Analyzing an OFDM System using Cyclic Prefix to Improve the Underwater Communication

Hussam Alraie*

Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu , Kitakyushu, Fukuoka 808-0196, Japan†

Kazuo ISHII

Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu , Kitakyushu, Fukuoka 808-0196, Japan
E-mail: alraie.hussam973@mail.kyutech.jp, ishii@brain.kyutech.ac.jp
www.lsse.kyutech.ac.jp

Abstract

Underwater Communication is one of the most difficult challenges facing researchers. OFDM technique has been used widely in 4G communication systems, and recently it was approved to be successfully implemented in 5G. Many researchers have improved the Underwater wireless communication system including Acoustic communication using the OFDM technique. We applied the Cyclic Prefix in this study to improve the underwater communication system. We started by studying the effects of Rician fading based on the OFDM system on the wireless channel. Then we analyzed the Bit Error Rate (BER) of the system in several scenarios, by applying the AWGN, Rician fading, and absorption factor to simulate the underwater channel.

Keywords: OFDM, Cyclic Prefix, 5G, Underwater, AWGN, Rician fading.

1. Introduction

The wireless signals underwater are scattered widely which affects the quality of the received data and will add more difficulties to restore the original data.
The propagation of the underwater acoustic signals is limited due to the high absorption of the water [1].
OFDM and MIMO-OFDM are used to improve the underwater communication response which can increase the data rate due to the multi-carrier property.
Tabeshnezhad, A., and Pourmina, M. A. used MIMO-OFDM to increase the data rate with QPSK digital modulation, and they used the Alamouti MIMO-OFDM to improve the underwater optical communication (UWOC) [2].
Thottappilly, A. worked on underwater acoustic communication and analyzed the OFDM system and doppler effectiveness on the transmission signal using MATLAB [3].

In this paper I will show the simulation result of an OFDM system with and without CP by analyzing the system in an Additive White Gaussian noise (AWGN) environment only, then compare the results after adding Rician fading and finally Rician fading with absorption effect which will simulate the underwater communication system.

2. Towards OFDM

A Frequency Division Multiplexing system (FDM) divides the whole bandwidth into non-overlapping channels.
Each channel has its carrier and to prevent the overlapping between each channel there is a guard period. The whole data transfers in parallel through the carriers as shown in Figure 1.

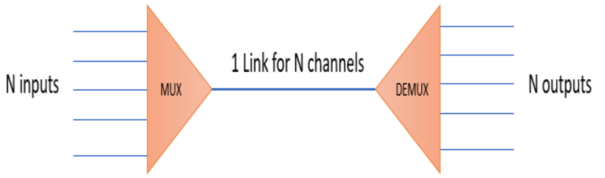

Fig. 1. FDM transfer method

Loss of bandwidth between each carrier is one of the disadvantages of FDM.
Time-divisions multiplexing system divides the channel into time slots that can be used for each user. The disadvantage of this method is that each user should wait until the end of the previous time slot to be able to send its data.
Orthogonal Frequency Division Multiplexing system (OFDM) is a multi-carrier modulation. The data transfers through different subcarriers in one symbol, and each carrier should be modulated using one of the modulation schemes such as QPSK, QAM, and BPSK.

The effects of the Underwater Acoustic (UWA) channel decrease the quality of communication due to the Doppler effect, low propagation speed, and harsh water channel. The cyclic Prefix (CP) adds a guard interval between each OFDM symbol which can help to prevent Inter Symbol Interference (ISI) [4].

OFDM System

In the OFDM system, we start by modulating the input data using one of the digital modulation schemes. The modulated data should be converted to parallel data which will be the input of Inverse Fast Furrier Transform (IFFT). IFFT transfers the signal from the time domain to the frequency domain. The converted data should be transferred as serial data through the channel. Figure 2 illustrates the process of the OFDM system transmission and receiving.
The channel characteristics add additional noise to the signal and decrease its quality.

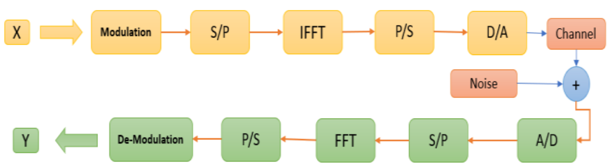

Fig. 2. OFDM system box chart

3. Methodology

We used the MATLAB simulation program to analyze the OFDM system in multiple scenarios with and without CP for 64,128 and 256 subcarriers:

- OFDM with AWGN only.
- OFDM with AWGN and Rician fading.
- OFDM with AWGN and Rayleigh fading.
- OFDM with AWGN, Rician fading, and absorption factor.

Then compare the BER for each scenario.
In the simulation, we assume that the absorption factor for underwater communication affects the signal by multiplying with a random number between [0 - 1].
0 means that the absorption effect suppresses the signal at 100% and 1 means that there is no absorption effect.

4. Results and discussions

(1) Scenario 1: OFDM with AWGN only
In this scenario, we simulate the OFDM system by adding AWGN only and compare the BER with and without CP.
Table 1 shows that BER is decreased by increasing the Signal Noise Ratio (SNR).

Table 1. BER comparison with and without CP

BER in AWGN		
Eb/N0 (dB)	BER CP = 0	BER CP = 4
1	0.00417	0.04
2	0.028	0.024
3	0.02164	0.0154
4	0.0078	0.0066
5	0.0027	0.0029
6	0.0011	0.001
7	0.00027	0.00026
8	$7.2 * 10^{-5}$	$3.9 * 10^{-5}$
9	$9 * 10^{-6}$	$4.99 * 10^{-6}$

It can be noticed that the BER decreased by about 50% when the SNR reach 8 dB.
(2) Scenario 2: OFDM with 64,128 and 256 subcarriers
In this scenario, we simulate the OFDM and compare the BER with and without CP for AWGN only then OFDM with AWGN, Rician fading, and absorption factor, using 64,128 and 256 subcarriers as shown in Figure 3.

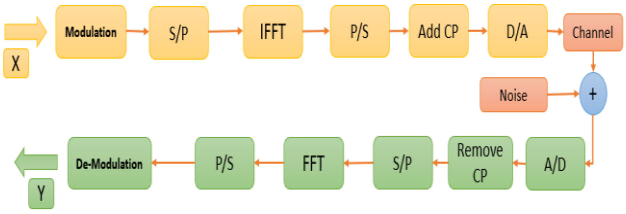

Fig. 3. OFDM simulation flow chart

Figure 4 illustrates the BER comparison in OFDM system CP free using 64 subcarriers. We can notice the effect of the absorption factor which increases the BER of the Rician fading channel.

For 64, 128, and 256 we use the same way of comparison with and without CP, and Tables 2, 3 and 4 show the results.

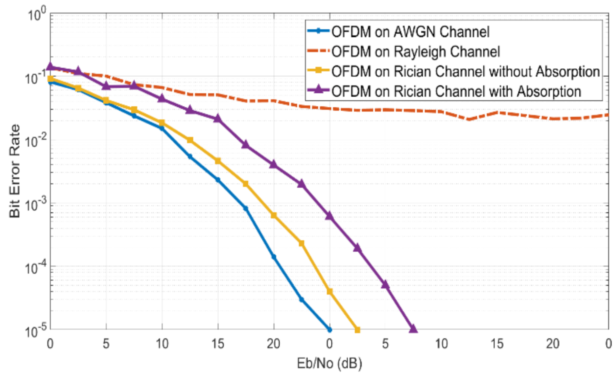

Fig. 4. BER in AWGN environment

Table 2. BER comparison with and without CP for 64 SCs

BER

SNR	CP_Free	CP = 1% of SC	CP = 3% of SC	CP = 5% of SC
6 dB	2.1×10^{-2}	1.4×10^{-2}	$1.4 * 10^{-2}$	1.2×10^{-2}
7 dB	8×10^{-3}	7.8×10^{-3}	10^{-2}	7.2×10^{-3}
8 dB	4×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3×10^{-3}
9 dB	1.95×10^{-3}	1.5×10^{-3}	1.76×10^{-3}	10^{-3}
10 dB	6×10^{-4}	4.5×10^{-4}	5×10^{-4}	4×10^{-4}

Table 3. BER comparison with and without CP for 128 SCs

BER

SNR	CP_Free	CP = 1% of SC	CP = 3% of SC	CP = 5% of SC
6 dB	1.6×10^{-2}	1.5×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
7 dB	10^{-2}	7.2×10^{-3}	7.3×10^{-3}	7.8×10^{-3}
8 dB	4.2×10^{-3}	3.9×10^{-3}	3.4×10^{-3}	3.6×10^{-3}
9 dB	1.8×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	1.7×10^{-3}
10 dB	5.9×10^{-4}	3.9×10^{-4}	5.3×10^{-4}	5.9×10^{-4}

Table 4. BER comparison with and without CP for 256 SCs

BER

SNR	CP_Free	CP = 1% of SC	CP = 3% of SC	CP = 5% of SC
6 dB	1.3×10^{-3}	1.3×10^{-3}	2.3×10^{-2}	1.8×10^{-2}
7 dB	7.5×10^{-3}	7.5×10^{-3}	1.3×10^{-2}	8.7×10^{-3}
8 dB	2.8×10^{-3}	3.3×10^{-3}	5.7×10^{-3}	3.7×10^{-3}
9 dB	10^{-3}	1.7×10^{-3}	2.2×10^{-3}	2.3×10^{-3}
10 dB	4.9×10^{-4}	5.7×10^{-4}	9.1×10^{-4}	8×10^{-4}

From Table 4 it can be noticed that using CP in an OFDM system with 256 subcarriers increases the BER because increasing the number of subcarriers extends to the OFDM symbol size, as a result, we need to increase the CP length to reduce BER which will reduce the efficiency of bandwidth. Table 2 and 3 show that using CP in an OFDM system with 64 and 128 reduce the BER and as a result, it increases the quality of the received signal.

Referring to Tables 2, 3 and 4 BER enhanced with values as shown in Tables 5, 6 and 7 which will summarize the results of BER improvement in percentage by changing SNR and CP values.

Table 5. BER comparison when CP = 1% of Sc

BER compared with CP_Free performance

SNR	CP = 1% of 64 SC	CP = 1% of 128 SC	CP = 1% of 256 SC
6 dB	-33.67%	-6.25%	0%
7 dB	-1.25%	-18%	0%
8 dB	-17.5%	-7.2%	+17.8%
9 dB	-25%	-33.67%	+70%
10 dB	-25%	-34.1%	+16.3%

Table 6. BER percentage comparison when CP = 3% of Sc

	BER compared with CP_Free performance		
SNR	CP = 3% of 64 SC	CP = 3% of 128 SC	CP = 3% of 256 SC
6 dB	-33.67%	0%	+77%
7 dB	+25%	- 27%	+73.33%
8 dB	-17.5%	-19.1%	+103.5%
9 dB	-10%	-16.67%	+120%
10 dB	-8.3%	-10.2%	+85.7%

Table 7. BER percentage comparison when CP = 5% of Sc

	BER compared with CP_Free performance		
SNR	CP = 5% of 64 SC	CP = 5% of 128 SC	CP = 5% of 256 SC
6 dB	-57.15%	0%	Increased more than a tribble
7 dB	-10%	-27%	+16%
8 dB	-25%	-19.1%	+32.14%
9 dB	-51.82%	-16.67%	+130%
10 dB	-33.67%	-10.2%	+63.26%

Tables 5,6 and 7 show that using CP with 1% and 3% of the 64 subcarriers in underwater OFDM system improves the BER by 33.67% and enhanced up to 57% when SNR reaches 6 dB while using 1% of 128 subcarriers improves the BER between 33-34 % but after increasing the SNR to 9 or 10 dB. In contrast, using CP in 256 subcarriers shows a negative response of the OFDM system even if CP length increases up to 5% of 256 subcarriers.

5. Conclusion

In this paper, a proposed relationship between the CP and the number of subcarriers shown in tables 5,6, and 7 showed that using CP improved the OFDM system using 64 and 128 subcarriers compared with 256 subcarriers. In addition, using 1% of CP in both 64 and 128 is the best choice compared with the studied scenarios, because it reduces the reserved bandwidth for CP. To get the same performance while using CP in both suggested systems we should make sure to increase the SNR from 6 dB in the 64-subcarrier system up to 9 dB in the 128-subcarrier system.

Using 3% of subcarriers was efficient for both 64 and 128 subcarrier systems, it improves the BER compared with CP_Free results while using 5% of subcarriers showed a better result in 64 subcarrier systems when the SNR reaches 6 or 8 dB compared with 128 subcarriers.

It can be noticed that using 1% is better than 3% of subcarriers because it reserved less bandwidth.

Using CP in 256 subcarriers simulated system showed the negative response of the BER performance under the comparison percentages.

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Authors Introduction

Mr. Hussam Alraie

He received his Master's degree from the Department of Communication Engineering, AL-Baath University, Homs, Syria in 2018. He is currently a Doctoral student in Kitakyushu, Life Science and System Engineering, Kyushu Institute of Technology, Japan.

Prof. Kazuo ISHII

He is currently a Professor at the Department of Human Intelligence Systems of Kyushu Institute of Technology, Japan. His research interests are in the fields of Underwater Robotics, Field Robotics, Neural Networks, and Intelligent Systems.