











Transmission Losses Due to Surface Reflections in Deep Water for Multipath Model

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Abstract. There are several factors which introduces transmission losses in deep water such as: surface reflections; surface ducts; bottom bounce; convergence zones; deep sound channel; reliable acoustic path; and ambient noise. Hence, it is crucial to model the acoustic channel characteristics and evaluate the effect of transmission losses by considering aforementioned factors in order to employ the network for specific application. This study primarily aims to estimate the transmission losses caused by surface reflections in deep water environments using a multipath acoustic channel model. The simulation is conducted, considering the impact of absorption, sound speed, temperature, and salinity. The depth of the network scenario is varied to analyze the effects of these factors on the transmission losses. It is evident from simulation results, the acoustic velocity increased by 250 m/s when the depth varies from 100 m to 7000 m and temperature decreased from 30 °C to 4 °C. Similarly, when the salinity increased from 30 ppt to 35 ppt, the acoustic velocity has been increased by 7.14% in deep water. An increase in transmission loss of 5 dB has been attained when the wind speed (W) increased from 4 m/s to 12.5 m/s. Similarly, the transmission losses are increased by 8 dB when the angle of incidence (Θ) increased from 20° to 30°.

Keywords: Absorption · Attenuation · Acoustic channel · Deepwater · Sound speed · Temperature · Transmission loss · Salinity · Surface reflection

1 Introduction

A network known as an underwater acoustic sensor network (UASN) consists of underwater devices equipped with sensors, which establish communication through acoustic signals [1]. Its primary objective is to monitor and gather data in underwater environments, including oceans, lakes, and rivers [2]. In contrast to conventional wireless sensor

networks [3], which employ radio waves for communication, UASNs utilize acoustic signals as their preferred communication medium [4, 5]. This preference arises from the fact that sound waves can travel much farther and faster in water compared to radio waves, making acoustics highly suitable for underwater communication.

Acoustic transmission characteristics are substantially influenced by the parameters of the underwater medium, including temperature, salinity, pressure, turbidity, dissolved gases, and seabed properties [6]. These factors play a crucial role in shaping how sound waves propagate and interact in underwater environments. Variations in temperature can cause sound to refract or bend, leading to changes in the transmission path and potentially affecting the accuracy of localization and communication systems [7]. Salinity, which refers to the salt content in water, also affects sound velocity. Higher salinity generally leads to increased sound speed. Variations in salinity can alter the density and compressibility of the water medium, thereby affecting the transmission path and the time it takes for sound to propagate from the source to the receiver [8]. Underwater pressure increases with depth, and this pressure variation affects the speed of sound propagation [9]. Higher pressures can lead to increased sound velocity due to the compressibility of water. Understanding pressure changes is crucial for accurately estimating the range, localization, and transmission characteristics of acoustic signals in different underwater depths.

The presence of suspended particles affects the transmission loss, signal-to-noise ratio, and overall clarity of the received acoustic signal. Dissolved gases, such as nitrogen and oxygen, can affect acoustic transmission. Gases can introduce additional scattering and absorption, impacting the propagation of acoustic waves. The concentration and distribution of dissolved gases in water can vary, influencing the transmission characteristics of acoustic signals [10]. In deep water, the water depth is much greater than the wavelength of the sound wave, and the surface acts as a nearly perfect reflective boundary for sound waves. This means that a significant portion of the sound energy incident on the surface gets reflected back into the water. These reflected sound waves can interfere with the original transmitted sound waves, leading to complex acoustic phenomena [11]. This will lead surface reflections, which inherently leads to transmission losses. Understanding these underwater medium parameters is crucial for designing and optimizing underwater acoustic systems. Accurate knowledge of these parameters helps in modeling sound propagation, estimating transmission losses, and developing algorithms and techniques to improve communication, localization, and sensing capabilities in underwater environments. Hence, this work focuses on effect on sound speed, salinity, and temperature with respect depth on acoustic transmission, thereby evaluating the transmission losses due to surface reflections for a multipath acoustic channel model.

2 Related Work

The advent of Underwater Acoustic Sensor Networks (UASNs) has generated significant interest across various fields, owing to their versatile applications in underwater monitoring, environmental sensing, marine exploration, and military surveillance. Within the realm of UASNs, addressing transmission losses becomes a crucial aspect for achieving reliable and efficient communication in underwater environments. To this end, extensive

research papers and studies have been devoted to investigating the factors influencing transmission losses in UASNs. These factors encompass path loss models, absorption and scattering effects, multipath propagation phenomena, channel estimation, equalization techniques, network topology, and routing considerations. By delving into these aspects, researchers aim to enhance the performance and efficacy of UASNs, striving to mitigate transmission losses and optimize communication strategies. The present research significantly contributes to the advancement of underwater communication systems, enabling them to function successfully amidst challenging underwater conditions and unlocking their full potential across diverse applications.

In [12], the authors have investigated the fundamental physics of wave propagation, specifically focusing on acoustic, electromagnetic (EM), and optical communication carriers. In [13], the authors have extensively studied the impact of propagation characteristics on underwater communication. In [14], the authors have focused on the relationship between propagation loss, ambient noise, and channel capacity in underwater communication. To address inaccuracies in sound speed estimation in oceans and seas, a mathematical model [15] has been proposed. This model provides a conversion framework between atmospheric pressure and depth, as well as depth and atmospheric pressure, aiding in sound speed determination. In [16], the authors have presented an experimental setup that investigates the impact of underwater medium parameters.

A method [17] has been proposed to enhance localization accuracy in underwater environments. To simulate underwater networks effectively, a specifically developed acoustic channel model [18] is employed. In [19], researchers have conducted real-time measurements of route loss in underwater acoustic channels. In [20], a deep learning-based framework has been introduced to enhance accuracy and throughput in channel modeling. The authors have provided a detailed account of the statistical properties of the channel model in [21]. Moreover, a novel technique for frame boundary estimation in UASN has been proposed in [22]. In [23], the authors especially address the clustering in UASN by focusing on the integration of three essential approaches in the context of IoT applications. In [24], the authors investigated how water absorption affected the hybrid phenol formaldehyde (PF) composites' mechanical characteristics.

3 Methodology

This comprehensive approach provides valuable insights into the complex acoustic environment of shallow and deep water, and enabling better understanding and modeling of underwater acoustic propagation.

3.1 Sound Speed

The transmission of sound through water differs significantly from electromagnetic (EM) waves, primarily due to its slow speed. Mackenzie's empirical formula, denoted by (1), provides a means to calculate sound velocity.

$$c(T, S, z) = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5(S - 35) + a_6z + a_7z^2 + a_8T(S - 35)a_9Tz^3 \quad (1)$$

3.2 Acoustic Propagation Loss

Propagation loss of sound refers to the reduction in the strength or intensity of sound waves as they travel through a medium or propagate in a given environment [27]. The loss associated with cylindrical spreading is expressed using Eq. (2), while spherical spreading loss is represented by Eq. (3).

$$L_{CS} = 10 \times \log(R_t) \quad (2)$$

$$L_{SS} = 20 \times \log(R_t) \quad (3)$$

3.3 Absorption Loss

Sound waves in a medium, such as air or water, experience absorption, where the energy of the sound wave is converted into heat [28]. The absorption is frequency-dependent, with higher frequencies generally being absorbed more rapidly which is represented using (4). Where, α is absorption coefficient in underwater, it represents the rate at which sound energy is converted into other forms, such as heat, due to the inherent properties of the water medium. The absorption coefficient is frequency-dependent, meaning that different frequencies of sound waves are absorbed to varying degrees. Higher frequencies generally experience greater absorption than lower frequencies. The absorption coefficient is represented using (5). Where, A_1 and A_2 represent the contributions of boric acid and magnesium sulphate components, respectively, in sea water. Similarly, P_1 , P_2 , and P_3 denote the depth pressure components for boric acid, magnesium sulphate, and pure water, respectively. The relaxation frequency for boric acid, denoted as f_1 (in kHz), is given by Eq. (6). In Eq. (6), S represents salinity (in parts per 1000), and T represents temperature in degrees Celsius. The relaxation frequency for magnesium sulfate, denoted as f_2 (in kHz), is given by Eq. (7).

$$L_{ab} = (\alpha \times R_t) \times 10^{-3} \quad (4)$$

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \quad (5)$$

$$f_1 = 2.8 \left(\frac{S}{35} \right)^{0.5} \times 10^{\left[4 - 1245 / (273 + T) \right]} \quad (6)$$

$$f_2 = \frac{8.17 \times 10^{\left[8 - 1990 / (273 + T) \right]}}{1 + 0.0018(S - 35)} \quad (7)$$

3.4 Transmission Loss Due to Surface Reflections

Transmission loss due to surface reflections in underwater environments refers to the reduction in sound intensity caused by the reflection of sound waves at the interface between water and the surface, such as the water-air interface or the water-seabed interface. These reflections result in energy being redirected away from the desired propagation path, leading to a decrease in received sound level. The transmission loss (assuming direct path) resulting from cylindrical spreading and absorption can be mathematically expressed using (8). The transmission loss due to surface reflections can be expressed using (9) by considering the wind speed (w) and angle of incidence (θ). Finally, the transmission losses when an acoustic wave transmits in a multipath environment can be expressed as sum of transmission loss due to direct path and surface reflections which can be represented using (10).

$$TL_{dp} = 20 \log_{10} R_t + \alpha R_t \times 10^{-3} \tag{8}$$

$$TL_{SR} = 10 \times \log \left[\frac{1 + \left(\frac{f}{f_1}\right)^2}{1 + \left(\frac{f}{f_2}\right)^2} \right] - (1 + (90 - w)/60) \left(\frac{\theta}{30}\right)^2 \tag{9}$$

$$TL_{Multi-path} = TL_{dp} + TL_{SR} \tag{10}$$

4 Simulation Parameters

To simulate the transmission losses of an UASN, several parameters need to be considered for the simulation model which helps in accurately predicting the transmission losses. Table 1 provides the detailed list of parameters used for simulation along with their ranges.

Table 1. Execution Parameters

Parameter	Range
Depth (meters)	100–7000
Temperature (°C)	27–4
Salinity (ppt)	30–37
Frequency (kHz)	0.1–100
pH	7.8
R_t (meters)	100
Wind speed (w m/s)	4–12.5
Angle of incidence (Theta)	20–36

5 Simulation Results

The speed of sound in deep water significantly impacts the transmission of underwater acoustics. As depicted in Fig. 1, a noticeable trend is observed regarding sound speed in relation to changes in the depth of the scenario and temperature. At a specific temperature and depth ($T = 30\text{ }^{\circ}\text{C}$, $D = 100\text{ m}$), the initial sound speed is measured to be 1450 m/s . However, as the depth increases to 7000 m and the temperature decreases to $4\text{ }^{\circ}\text{C}$, the sound speed significantly rises to 1650 m/s , as evident in Fig. 1. This variation in sound speed, influenced by both temperature and depth, emphasizes the significant relationship between these parameters and their impact on sound propagation characteristics in the given underwater environment. Understanding these variations is essential for accurate acoustic communication and exploration in deep water environments.

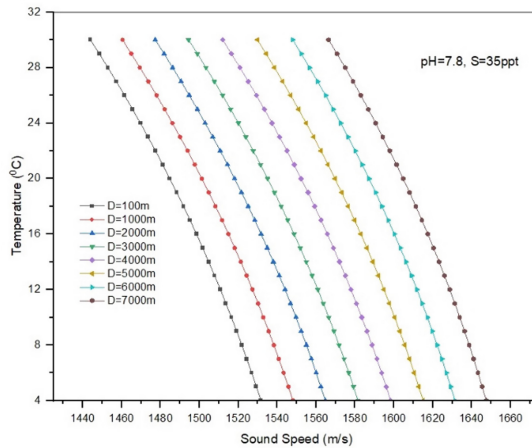


Fig. 1. Acoustic velocity disparities in accordance with temperature in deep water.

Variations in salinity significantly influence the acoustic velocity in deep water. Changes in salt concentration alter the water's density and compressibility, leading to modifications in the sound speed. Higher salinity levels typically result in increased sound speed, while lower salinity levels correspond to decreased sound speed.

These salinity-induced changes in sound speed have implications for underwater acoustic communication, sonar systems, and environmental monitoring in deep-water environments. As the depth increases and salinity levels rise, the sound speed also increases. At a specific salinity ($S = 33\text{ ppt}$), different sound speed profiles are observed along the depth, ranging from 1540 m/s to 1650 m/s , as depicted in Fig. 2. This demonstrates the direct correlation between depth, salinity, and the resulting variations in sound speed. The frequency of sound waves plays a crucial role in determining the transmission loss in deep-water environments. Figure 3, demonstrate the transmission loss by varying salinity, and temperature with respect to depth in deep water.

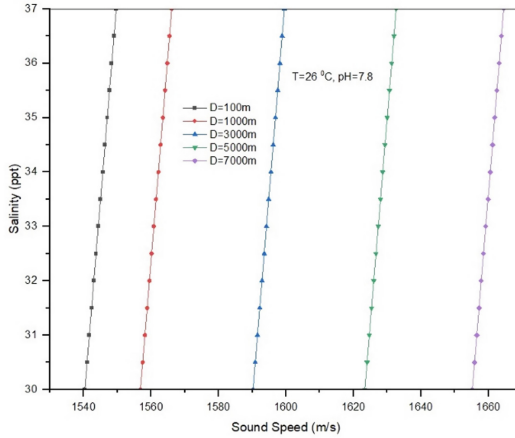


Fig. 2. Acoustic velocity disparities in accordance with salinity in deep water.

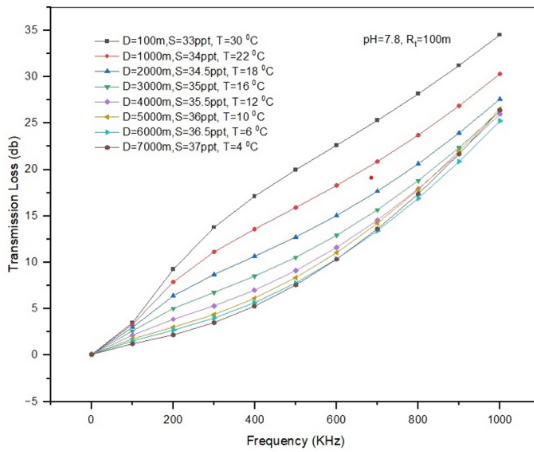


Fig. 3. Frequency vs Transmission losses in deep water.

The presence of different chemicals in underwater environments can lead to sound absorption. Chemical components such as dissolved gases, salts, and organic matter have distinctive absorption characteristics, influencing the propagation of sound waves in the water medium. These chemicals interact with sound waves, absorbing energy at specific frequencies and resulting in a reduction in sound intensity over distance (see Fig. 4).

The transmission losses due to surface reflections are purely depends on frequency, windspeed and angle of incidence. Figure 5, shows the transmission losses due to surface reflections under various wind speed values at a particular depth in deep water. It is observed that, the transmission losses are directly proportional to wind speed and frequency. Similarly, the angle of incidence at which the acoustic wave reflected back from

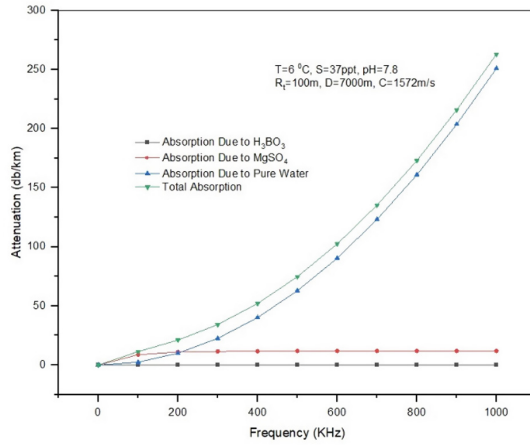


Fig. 4. Absorption in deep water due to various chemical compositions in deep water.

the surface also had an impact on transmission losses. Figure 6, shows the transmission losses due to surface reflections under various angle of incidence values at a particular depth in deep water. As the angel of incidence increases, the transmission losses are gradually decreased.

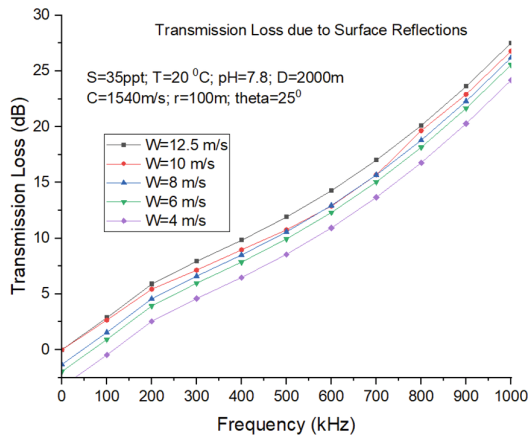


Fig. 5. Transmission Losses in deep water for multipath model with varying wind speed.

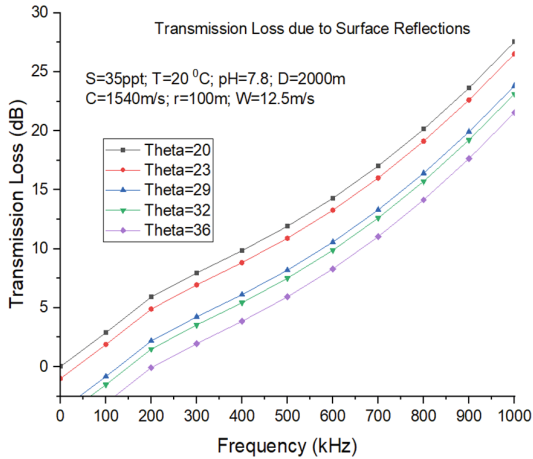


Fig. 6. Transmission Losses in deep water for multipath model with varying theta.

6 Conclusion

The primary objective of this study is to assess transmission losses resulting from surface reflections in deep water environments using a multipath acoustic channel model. The simulation explores the impact of absorption, sound speed, temperature, and salinity on these losses, while varying the depth of the network scenario to analyse their effects. The simulation results reveal noteworthy observations. When the depth varies from 100 m to 7000 m and the temperature decreases from 30 °C to 4 °C, the acoustic velocity increases by 250 m/s in deep water. Similarly, a 7.14% increase in acoustic velocity is observed when the salinity rises from 30 ppt to 35 ppt. Moreover, the study shows that an increase in wind speed (W) from 4 m/s to 12.5 m/s leads to a 5 dB rise in transmission loss. Similarly, as the angle of incidence (Theta) increases from 20° to 30°, transmission losses escalate by 8 dB. By understanding these transmission loss factors, this research contributes valuable insights into optimizing acoustic communication in deep water environments and improving the performance of underwater acoustic sensor networks.

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