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Research Article

Channel Estimation using Pilot-Assisted OFDM for Underwater Acoustic Communication

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ABSTRACT

Underwater communications research is significant to researchers because of the challenges and difficulties in transmitting wireless signals within this environment. Underwater Acoustic Communications (UWA) are characterized by the fact that they can travel long distances compared to the radio signal, which makes it very effective compared to other types, in addition to the lack of costs in establishing these types of systems. OFDM technique has been used widely in 4G communication systems, and recently it was approved to be successfully implemented in 5G. One of the most important aims of developing communications systems is to reduce the bit error rate (BER), and since the underwater communication signal is subject to many influencing factors that reduce the accuracy of the signal when it reaches the receiver, such as absorption and multipathing, researchers must improve the performance of the OFDM system by removing this effect. The channel effect is reduced by selecting some subcarriers from the OFDM system and assigning them as pilots. These Pilots are given higher power to determine the channel effect and then use the appropriate equalizer to reduce the effect and improve signal accuracy. In this study we tested the appropriate number of pilots to estimate the channel response, with a linear equalizer to reduce the effect at the receiver, then compared the BER before and after adding the equalizer.

1. Introduction

70% of the Earth is covered by water and still a large part of it is undiscovered. Underwater robots can reach depths that humans cannot, but they suffer from problems in the way data is transmitted wirelessly. Data quality at the receiver is affected when the transmitting wireless signal transfers through the water due to multiple parameters involved, which makes it more difficult to recover the original signal. Underwater communication networks have drawn the attention of researchers and put them facing many theoretical and practical challenges. The emergence of new applications for this type of communication, such as underwater sensors, autonomous vehicles, and robots, has led to increased research and investigation, to make these applications more effective for collecting information, especially in real-time applications [1]. Three types of underwater communication have been implemented which are: Radio Frequency (RF), Optical, and Acoustic communication. Radio frequency communication provides a high transmission rate within a short distance. Raji et al. [2] experimented with a live video transmission over RF communication over UDP. Underwater Optical Communication (UWOC) had also a disadvantage in that the particles in the sea absorb the optical signals [3]. They achieved 6.8 Mbps within the one-meter distance between the transmitter and receiver. Acoustic transmission systems have distinct capabilities for transmission across the water, as data can reach several kilometers [4], [5], making them a distinctive choice for most important applications in marine exploration. The low transmission rate within this type of communication makes studying the signal quality very important because high BER for UWA communication means that even kbps will be of low quality.

The wireless signals spread based on the mechanical and electromagnetic properties of the propagation medium.

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The speed of propagation of the acoustic waves in liquids is about 5 times less than the speed of propagation in a vacuum [6]. Increasing the transmission rate is one of the challenges that researchers face by using multiple antennas at the transmitting and receiving end of the OFDM system. Multi Input Multi Output (MIMO) system has been used to increase the data rate in underwater environments. MIMO-OFDM with generalized Lite Emitting Diode (LED) has been used to improve spectral efficiency by increasing the data rate in Underwater Optical Communication (UWOC) [7]. Pilot-OFDM is used to estimate the underwater acoustic channel which helps to enhance the performance using Least Square Error (LSE), Mohsin Murad et. al. conclude that increasing the number of Pilots doesn't increase the system performance [8]. The effect of the number of pilots in the OFDM system has been studied in this paper by changing the frequency and the number of subcarriers with and without adding the equalizer, without adding the cyclic prefix to this system, and then the effect of adding the cyclic prefix on it was studied. we will compare the BER performance of the OFDM with and without adding CP, when we add the Additive White Gaussian Noise (AWGN) only, then we incessant the study by adding the Rician channel which is the simulation of the underwater propagation of the signal as shown in the experiment of Kulhandjian et. al. [13]. The comparison was made to the OFDM system by varying the number of subcarriers in each study.

2. Underwater Acoustic Channel

Three different factors affect the transmission of underwater acoustic signals which are: absorption, scattering, and noise.

The amount of signal energy absorption was determined as a function of frequency if the frequencies were less than 50 kHz via Thorpe's equation and as a function of frequency and other parameters such as the acidity percentage when the frequency exceeded 50 kHz [9], [10]. Eq.1 and Eq.2 explain the mathematical formula of each case:

$$a(f) = \frac{0.11\, f^2}{1+f^2} + \frac{44\, f^2}{4100+f^2} + 2.75 \times 10^{-4} + 0.003 \qquad (1)$$

$$a = \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \qquad (2)$$

Where a is the absorption, f is the frequency, the first part of Eq.2 explains the B(OH)3, which is the Boric Acid, and the second part of Eq.2, expresses the MgSo4, f_1, f_2 are the relaxation frequencies for both components. The final part indicates pure water. The multipath effect occurs because of receiving the **p**aths as a result of the signal being reflected from the surfaces (floors) of bodies of water. To decrease the Inter Symbol Interference (ISI) caused by the propagation in the Underwater Acoustic (UWA) channel, CP adds intervals between the successive OFDM symbols [11]. The rate of impact of noise on the underwater acoustic signal is also frequency dependent, as the source of noise is multiple, such as wind, turbulence, and shipping noise sources. For narrow ranges of frequencies on the order of kilohertz, the noise relationships are expressed by the following equations [12]:

$$10 \log N_t(f) = 17 - 30 \log(f) \qquad (3)$$

$$10 \log N_{th}(f) = -15 + 20 \log (f) \qquad (4)$$

$$10 \log N_w(f) = 50 + 7.5 \sqrt{w} + 20 \log (f) - 40 \log (f + 0.4) \qquad (5)$$

$$10 \log N_s(f) = 40 + 20\,(S - 0.5) + 26 \log (f) - 60 \log (f + 0.03) \qquad (6)$$

$$N_{total} = N_t + N_{th} + N_w + N_s \qquad (7)$$

OFDM System

The data is modified in the OFDM system using one of the digital modulation schemes like Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or any other type of modulation. The modified data is converted from a series of bits to parallel bits to be entered into the Inverse Fast Fourier Transform (IFFT) system as shown in Figure 1. The transmitted data should be sent as serial bits, therefore the output of IFFT should be converted back to a series of bits. Based on the medium by which we transfer the data in the channel will affect the quality of the signal, and also describe the wireless propagation.

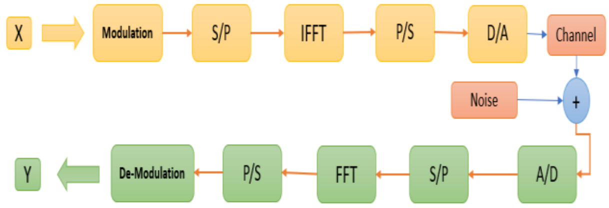

Figure. 1. OFDM system box chart

3. Methodology

MATLAB simulation software was used to estimate the underwater channel effect using a different number of Pilots based on the number of subcarriers in the OFDM system. We have implemented the procedures according to the following steps:

- Simulate the underwater acoustic channel based on the flow chart shown in Figure 2.
- Apply the OFDM system on the generated bits using a different number of subcarriers.
- Develop a linear equalizer based on the underwater channel effect at the receiver.
- The equalizer had been designed based on a factor, this factor is determined by the mean ratio of the received to the transmitted signal.
- Check and compare the BER for each status.

The absorption effects in the underwater environment are based on the frequency as shown in Figure 2.

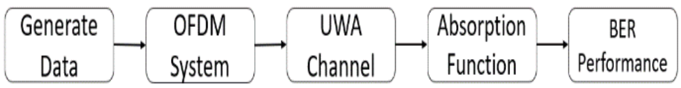

Figure. 2. Underwater simulation flow chart.

The BER comparison had been studied to compare the performance of the system before and after adding the suggested equalizer. In the simulation, we didn't add CP to the tail of the OFDM symbol.

4. Simulation Results

Scenario 1: Pilot-OFDM channel estimation without equalizer.

We studied the BER performance by applying 256 subcarriers OFDM system on the UWA environment with different numbers of Pilots. Figure 3 illustrates that changing the number of Pilots didn't enhance the BER performance, because of equalization at the receiver. The BER remained at approximately 5×10^{-2}.

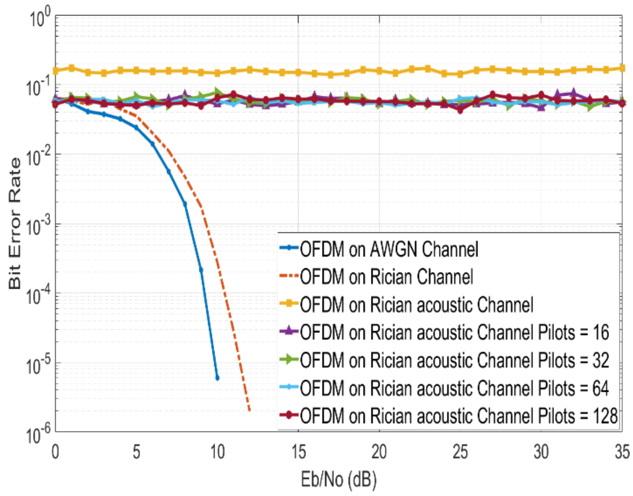

Figure. 3. Pilot-OFDM for UWA BER comparison without equalizer in OFDM 256 subcarriers

Scenario 2: Pilot-OFDM channel estimation with equalizer.

The BER had been studied within the 32 and 64 OFDM systems was studied by changing the number of pilots to determine the lowest number that enables us to estimate the channel. The bandwidth that we simulated the performance was 32 kHz, and the frequency was 10 kHz.

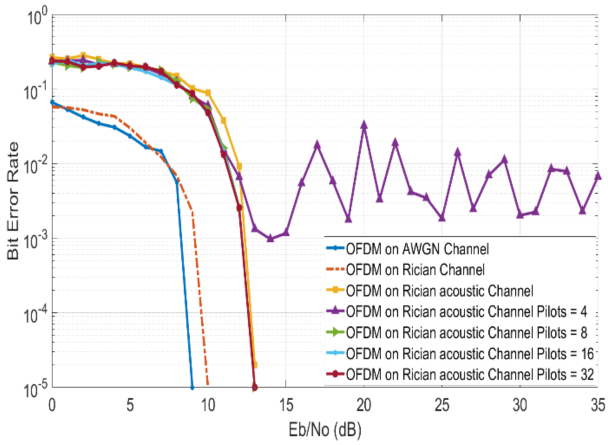

Figure. 4. Pilot-OFDM for UWA BER comparison with an equalizer for OFDM 64 subcarriers (Frequency = 10 kHz).

We can conclude from Figures 4 and 5 that using two or four Pilots for both 32 and 64 OFDM systems was not enough to estimate the channel, because the BER performance in both cases showed an instability response, in addition, the BER still can't reach zero and stay in 10^{-1} for two Pilots in 32 OFDM system, and about 5×10^{-2} when we use four Pilots for both 32, and 64 OFDM system even after adding equalizer.

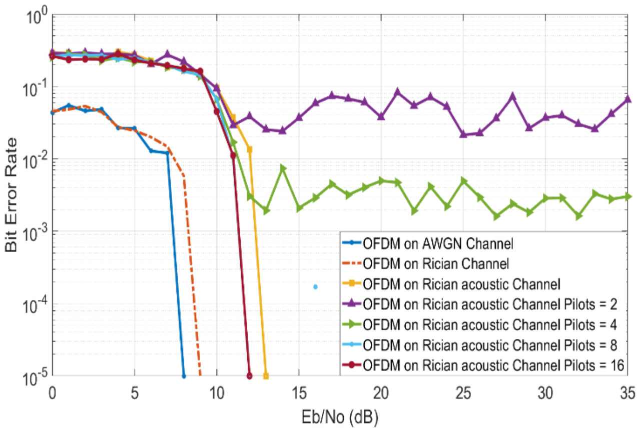

Figure. 5. Pilot-OFDM for UWA BER comparison with an equalizer for OFDM 32 subcarriers (Frequency = 10 kHz).

When we increase the number of Pilots, we can notice the enhancement of BER performance. Using more than four Pilots in the 64 OFDM system might be better than using the same number of Pilots in the 32 OFDM system, because we only consumed 12.5% of the number of subcarriers, while in the 32 OFDM system, we consumed 25%. We got similar results when we increased the frequency to 20, 30, 40, and 50 kHz. To know the effect of the CP added to the OFDM system, it is necessary to study its effect and compare it within the underwater communication environment using MATLAB. The absorption effect was simulated by adding the absorption factor to the Rician fading channel, and then BER comparison with and without CP plotted out for different numbers of subcarriers 64, 128, and 256 as shown in Figure 6.

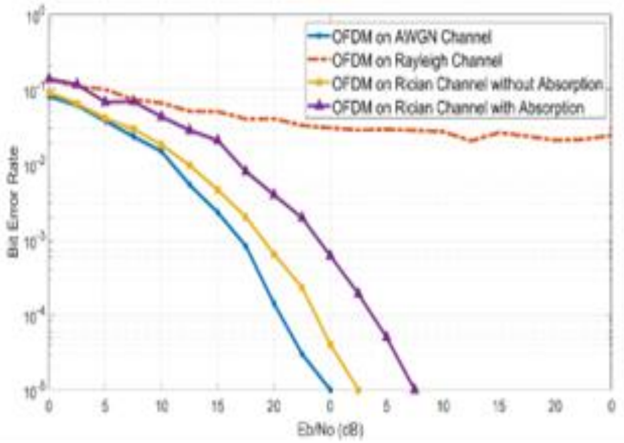

Figure. 6. BER comparison in UWA environment in OFDM system using CP.

Table 1. 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 2. 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 3. 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 3 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. Tables 1 and 2 show that using CP in an OFDM system with 64 and 128 reduces the BER, as a result, it increases the quality of the received signal. Referring to Tables 2, 3, and 4 BER enhanced with values which will summarize the results of BER improvement in percentage by changing SNR and CP values.

Table 4. BER comparison when CP = 1% of Sc

SNR	BER compared with CP_Free performance		
	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 5. BER percentage comparison when CP = 3% of Sc

SNR	BER compared with CP_Free performance		
	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 6. BER percentage comparison when CP = 5% of Sc

SNR	BER compared with CP_Free performance		
	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 4, 5 and 6 exhibit 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, Pilot-OFDM assisted in estimating the underwater channel using linear equalizer has been studied. Tables 4, 5 and 6 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.

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. We can conclude from the Pilot-OFDM simulation results using linear equalizer that using 8 Pilots can estimate the channel for both 32 and 64 OFDM subcarrier systems. It is better to use it in the 64 OFDM system because it uses 12.5% of the total number of subcarriers, while it consumes 25% of the 32 OFDM subcarrier system. Doubling the data rate in the underwater acoustic system will be our challenge in future work.

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Authors Introduction

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