried out after parallel to serial conversion.The signal, after traversing through the channel reaches the receiver and undergoes the reverse of operations carried out at the transmitter.

Techniques to undo the effects of the channel on the signal such

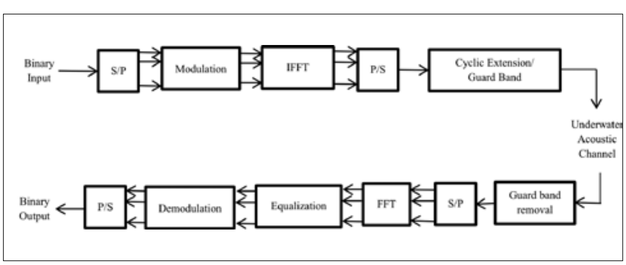

Fig. 1.General block diagram of an OFDM System

as multipath, intersymbol interference, etc. are implemented in the equalizers which are widely used in practical communication systems. However, their implementation and analysis are usually complicated. OFDM provides a simple and efficient technique for channel equalization. With the help of the cyclic prefix in OFDM, the channel effect is turned into a cyclic convolution operation. The cyclic convolution in the time domain corresponds to multiplication in the frequency domain. This gives a very simple equalizer structure i.e. multiply each subcarrier by a per-carrier constant value at the receiver in order to undo the channel effects of the multipath. The length of the cyclic prefix is chosen to be greater than the expected multipath spread.

Modulation techniques

In the simulation studies, the modulation techniques used are Quadrature amplitude modulation (QAM) and Phase-shift keying (PSK).

Quadrature Amplitude Modulation: Quadrature amplitude modulation (QAM) is performed by changing the amplitude and phase of a carrier in accordance with the input data. A variety of forms of QAM such as 4-QAM, 8-QAM, 16-QAM, etc.are available and using higher order QAM, it is possible to transmit more bits per symbol. But, the points on the constellation move closer and the transmission becomes susceptible to noise, resulting in a higher bit error rate for higher order QAM than that for the lower order QAM variants. Hence, there exist a trade off between the data rates and bit error rates for a given system.64-QAM and 256-QAM are often used in digital cable television and cable modem applications. Fig. 2 gives the constellation diagram for the transmitted 16-QAM symbols.

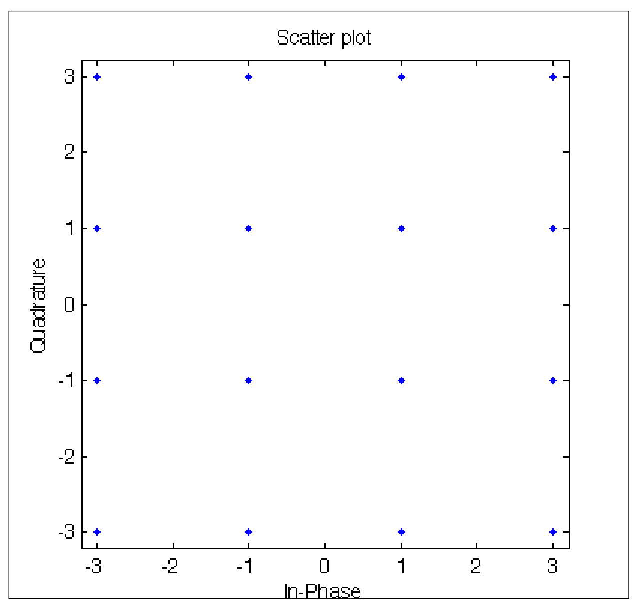

Fig. 2. Constellation diagram of 16-QAM

Phase-shift keying: Phase-shift keying (PSK) is a digital modulation scheme that conveys data by modulating the phase of a carrier wave according to the input. The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the phase of the received signal and maps it back to the symbol it represents, thus recovering the original data. In MPSK, data can be transmitted at a faster rate compared to the simplest binary phase shift keying (BPSK).

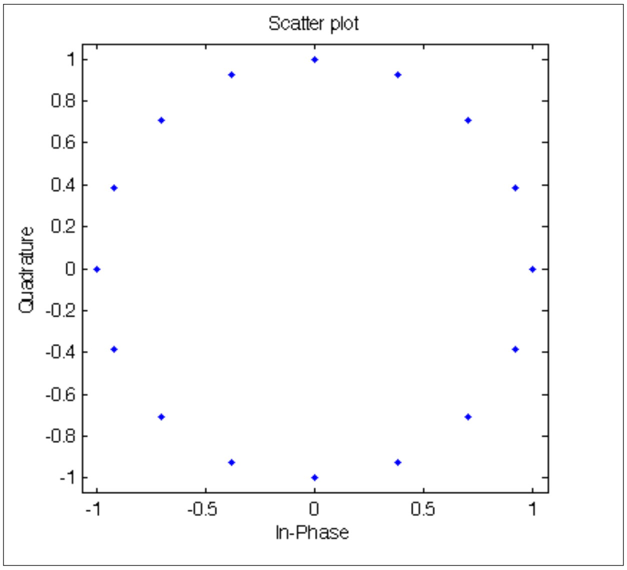

Fig. 3. Constellation Diagram of 16-PSK.

Fig. 3 gives the constellation diagram for the transmitted 16-PSK symbols.

Bellhop

Bellhop is a highly efficient ray tracing toolbox for predicting acoustic propagation in underwater environments. It can produce a variety of useful outputs including transmission loss, eigen rays, channel impulse response, etc. for the environment specified by the user. In the simulation studies, Bellhop is used in order to obtain the channel impulse response, which is convolved with the transmitted signal to model an underwater acoustic communication scenario.

The environmental data like the sound speed profile of the water column obtained from the CTD data, the number of transceivers and their depths, frequency of operation etc. have to be given as input to the Bellhop.The rays are traced by numerically solving the differential ray equations (Porter *et al.*, 1987). The resulting rays undergo refraction due to the variation of sound speed with depth.

Sound Speed Profile

The speed of sound in seawater varies with temperature, salinity, and pressure. Although the variations in the speed of sound are not large, they influence the sound propagation in the ocean. The sound speed in the ocean can be well described by the Leroy's formula as given below:

$$C = 1492.9 + 3(T-10) - 6 \times 10^{-3}(T-10)^2 - 4 \times 10^{-2}(T-18)^2 + 1.2(S-35) - 10^{-2}(T-18)(S-35) + z/61 \quad (1)$$

where C is the sound speed in meters per second, T is the Temperature in degrees centigrade, S is the salinity in parts per thousand and *z* is the depth in meters. The ray trace and normalized channel impulse response plots for a source at a depth of 50m and a receiver stationed at 1km away at a depth of 100 m, plotted using the Bellhop along with the assumed sound speed profile shown in Fig. 4, are furnished in Figs. 5 and 6.

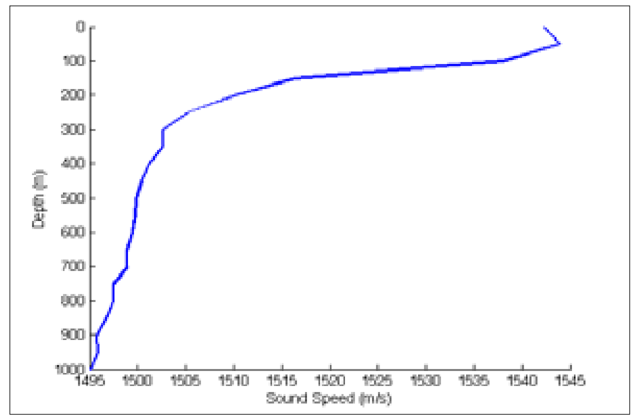

Fig. 4. Sound Speed Profile plotted using the CTD data collected

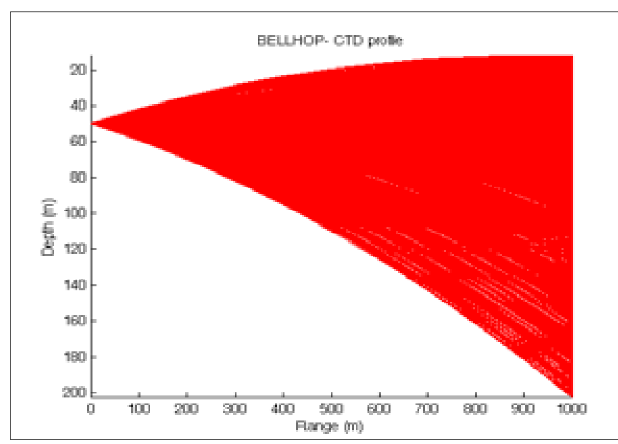

Fig. 5. Ray trace plot

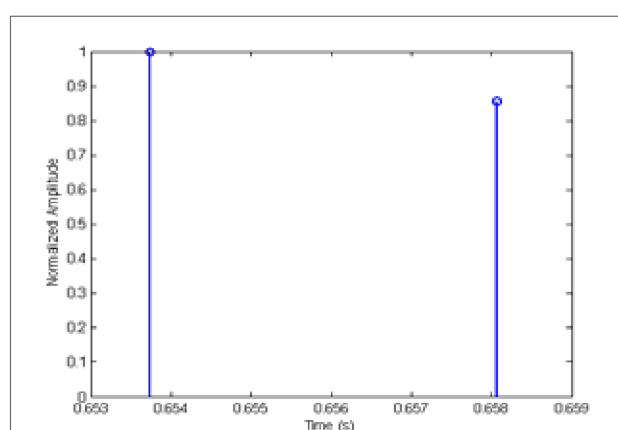

Fig. 6. Normalised Channel Impulse Response

Bit Error Rate Performance

The data consisting of 2048 bits has been partitioned into several bit streams of 4 bits each, for the purpose of modulation. The IFFT of the modulated signal is computed followed by the insertion of guard band for eliminating ISI. This signal is then convolved using the channel impulse response generated with the Bellhop model. Upon reception, the guard band is removed and the FFT of the resultant signal is computed. The signal recovered after undoing the channel effects is then demodulated to get back the binary data and the bit error rate has been computed. In the simulation, 16-QAM and 16-PSK modulation schemes have been studied separately and their bit error rate performances compared for various signal-to-noise ratios.

Results and discussion

16-QAM based OFDM and 16-PSK based OFDM have been simulated in Matlab. From the simulation studies, it has been observed that 16-QAM based OFDM offers lower bit error rates than that for the 16-PSK based OFDM. Figs. 7(a) and 7(b) show the constellation diagram for the received 16-QAM and 16-PSK symbols respectively.

16-QAM based OFDM offers lower bit error rate compared to 16-PSK based OFDM, due to larger distance between the closest points in the constellation diagram. Fig. 8 shows the variation of BER for 16-QAM and 16-PSK based OFDM with respect to the SNR variations where as Fig. 9 shows the plot of original and recovered messages for 16-QAM based OFDM through the underwater channel. In QAM based OFDM methods, the number of points in the constellation diagram has also been varied to study the trend of bit error rate performances. As the number of points in the constellation plot of QAM increases, the bit error rate increases,due to decrease in the distance between the points in the constellation plot. Fig. 10 shows the variation of BER for 4-QAM, 16-QAM and 256-QAM based

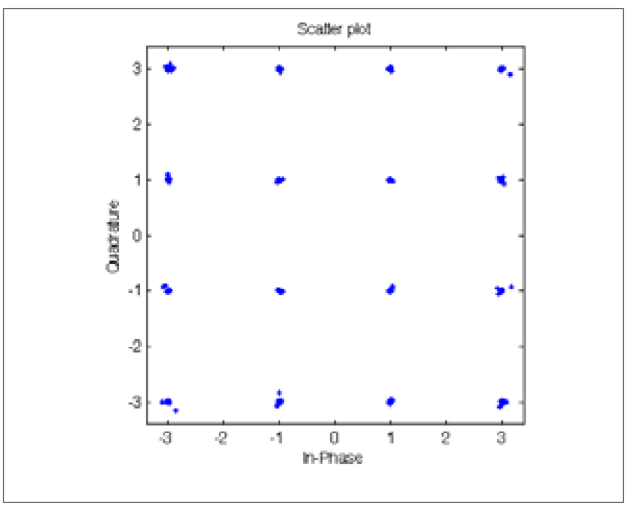

Fig. 7(a) Constellation Diagram of Received 16-QAM Symbols

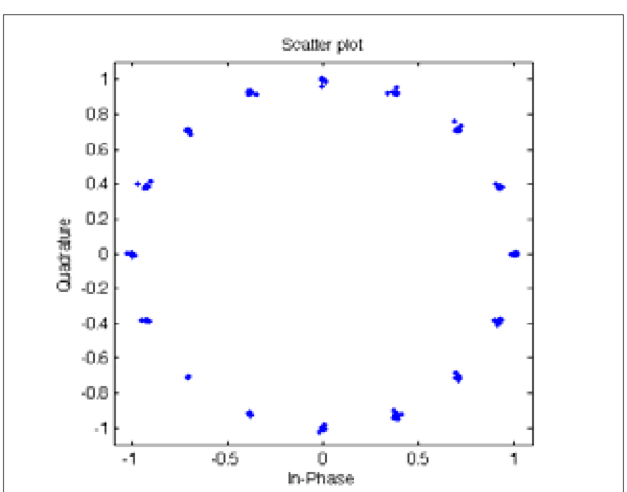

Fig.7(b) Constellation Diagram of Received 16-PSK Symbols.

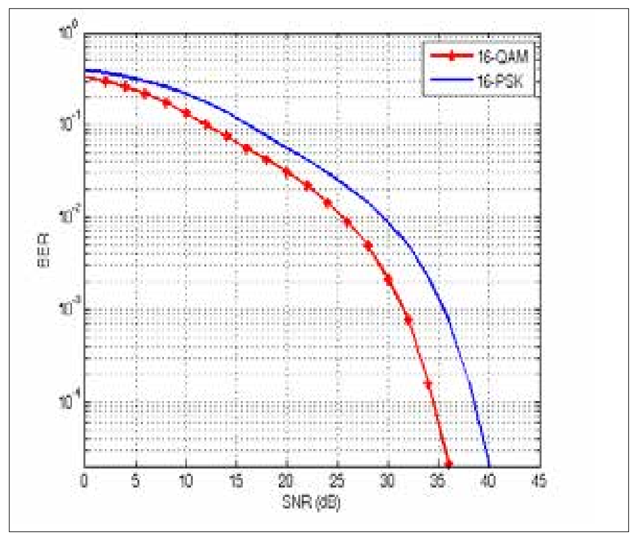

Fig. 8. Bit Error rate plots for 16-QAM and 16-PSK schemes with respect to SNR variation

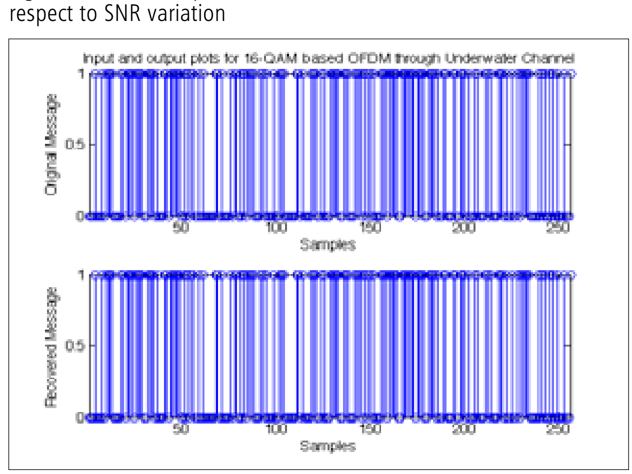

Fig. 9. Original and recovered messages for 16-QAM based OFDM through underwater channel.

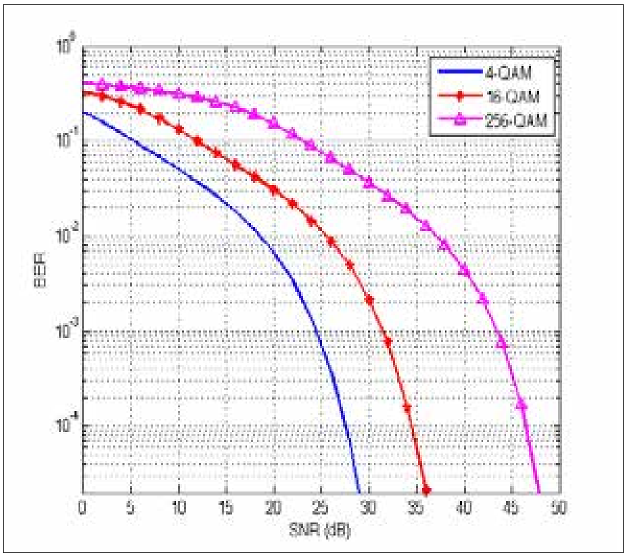

Fig. 10. Bit Error rate plots for 4-QAM, 16-QAM and 256-QAM with respect to SNR variation

OFDM with respect to the SNR variations. Among the three schemes compared, 4-QAM offers lower bit error rates.

OFDM has been simulated using 16-QAM and 16-PSK based modulation techniques. With the help of Bellhop, the underwater environment has been simulated and the bit error rates have been computed for 16-QAM and 16-PSK based OFDM schemes. As seen from the plots, 16-QAM offers lower bit error rates compared to 16-PSK based OFDM. The performance has also been compared for 4-QAM, 16-QAM and 256-QAM OFDM systems and among the three schemes compared, 4-QAM has been found to offer lower bit error rates.

Acknowledgements

The authors gratefully acknowledge the Department of Electronics, Cochin University of Science and Technology, for extending all the facilities for carrying out this work.The authors also acknowledge the Kerala State Council for Science, Technology and Environment and the University Grants Commission for the financial assistances.

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