OFDM Simulator for Underwater Acoustic Communications

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***Abstract*—Underwater acoustic (UWA) communication holds immense potential for military applications due to the unique challenges posed by the underwater environment. While traditional radio-frequency (RF) communication is effective in open air, its effectiveness is significantly diminished underwater due to high absorption, scattering, and signal degradation caused by the water medium. In contrast, UWA leverages sound waves to transmit data, overcoming many of these obstacles and offering several compelling motivations for military use. For achieving a deeper comprehension of underwater acoustic (UWA) communication, the development of an OFDM simulator is essential. To this end, we first analyze basic OFDM simulator designed for the typical path-delayed channel model that consists of 6 delay taps. Applying this to the UWA channels, we observe the severe performance loss occurs. In concluding this paper, we underscore the imperative of addressing the challenges of UWA channels.**

I. Introduction

Advancements in technology have spurred a growing demand for underwater acoustic (UWA) communication, particularly in military applications like unmanned underwater drones. However, UWA communication operates under significantly challenging conditions compared to terrestrial communication, presenting several major obstacles: 1) Severe Noise: The underwater realm is rife with environmental factors that contribute to noise, including water currents, marine life activities (as referenced by [1]), tidal forces, and ship engine vibrations (as noted in [2]). 2) Signal Attenuation: The underwater medium absorbs signals, leading to substantial attenuation. Consequently, the effective signal transmission range is limited to a few kilometers, while the available bandwidth is also constrained due to attenuation linked with the transmission frequency. 3) Path Delay and Scattering: Sluggish signal propagation, driven by refraction and reflection, contributes to prolonged path delays. Additionally, scattering stemming from reflections off the ocean's surface and seabed further compounds this effect. 5) Pronounced Doppler Effect: The gradual propagation delay, alongside other factors, results in a pronounced Doppler effect (cited as [3]). This phenomenon, accentuated by interactions with sea surface motion and uneven seabed terrain, disrupts orthogonality, leading to inter-channel interference (ICI) within orthogonal frequency division multiple access (OFDM) systems.

The properties mentioned earlier, which are intrinsic to the UWA channel, cumulatively erode the effectiveness of communication, prompting the requirement for the development of dedicated communication systems for the UWA channel environments by encompassing these distinct traits. Our primary goal centers on formulating a comprehensive communication system model meticulously tailored to the intricacies of the UWA channel.

We explain a concise overview of the primary design components of OFDM in relation to UWA communication.

A. Channel Coding and Modulation

For the sake of implementation convenience of this study, we opt for convolution coding. We plan to encompass the adoption of more sophisticated coding schemes like LDPC and Turbo codes. These advanced coding techniques hold the promise of enhancing overall performance while considering the unique properties of the channel. For muldation, we consider QPSK.

B. IFFT

In contrast to terrestrial OFDM, UWA communication demands a considerable allocation of resources to compensate for extended path delays. Consequently, the number of subcarriers increases to both enhance spectral efficiency and manage the short coherence bandwidth effectively.

C. Discrete-Multi Tone (DMT)

Given the low carrier frequency characteristic of the UWA channel due to severe path loss, we employ DMT techniques. These techniques modulate frequency domain symbols within the passband, eliminating the need for up-conversion as seen in baseband modulation (as described in [5]).

D. Synchronization

To establish communication initiation, a known preamble is appended at the beginning of the OFDM data. This preamble enables the receiver to approximate the communication's start time. During FFT processing to extract frequency symbols, precise selection of transmitted signal samples is essential

This work was supported by Korea Research Institute for defense Technology planning and advancement(KRIT) - Grant funded by the Defense Acquisition Program Administration(DAPA) (KRIT-CT-22-078)

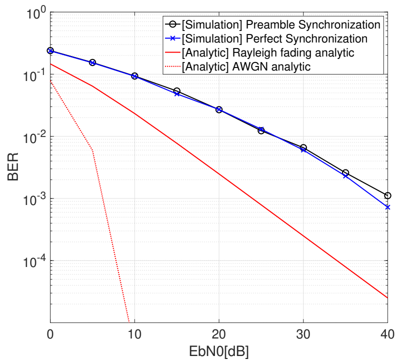

Fig. 1. EbN0 versus BER with multipath channel model

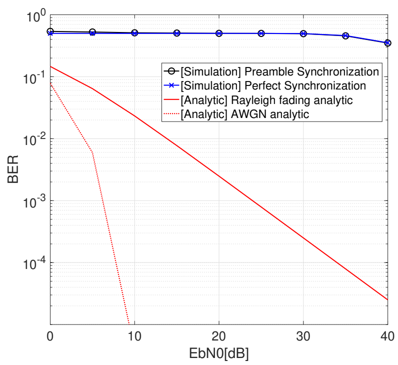

Fig. 2. EbN0 versus BER with UWA channel model

to avoid phase rotation in the frequency domain. Symbol-time offset (STO) facilitates correction in either the time or frequency domain. Additionally, synchronization compensates for Doppler effects. Doppler's influence is particularly disruptive to OFDM performance as it can compromise symbol orthogonality.

E. Channel Equalizer

Regular insertion of pilot signals at fixed intervals aids in estimating and mitigating channel effects. Proper preamble synchronization and channel equalization can counteract the impact of minor Doppler and path delays. However, for substantial Doppler and path delay scenarios, specialized synchronization techniques become necessary to rectify these effects.

II. Numerical Results

In this section, we provide an overview of our OFDM simulator's key parameters and the corresponding numerical outcomes. We employ a $1/2$ rate convolutional code for encoding and utilize a Viterbi decoder. In our simulations, we configure the Fast Fourier Transform (FFT) size to be 1024, while the CP length is set to 256. Our initial simulations involve OFDM transmission over a path-delay channel characterized by 6 taps. Notably, the longest delay tap occurs at the $10th$ position, exhibiting a signal attenuation of -25dB. Each of these delay channel components undergoes Rayleigh fading with consistent channel power.

Within the framework of this multipath channel, our primary objective is to assess the functionality of the OFDM simulator under the influence of path-delay conditions. The resulting Bit Error Rate (BER) performance is depicted in Figure 1, illustrating the BER response as the Eb/N0 ratio ranges from 0dB to 40dB. Our observations reveal that the preamble efficiently facilitates communication synchronization, while a pilot-based channel equalization strategy successfully compensates for trivial Symbol Timing Offset (STO) issues, as discussed in reference [6]. Nonetheless, as indicated in Figure 2, we observe the limitations in the simulator's performance. Specifically, as we transition to the UWA channel, the OFDM simulator's reliability diminishes. In our UWA channel simulation setup, the transmitter-receiver separation spans a distance of $1km$, and a sampling rate of 10KHz is employed, leading to a utilization of 400 delay taps, as described in reference [7].

Several potential factors contributing to the OFDM simulator's performance degradation within the UWA channel model are identified. Despite achieving precise synchronization, challenges arise. Firstly, the CP may struggle to absorb the impact of significant path-delay, and secondly, the equalizer may struggle to rectify substantial Symbol Timing Offset (STO) and Carrier Frequency Offset (CFO). As a solution, we intend to implement sliding window techniques for estimation and compensation in scenarios of this nature.

III. Conclusion

This paper focuses on adapting OFDM building blocks for the underwater acoustic (UWA) channel. We cover channel coding, modulation, IFFT, CP length, synchronization, and equalization, tailoring them to the UWA channel. Our analysis involves using this custom OFDM structure with two channel models. While our current OFDM simulator suits short multipath channels, future work includes improving it. We aim to introduce advanced receiver synchronization and parameter optimization for effective operation in the UWA channel model.

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