

Modelling and Simulation of IDMA-OFDM for Underwater Acoustic Communication

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ABSTRACT

The Ocean exhibits phenomenon of changing acoustic signal transmission due to its non-stationary nature. Water columns in between transmitter and receiver are not fixed at any point of time. Thus, designing of a wireless communication systems for underwater applications becomes significantly challenging. The speed of sound in water is 1500 m/s which introduces large delay spread in acoustic signal due to multipath phenomenon. The large time delay causes Inter-symbol Interference; this ISI degrades the performance of many receivers. However orthogonal frequency division multiplexing is multi-tone modulation reduces long time delay spreads of acoustic channels. The Interleave division multiple access distinguishes each user with the unique random interleaver code. The IDMA-OFDM is superior design for reducing error bursts in multi-access underwater applications. A Simulink based simulation model of IDMA-OFDM system has been discussed in this paper. Satisfactory performance of the implementation was observed through analysis of BER with respect to SNR. The results have been concluded by comparing simulated data in BER tool of Simulink.

Keywords: BER, interleave division multiple access, orthogonal frequency division multiplexing, underwater communication, QAM

1. INTRODUCTION

Underwater wireless acoustic communication mostly depends on acoustic wave transmission as RF waves require large antenna size and high transmission power. Optical waves do not travel much distance and require line-of-sight in between the transmitter and the receiver so that it is difficult to communicate in case of mobile nodes. In recent years, underwater acoustic communication has gained much attention for applications like unmanned submarines, underwater robots/vehicles, and sensor nodes. The shallow-water channel is considered to be the most difficult acoustic medium for data transmission. Developing a reliable communication system for underwater application is really challenging and major difficulties in underwater acoustic communication are multipath interference and bandwidth of operation¹. Orthogonal frequency division multiplexing (OFDM) is a technique used to transmit a bit stream by dividing it into parallel bit-streams each with low bit rate and this parallel bit stream is further modulated over several modulation sub-carriers and then transmitted over additive white Gaussian noise channel. This avoids the overlapping of each sub-carrier channel thus eliminates inter-carrier interference². These days OFDM scheme is used in terrestrial digital radio and television broadcasting applications. The basic idea behind OFDM modulation is nothing but implementing an overlapping multi-carrier modulation for replacing a wideband signal to simultaneously transmitted narrowband signals. To implement OFDM Tx and Rx in discrete time IFFT and FFT are used respectively. To reduce ISI, OFDM symbol period should be greater than maximum delay spread^{3,4}.

Interleave division multiple access (IDMA) is a new technique used in multiple access schemes like DAB, HDSL, VHDSL and many other applications. The performance of CDMA technique is limited due to effect of multi-access interference (MAI) and inter-symbol interference (ISI)^{5,6}. IDMA employs simple chip-by-chip iterative multi-user detection technique which stands out unique from CDMA. IDMA is superior than CDMA in respect of highest spectral efficiency, uses chip-by-chip interleaving process makes design of iterative receiver low complex compared to RAKE receiver, it differentiates signals from different users and does not restrict with channel coding⁷.

This paper brings basic principle of IDMA-OFDM system for underwater acoustic communication and analysis of BER design using BER tool in Matlab 2013a. To have a clear idea about working of this designed system considered an Image data as input. Signal resembling the transmitted image is obtained at receiver. Still it may be necessary to improve BER making chip size equal to encoder length. The conventional CDMA multi-user detection scheme requires knowledge of correlation factors for all CDMA spreading codes. As number of users increases it can become quite a complicated issue for handling large matrix theory used in the past to tackle the problem. IDMA does not provide these signature sequences and simplifies this problem. Also IDMA includes low cost iterative MUD for systems with large number of users. It outperforms robust scheme in multi-path interference channel for underwater communication applications.

OFDM is multi-carrier modulation technique, splits high data stream into low rate data stream, and transmits

simultaneously over large number of sub-carriers. The symbol duration increases for low rated parallel sub-carriers. The dispersion in time caused by multipath delay spread is decreased. The orthogonality of sub-carrier spectra overlaps but still allows the sub-carrier signals to be recovered without fail. This helps to avoid intersymbol interference. The OFDM demodulation should perform before iterative MUD (IDMA) so that ISI and MAI are independently reduced to get lesser BER^{8,9}.

2. IMPLEMENTATION OF IDMA-OFDM

The modelling and simulation of the IDMA-OFDM system was for underwater acoustic applications. A block diagram has been modelled for IDMA-OFDM system which is suitable for underwater communication system, which consists of the Hamming encoder, which encodes the input sequence then interleaving operation was done with the help of random interleaver. The rectangular 64-QAM was used as modulation technique to perform IFFT operation then transmitted the complex signal over additive white Gaussian noise channel. Noises can be of two types – one is man-made noise and the other is ambient noise, the ocean consists of both the noises. The man-made noise dominates the other noise near sea-surface and around sea-shore, whereas ambient noise is dominant at deep sea level. The ambient noise sources can be described as having continuous spectrum and Gaussian statistics¹⁰. Hence, we considered AWGN to be noise channel for underwater application, as shown in Fig. 2.

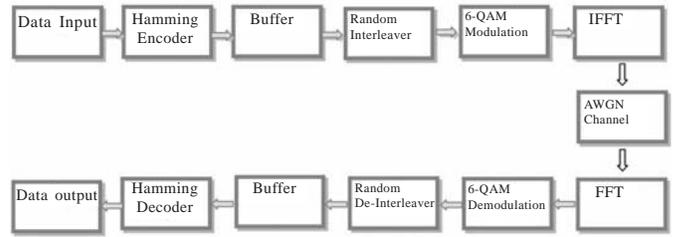


Figure 1. Block diagram of IDMA-OFDM system^{2,4}.

and simulation results wrt time. The design of IDMA-OFDM System Simulink model is as shown in Fig. 2. The input data stream is generated randomly by BBG, this bit stream is encoded with (7, 3) size. This code is permuted by Random interleaver with unique permutation number. Interleaving is to permute the sequence as such only intended user can de-interleave it. The 64-QAM modulator was used with user-defined bit mapping. Figure 3 shows the constellation mapping for user defined bit-mapping of 64-QAM modulator.

The IFFT operation was performed on this QAM symbol and the signal was transmitted over AWGN model as shown in Simulink model. The performance of any communication system is characterised under noisy environments. This is an empirical part of design process. The noise incorporates the distortion in transmitted signal, hence causes incorrect decisions at receiver side, resulting in bit errors.

The signal after performing FFT operation had a magnitude shown above Fig. 4. The bit error rate is nothing but the ratio

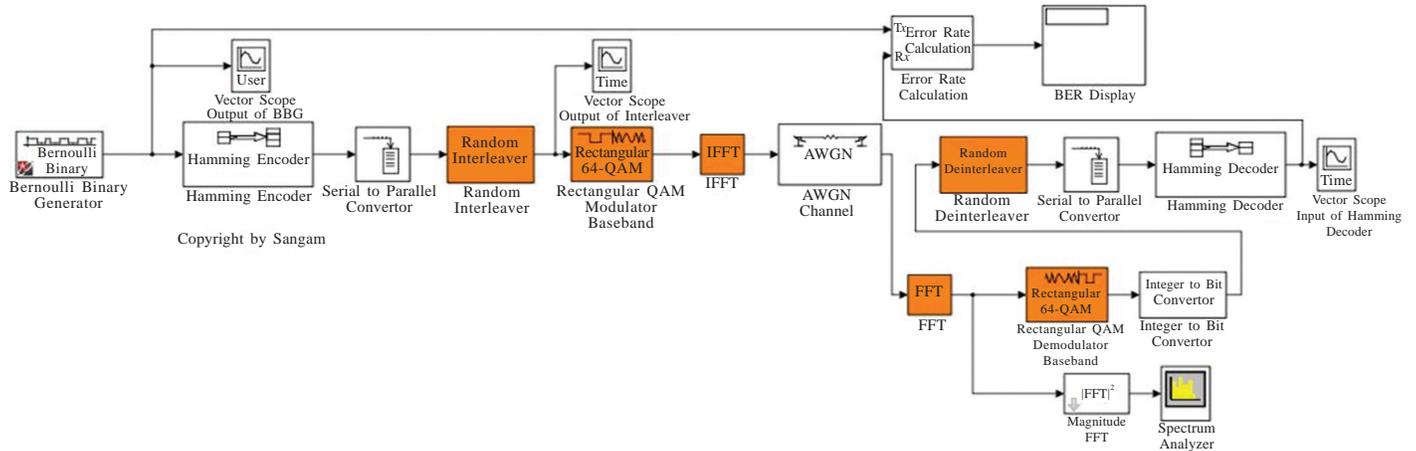


Figure 2. Simulink model of proposed IDMA-OFDM system.

At the receiving end, FFT operation was performed on received signal to convert the time domain signal into frequency domain. The demodulation operation was performed using 64-QAM demodulator on received FFT complex signal into integer values. The integer-to-bit convertor block gives a bit stream which gets further processed by random de-interleaver, and then Hamming decoder to get an original bit-stream. The block diagram of OFDM-IDMA is as shown below as Fig. 1.

Simulation model was made in line with the block diagram modelled in Fig. 1 with the help of Simulink, which is a graphical tool used for modelling multi-disciplinary communication systems with customisable block libraries of communication block set. It features analysis of data flow

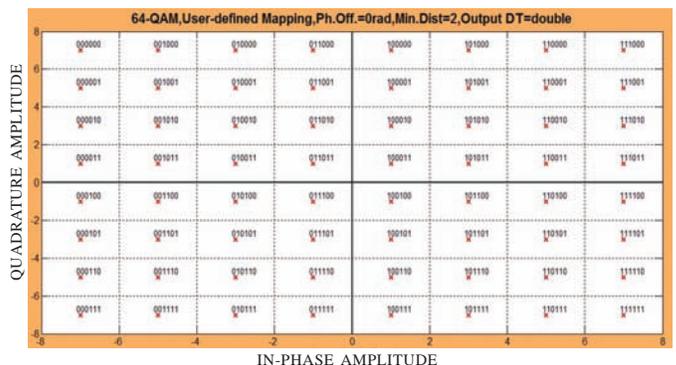


Figure 3. Constellation for user-defined bit-mapping of 64-QAM.

of no of errors to the total no of bits transmitted. The BER tool illustrates the relationship between BER v/s Eb/No (SNR), thus BER is compared with theoretical exact and theoretical approximation of QAM-Hamming with block size (7,4) and (31,26) as shown in results Fig. 10.

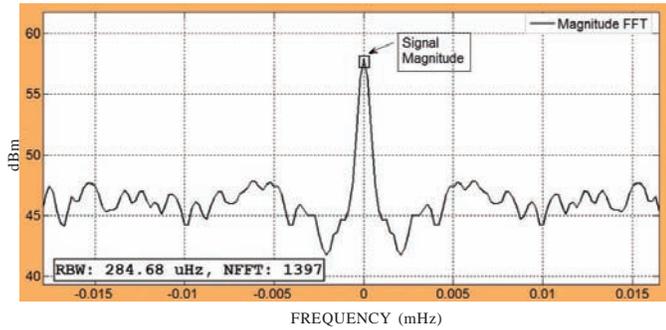


Figure 4. Magnitude of FFT operation of proposed Simulink model with input from BBG.

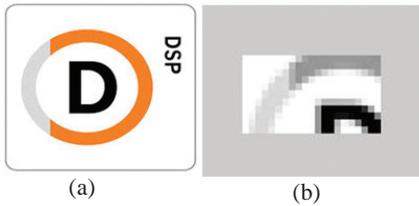


Figure 5. (a) Original image, and (b) A re-sized and cropped binary image

3. SIMULATED EXPERIMENT

To prove the designed model of proposed IDMA-OFDM system, an experiment was conducted by considering an image. A small part of data of the image was taken as an input to the system by resizing it randomly to overcome the simulation time constraints. Hence, the entire image need not be considered, the original image and a re-sized-cropped image was considered for the experiment, as shown in Fig. 5.

The input (binary image) is taken from workspace; based on the image, the Hamming encoder generates a sequence code as chip elements. The random interleaver permutes these chip elements; this data is modulated with 64-QAM technique. The

IFFT operation is performed over output data of 64-QAM, then the signal was sent over AWGN channel. Moreover at receiver side FFT operation followed by de-mapping de-interleaving (chip-by-chip) process, the output of de-interleaver decoded by Hamming decoder. The Simulink model of the experiment is shown as Fig. 6. Figures 2 and 6 are similar but the input provided at Fig. 2 is BBG and at Fig. 6 is binary image.

The received data was further processed as shown in the Fig. 7. The flow chart explains the operation to be performed on the received image during the process. The processing of the image takes the following steps:

1. Read an image, convert image into gray-scale image.
2. Re-size and crop the selected image.
3. Convert the image from decimal-to-binary.
4. Convert unsigned integer 8 to double format.
5. The double formatted data is given as input to the proposed system.
6. The double formatted data is to be 1D format.
7. Convert the 1D format data into 2-D matrix.
8. Perform binary-to-decimal operation on the 2-D Matrix.
9. The matrix is in double format; convert it to unsigned integer 8 data type.
10. This data is in vector form; convert it into matrix, as shown in Fig. 7.

The recovered image pixels were compared with original resized-cropped image pixels and were placed in another variable to know how much data was received correct with and without any loss.

After processing the image generated, resemblance with original input image as shown in Fig. 8, which is similar to the cropped image and a lossy in nature and could be used for BER processing.

The spectrum of magnitude of FFT of the received data from the simulation is as shown in Fig. 9. This implies that the proposed system have moderate BER. This shows that the proposed design of the system should be able to receive at least 50 per cent data of the original image transmitted, as shown in Fig. 8. The BER can be further reduced by adapting new algorithms and efficient encoding schemes.

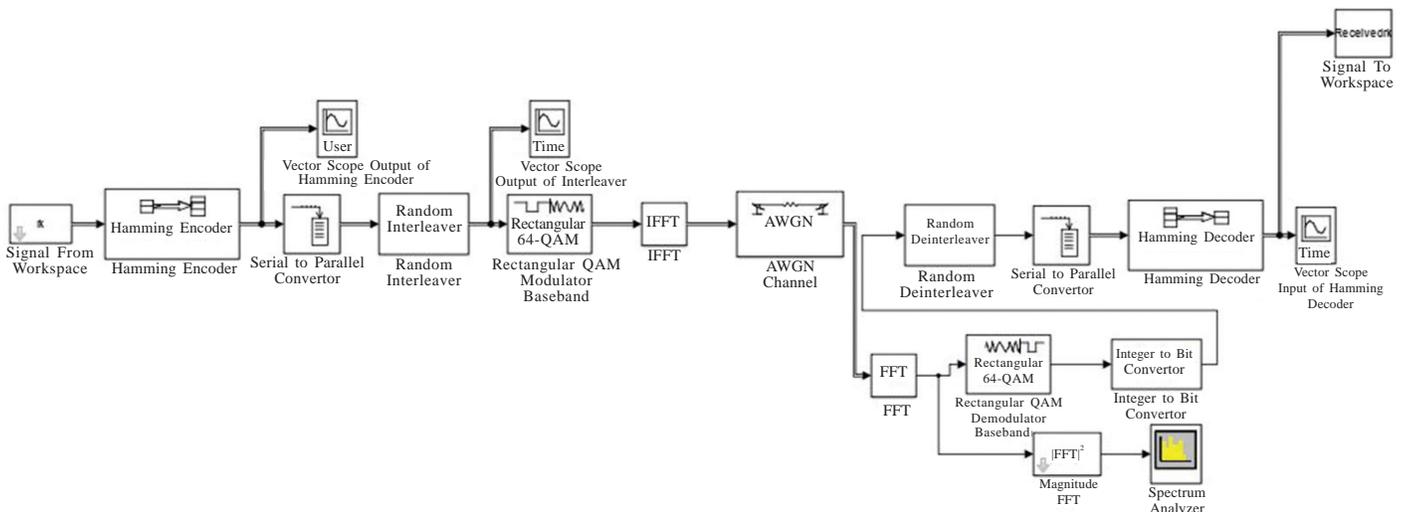


Figure 6. An image data is sent and recovered through proposed system model.

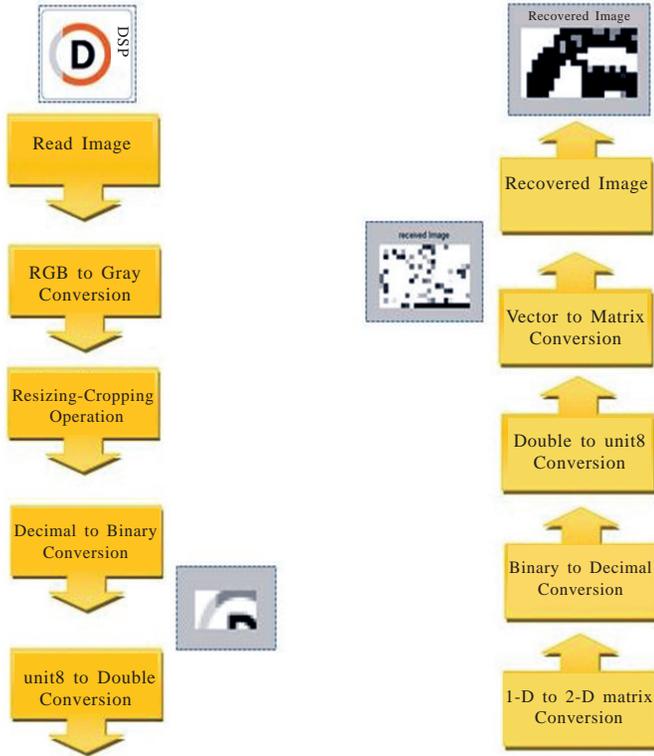


Figure 7. A flow chart of an image before processing and after processing.



Figure 8. An image before processing and after processing.

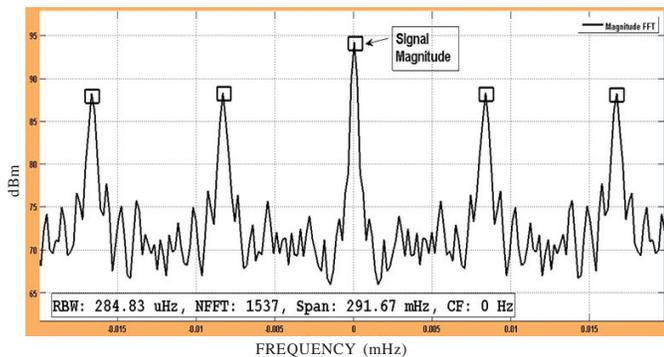


Figure 9. Magnitude of FFT operation over received image data.

4. BER ANALYSIS

The BER plot of the system performance in different noise AWGN environments as shown in Fig. 10, was generated with the help of BER tool. Here BER plots of proposed system and the line plots are theoretical-exact and theoretical approximated plots of 64-QAM without coding, with coding HME block size (7, 4) and (31, 26). Table 1 gives conclusive findings from this BER plot. For low data rates, the Table 1 gives the data.

- When chip size is equal to length of spreading code, then it is a significant BER.
 - When chip size is greater than the length of spreading code results BER increases with order of 10. For high data rates
 - If chip size is equal to length of spreading code, implies significant BER.
 - If chip size is greater than the length of spreading code, results moderate BER which may increases by factor 2.
- Thus the choice of chip size plays important role over here, which signifies the lesser BER with respect to the theoretical approximated value.

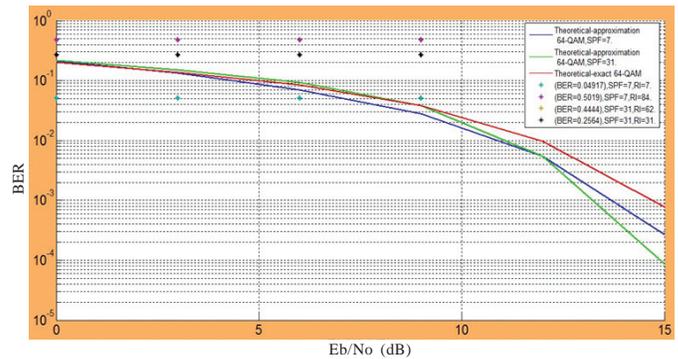


Figure 10. BER pperformance of IDMA-based OFDM system in AWGN channels.

Table 1. Analysis of the BER plots with different configurations of random interleaver chip

BER	HME (n,k)	Buffer size	Random interleaver chip size	Samples/frame
0.04976	(7,4)	7	7	4
0.5094	(7,4)	84	84	4
0.2564	(31,26)	31	31	26
0.4444	(31,26)	62	62	26

5. CONCLUSION

This paper proposes a new Simulink model of IDMA-OFDM system for multi-access communication for the underwater communication scenario as an application. The analysis of BER was conducted by considering an image as input for transmission. Basically IDMA adapts chip-by-chip multi-user detection receiver with low complexity as it is an extension of CDMA. Simulation of IDMA-OFDM for underwater application was done satisfactorily with the help of Matlab Simulator-based BER tool. The implementation of IDMA-OFDM model is applicable for the MIMO-based underwater applications which are using multipath with multi-user or signal configurations.

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In the current study Sangram More has done simulation and programing of IDMA-OFDM system for underwater acoustic communication using Matlab Simulink.

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In the current study K. Krishna Naik has done concept and design of modelling of IDMA-OFDM system for underwater acoustic communication.