BER Performance Evaluation of Underwater Communication System with Spatial Diversity

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Abstract

Objectives: To use diversity technique to improve the Bit Error Rate (BER) performance of Underwater Acoustic Communication (UWAC). **Methods/Analysis:** Orthogonal Frequency Division Multiplexing (OFDM) is used in UWAC to effectively deal with the multipath propagation delay and also it produces high bitrate underwater communication. The three major factors that are considered in UWA propagation are attenuation, time varying multipath and low speed of sound. The noise that is considered in UWAC is ambient noise. **Findings:** To overcome the effect of multipath fading, diversity technique is used in UWC. Spatial diversity along with Maximal Ratio Combining (MRC) is found to be a better approach to improve the error performance. **Novelty/Improvement:** OFDM along with spatial diversity and MRC will mitigate the system against channel fading.

Keywords: Maximal Ratio Combining, Orthogonal Frequency Division Multiplexing (OFDM), Spatial Diversity, Underwater Acoustic Communication (UWAC)

1. Introduction

Underwater Acoustic communications (UWAC) gave the wireless communication a new challenge to explore because of its various difficulties such as attenuation, multipath propagation, limited bandwidth, rapid time variation and severe fading¹. The main applications of underwater communications are in Remotely Operated Vehicles (ROV), Underwater sensor Networks (UWSN), military and navigation applications, diving purposes Autonomous Underwater Vehicles (AUV), underwater sports etc. Irrespective of different signals that can be used to propagate in wireless media, sound (acoustic) signals are mainly used in underwater media². Doppler Effect is another issue in UWAC which is generally caused by TX / RX motion and the moving sea surface³. Orthogonal Frequency Division Multiplexing (OFDM) technique which is found of greater importance in wireless 3G/4G communications also has its importance in UWAC. In OFDM, a single channel is utilized for many sub-carriers on adjoining frequencies and also the sub-carriers in an

OFDM system overlap on each other to increase the spectral efficiency. Also, the main disadvantages such as Inter Symbol Interference (ISI) and Inter Channel Interference (ICI) can be reduced by using OFDM. However diversity combining techniques are used to overcome the fading effect in wireless communications⁴. They are also used to increase the performance of the radio channel, without further increasing the transmitted power. In this particular paper we used the spatial diversity technique with Maximal ratio Combining (MRC) at the receiver of UWAC system to improve the bit rate performance.



Figure 1. OFDM Functional block.

The rest of the paper is arranged as follows: Section II marks out the system model. Section III gives a brief view of the diversity techniques that are used. Section IV gives the simulated result followed by conclusions and future scope in Section V.

2. System Model

2.1 OFDM

One of the most important reasons for choosing OFDM in UWAC is in its way to deal with multipath propagation delay and also for high bit rate underwater communication⁵. It transmits a bit stream by dividing in to 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 the additive white Gaussian noise channel as shown in Figure 1.

To implement OFDM TX and RX in discrete time, IFFT and FFT are used respectively. Apart from the advantages of regular OFDM, if this technique is used in underwater medium it has many more advantages such as:

(i)Effects of channel distortion can be reduced by using pilot carriers.

(ii)Performance of the communication scheme can be improved by using interleaving and Forward Error Correction (FEC).

(iii)Diversity techniques will further improve the performance against fading channel impairments.

The transmitted signal after performing IFFT is given by

$$x[t_n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[f_k] \exp(j2\pi k / N)$$

 $n=0, 1...., N-1$ (1)

The received signal is given by

$$\widehat{x}[t_n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} H[f_k, t_n] X[f_k] \exp(j2\pi h / N) + w[t_n]$$
(2)

Here $X[f_k]$ is the transmitted data of the kth subcarrier, $x[t_n]$ is the discrete time sample of the UWA-OFDM, N is the number of subcarriers, $H[f_k, t_n]$ is the time variant channel transfer function and $w[t_n]$ is the ambient noise.

2.2 UWC Channel

The three main factors that characterize the acoustic underwater propagation are attenuation which increases with signal frequency, low speed of sound and timevarying multipath propagation. The noise which affects the underwater channel is the ambient noise or the background noise. The waves caused by the sea surface, interior turbulence, fluctuations in the speed of the sound etc., contribute for random signal variations. The path loss of UWC channel is given by⁶.

$$A(l,f) = (l/l)^{k} a(f)^{l}_{r}$$
(3)

Here f is the signal frequency, with reference to l_r , l

is the transmission distance, a(f) is the absorption coefficient and k is the path loss exponent. a(f) is expressed using the thorp's formula^Z

$$10 \log_a(f) = 0.11$$

$$\frac{f^2}{1+f^2} + 44 \frac{f^2}{4100+f^2} + 2.75 * 10^{-4} f^2 + 0.003$$
(4)

Figure (2) shows the variation of a(f) with frequency



Figure 2. Absorption coefficient in dB/km.

Turbulence, waves, shipping and thermal noise are generally used in modeling ambient noise. Generally ambient noise sources are illustrated by continuous Power Spectral Density (PSD) and Gaussian statistics. The PSD of the noise components as a function of frequency in kHz is given by the following empirical formula. Overall PSD is given by

$$N(f) = N_{t}(f) + N_{s}(f) + N_{w}(f) + N_{th}(f)$$
(5)

Where $N_t(f)$ is the turbulence noise, $N_s(f)$ is the shipping noise, $N_w(f)$ is the noise caused by waves and $N_{th}(f)$ is the thermal noise.

2.3 Diversity Technique

The main use of diversity technique is to overcome the effect of multipath fading in UWC. The useful way to

improve the error performance in UWC is to use spatial diversity. Space-time-coding will make nonstandard conformable modifications mandatory and so it is not appropriate for improving the existing systems. Therefore spatial diversity techniques can be used for standardized systems⁸. The frequency selectivity of the transfer function of the channel can be increased by selecting cyclic delays at the transmitter and receiver antennas. By combining or selecting many signals that are passing through different propagation paths, diversity receiving technologies can lessen the influence of propagation distortion. Maximum Ratio Combining (MRC) and Selective Combining (SC) are the methods for incorporating received signals in diversity receivers. MRC is greater than SC in terms of improving the signal-to-noise ratio (SNR)⁹. The general form of MRC is shown in Figure 3.



Figure 3. Maximal ratio combining.

The basic idea of MRC is weighted and coherent addition of samples. For multi RX-antenna OFDM systems, we use a maximal ratio combiner for a subcarrier-wise

combination of the N_r RX-antenna signals¹⁰.

$$R_i(m) = H_i(m).S(m) + n_i(m)$$
 (6)

Here $R_i(m)$ is the received signal at RX-antenna in branch i and subcarrier m,

S is the data symbol,

 H_i denotes the complex Gaussian distributed fading coefficient from the TX-antenna to RX-antenna i with zero mean and unit variance.

$$H_i = \frac{1}{\sqrt{2}} \pm \frac{1}{\sqrt{2}}j \tag{7}$$

'+' for i=1, 3..... '-'for i=0, 2

 n_i is the complex-valued noise as referred in equation 5.

For simplicity and without loss of generality, we skip subcarrier index m. using these N_r samples; a maximal ratio combiner calculates the received signal R as

$$R = \frac{1}{\sqrt{N_r}} \sum_{i=0}^{N_r - 1} H_i^* R_i$$

S. $\frac{1}{\sqrt{N_r}} \sum_{i=0}^{N_r - 1} |H_i|^2 + \frac{1}{\sqrt{N_r}} \sum_{i=0}^{N_r - 1} H_i^* R_i$ (8)

for each subcarrier.

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Its SNR can be calculated as

$$SNR = \sum_{i=0}^{N_r - 1} \frac{E\{|S|^2\} |H_i|^2}{\sigma^2}$$
(9)

The following are the steps to apply diversity technique for UWC channel.

• At the transmitter

Step 1. Generate random data source

- Step 2. Apply QPSK Modulation.
- Step 3. Convert serial data to parallel data.
- Step 4. Apply IFFT technique.
- Step 5. Add Cyclic Prefix.
- Step 6. Convert parallel data to serial data.

Step 7. Pass the information through UWC channel

- At the receiver
- Step 8. Apply equalization.
- Step 9. Perform hard decision decoding.
- Step 10. Apply FFT.

Step 11. Demodulate the data.

- Step 12. Convert parallel data to serial data
- Step 13. Calculate the number of errors.

For conventional OFDM without diversity, steps 8 and 9 are replaced by converting serial data to parallel data and removing cyclic prefix.

3. Simulation Results

Figure 4 shows the BER performance with and without iversity.

As we increase the number of receiving antennas at the receiver side the performance increases as shown in Figure 5. This work is an improvement than what is referred in⁵ in terms of BER performance. Methods to improve signal quality can be designed depending on the environment and the expected interference. Multiple scattering of the underwater channels has to be studied further¹¹.



Figure 4. BER to SNR graph for OFDM and diversity technique.



Figure 5. BER to SNR graph for OFDM and diversity technique with increasing number of receiving antennas.

4. Conclusion

In this paper, we have applied OFDM technique to UWC and further improved its performance against fading channel impairments by using diversity techniques. As we increase the number of receiving antennas further improvement is observed and BER is decreased. On application of interleaving, efficiency of the system can be improved by making the system more robust against channel distortion

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6. References

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