Survey for the Underwater Acoustic Channel Simulation

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***Abstract*—With the rise in marine and underwater activities, there is a natural uptick in the demand for underwater communication. As various underwater communication techniques are developed, a channel including the characteristics of the underwater environment is required to verify the communication performance. In this paper, we present a compressive survey for key elements and implementation methods for reproducing an underwater channel when using acoustic waves.**

I. Introduction

Underwater communication is a pivotal approach for facilitating information exchange within the marine environment. Its significance extends across various domains, encompassing ocean research for disciplines like oceanography and the study of marine animal behavior, underwater resource development, including activities such as petroleum drilling and ocean wind power generation, as well as military applications like naval operations, which include communication between surface vessels and submarines [1]. Particularly, with the ongoing advancement of relevant technologies, the necessity of underwater communication is projected to escalate even further.

The primary distinction between underwater communication and terrestrial wireless communication lies in the medium. Unlike traditional wireless communication that employs air as its medium, underwater communication operates within the medium of water, leading to significant differences in physical characteristics [2]. Communication utilizing radio frequency bands anticipates high data rates and is relatively robust against Doppler effects due to rapid propagation. However, such frequencies experience substantial attenuation underwater, thereby limiting communication range. On the other hand, acoustic waves, a key consideration in underwater communication, offer broad communication ranges but introduce effects such as low data transfer rates, significant Doppler effects stemming from lower propagation speeds, and large delay spreads due to low-frequency effects, leading to intersymbol interference [3]. Therefore depending on the objectives of underwater communication, one can opt for radio frequency band communication or acoustic communication. This survey paper places its focus on the latter, specifically on acoustic waves. It aims to summarize considerations relevant to the propagation characteristics of acoustic waves and factors to account for when establishing underwater acoustic (UWA) channels.

II. Underwater acoustics channel

In this section, we introduce the factors to be considered in the UWA channel simulator and implementation methods.

A. Acoustic path loss

The large-scale model of a UWA channel can be constructed either through equation-based formulations or simulation methods involving ray tracing. In the former approach, the path loss of the channel is characterized by both distance l and signal frequency f as

$$A(l,f) = A_0 l^k a(f)^l, \tag{1}$$

where A_0 is a scaling constant, k is the spreading factor that depends on how propagation occurs, and $a(f)$ is the absorption coefficient which can be expressed in dB/Km using Thorp's formula [4] as

$$10\log a(f) = 0.11\frac{f^2}{1+f^2} + 44\frac{f^2}{4100+f^2} + 2.75\cdot 10^{-4} f^2 + 0.003. \tag{2}$$

While the signal attenuation based on this approach can be calculated relatively easily, it tends to be relatively inaccurate in representing the actual signal attenuation in the ocean due to the lack of consideration for various factors such as salinity, temperature, and other variables. On the other hand, simulation-based attenuation with tools like Bellhop and Kraken, which take the underwater environment into account, demands higher computational complexity. In addition, the marine environment, such as sound wave velocity according to depth and reflection coefficient of the surface or bottom, is required as input to the simulator. These simulators, however, provide a more accurate representation of the ocean environment [5].

B. Small-scale channel

The UWA channel possesses the characteristic of time variation, and paths scatter, causing spreading in both the time and frequency domains. This phenomenon is more pronounced in underwater communication compared to terrestrial wireless communication. To achieve a more accurate channel representation, it is necessary to consider these effects.

In [7], the authors computed correlations based on variations in both the time and frequency domains and utilized these

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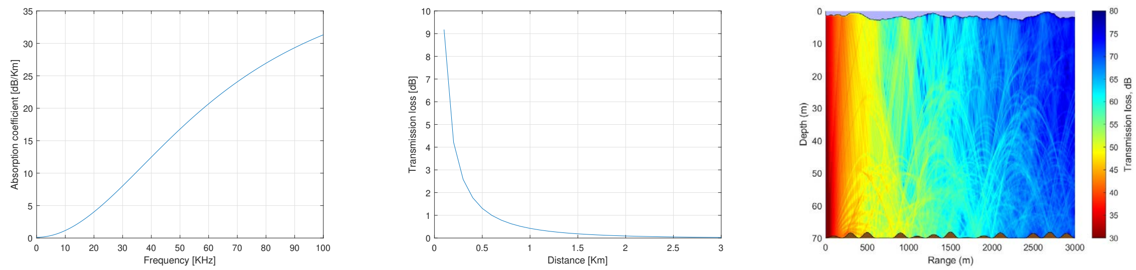

(a) (b) (c)

Fig. 1. (a) Absorption coefficients from Thorp's empirical formula, (b) Path loss according to the distance in eq. (1) when $A_0 = 1$ and $f = 24kHz$, (c) Transmission loss from Bellhop simulator [6].

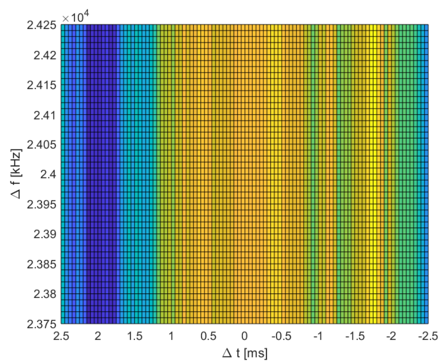

Fig. 2. An example time-frequency response of the statistical small-scale path when center frequency $f = 24kHz$.

calculations to represent the paths of the small-scale channel, γ_p, using an auto-regressive (AR) -1 model as

$$\boldsymbol{\Delta\gamma}_p[n+1] = \mathbf{A}_p \boldsymbol{\Delta\gamma}_p[n] + \mathbf{w}_p[n], \quad n = 0, 1, ... \tag{3}$$

where $\boldsymbol{\gamma}_p$ is the vectorization of the frequency change of γ_p, $\mathbf{A}_p = \mathsf{diag}(\alpha_p(f_k))$, α_p is a function of intrapath statistic and time-variant, and $\mathbf{w}_p[n] \sim \mathcal{CN}(0, \mathbf{W}_p)$, which is a function of α_p and correlation of frequency domain.

Apart from the unique characteristics induced by the underwater environment, Doppler effects can also arise due to the physical movements of the transmitter and receiver. Examples of such movements include natural motions caused by currents and movements of the transmitter and receiver, such as ships or submarines. The Doppler effect causes changes in the phase of each path through frequency variations, and from a statistical standpoint, each motion is independent. In particular, within the same paper [7], the statistical characteristics of empirically measured data were demonstrated to exhibit mathematical similarities in approximation. This finding indicated that the proposed technique could be effective in representing underwater channels.

C. Noise in underwater acoustic communication

Noise considered in UWA communication can be composed of ambient noise and noise from external factors. The sources of ambient noise can arise from mechanisms within the Earth's interior, such as ocean currents, underwater volcanoes, and external noise that may be generated by marine life or ice cracking. These types of noise can be approximated using a colored Gaussian model [8].

III. Conclusion

In this paper, we have surveyed the elements essential for accurately representing the characteristics of the underwater environment in UWA channel simulations. With the specific marine environments of interest, the beam tracing technique can capture macroscopic channel features, and by employing statistical information, the small-scale channel can be represented to approximate real UWA channels. Consequently, through this approach, when verifying the performance of UWA communication methods, reproducing a channel that reflects the underwater environment's attributes will enable more precise assessments.

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