Comparison of Acoustic Channel Characteristics in Shallow and Deep-Sea Water

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Abstract. The vital technology in the marine industry, underwater acoustic communication (UWAC), which has a crucial subsidiary role in undersea surveillance and military maneuvers. Now a days, the utmost prevalent and enduring system for undersea exploration is UWAC due to diminutive attenuation (signal reduction) of sound. However, the sound speed has abnormal variations with respect to the ocean columns. Usually, ocean water columns have been classified into two types based on the depth; such as shallow (0–100 m) and Deep-sea water (100-few thousands of kilometers). The physical (temperature, salinity) and chemical characteristics (pH, dissolved oxygen, nutrient salts) of these water divisions has abnormal variations with respect to the topographical regions and water depth. In addition, numerous factors such as; wave speed; multipath, interference, doppler spread have shown a great influence on sound propagation in underwater. Hence, a proficient channel modelling is required to analyze the effect of aforementioned parameters in order to achieve reliable communication in underwater environment. Therefore, in this work an acoustic channel model has been proposed for analyzing the sound speed variations and transmission losses in shallow and Deep-sea water scenarios. The effect of temperature, salinity on sound speed with respect to water depth has been estimated. Finally, the simulations outcomes of both shallow and Deep-sea water have been compared in terms of attenuation, sound speed, and transmission losses.

Keywords: Absorption · Attenuation · Acoustic Channel · Deepsea · Sound Speed · Temperature · Transmission Loss · Salinity

1 Introduction

Since they serve as enabling technology for a number of applications, underwater acoustic sensor networks (UASN) are gaining importance in the scientific community. The purpose of the underwater acoustic sensor networks (UASN), which are made up of submerged sensors, is to collect data on the portions of rivers and oceans that have not yet been extensively studied. A variable number of vehicles, anchored sensors, and

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floating sensors are present in these networks, which are scattered throughout the study area [1]. These nodes create a channel of communication that includes one or more hops. Underwater devices can communicate with one another through optical, radio, electromagnetic, and acoustic waves [2].

Researchers like acoustic communication because it has a wide range and can convey digital data across an underwater channel. Significant research challenges are introduced by the network properties of the UASN (node mobility, transmission range, power), as well as the properties of the underwater medium (temperature, pressure, salinity, and pH), such as constrained bandwidth, multipath fading, constrained battery, and constrained data capacity [3]. Temperature, salinity, and sound speed with respect to depth are the key variables that affect an underwater habitat [4]. The undersea environment is also unpredictable because of a number of factors, including wave height, turbid currents, water pressure, water chemical compositions, and wave speed [5]. To create a trustworthy network, the suggested channel model must be able to detect changes in the properties of the underwater medium and network parameters. The operating frequency and sound speed of an acoustic channel model in an underwater environment typically affect how well it performs [6].

Underwater conditions can be influenced by temperature, salinity, depth, and pH [7, 8]. With respect to water depth, the sound speed varies as temperature and salinity change. The salinity of seawater varies with both water depth and location [9]. Salinity has been calculated from ocean dissolved salt concentrations and measured in parts per thousand (ppt). The establishment of links between the sensor nodes is impacted by these erratic changes in sound speed (based on temperature, salinity, water depth, and pH) and absorption (dependent on acoustic frequency, transmission distance). The creation of effective communication links between the sensor nodes is another factor which is influenced by change in sound speed [10, 11]. In order to ensure dependable communication between the sensor nodes in a deep underwater network, an efficient acoustic channel model that considers the impacts of sound speed, absorption losses, and transmission losses must be incorporated. Hence, this work is focused on developing a channel model which illustrates the comprehensive analysis of aforementioned channel characteristics in both the water divisions such as; shallow and Deep-sea scenarios.

2 Literature Review

Acoustic signal transmission through a water body as the route of propagation is significantly impacted by the marine environment. A few of the difficulties the acoustic channel faces are the Doppler shift, strong multi-path propagation, high attenuation, confined bandwidth, severe fading, extended delay spread, rapid time variation of the channel, route loss, and noise [12]. Therefore, it is crucial to conduct study and have a complete understanding of how the underwater environment influences the communication signal in both the regions (shallow and deep water) of the marine environment in order to construct and create reliable underwater communication systems. Although terrestrial networks have received a lot of attention from research teams, it is difficult to establish similar networks underwater due to the high absorption of electromagnetic radiation there. Additionally, there are several network constraints that separate terrestrial networks from underwater networks [13–24], including propagation delay, topology, power requirements, mobility, network life, data rate, etc.

Before comparing the issues and effects of employing different communication carriers, the authors in [25] supplied and explored the underlying physics of basic wave propagations using the fundamental physics ideas (acoustic, EM, and optical). The effects of propagation properties, such as sound speed, channel delay, absorption, scattering, multipath, waveguide effects, and ambient noise, have been studied by the authors in [26]. The dependence of the channel capacity on depth and temperature was examined by the authors in [27] using enhanced propagation loss and ambient noise models. A mathematical model [28] that allows the conversion of atmospheric pressure to depth and depth to atmospheric pressure has been presented in order to reduce errors in the sound speed in oceans and seas. An experimental setup that demonstrates how salinity, temperature, and pressure affect the physical characteristics of the deployed environment and sound speed fluctuations is detailed in [29]. A technique for raising localization accuracy [30] in water involves calculating the sound speed at a particular location over time. An acoustic channel model has been created to simulate networks in aquatic environments [31].

An underwater acoustic channel path loss has been measured in real-time [32]. Recent advances in deep learning and artificial intelligence have been used to predict the characteristics of underwater acoustic channels in order to increase accuracy and throughput. A deep learning-based framework for underwater channel modelling has been presented [33] to improve the accuracy of channel models. The channel model's primary statistical properties have been outlined and discussed in [34]. The literature has provided insight into how variations in the underwater medium's characteristics impact underwater sound propagation. Therefore, it is important to address and take into consideration the effects of temperature, salinity, absorption, and transmission losses brought on by changes in the sound speed. These variations in sound speed brought on by the unpredictability of the undersea environment change how links grow in the network. Since transmission losses and absorption must be considered, the suggested study objective is to analyze and compare the acoustic channel parameters in shallow and Deep-sea scenarios.

3 Methodology

The influence of underwater physical parameters such as temperature and salinity on sound speed has been estimated using designed acoustic channel model for shallow and Deepsea water scenarios. The channel model evaluates the attenuation which is attained because of chemical compositions of the sea water. The transmission losses for both shallow and Deepsea water scenarios have been evaluated with respect to the frequency and distance. The performance measures of proposed channel model have been compared in terms of sound speed, attenuation, and transmission losses for both shallow and Deepsea water scenarios.

3.1 Sound Velocity

One of the key distinctions between acoustic waves and EM transmission is the extraordinarily slow speed at which sound travels through water. Pressure, salinity, and temperature are a few factors that affect the undersea sound speed. Normal ocean surface sound propagation occurs at a speed of around 1520 m/s, which is four orders of magnitudes quicker than airborne sound propagation but five orders of magnitude slower than light propagation. Environmental changes have a direct impact on the sound speed of water (temperature, salinity, and depth). For computing sound velocity as a function of temperature, salinity, and depth, Mackenzie presents an empirical formula [35] which is epitomized using (1).

$$c(T, S, z) = a_1 + a_2 T + a_3 T^2 + a_4 T^3 + a_5 (S - 35) + a_6 z + a_7 z^2 + a_8 T (S - 35) a_9 T z^3 \tag{1}$$

3.2 Propagation Loss of Sound

Undersea acoustics attenuate due to spreading, dispersion, and absorption. A measure of signal degradation brought on by the geometrical spreading effect that happens as a sound wave travels away from its source is called spreading loss. In underwater acoustics, there are two basic kinds of spreading mechanisms: cylindrical and spherical. The loss is expressed using (2) for cylindrical spreading and (3) for spherical spreading, respectively. L_{CS}, L_{SS}, and R_t stand for transmission range, loss due to cylindrical spreading, and loss due to spherical spreading, respectively [36].

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

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

3.3 Absorption Coefficient

An empirical formula [36] for the absorption coefficient has been used for the frequency range of 100 Hz to 1 MHz which is represented using (4) and it is a function of frequency, pressure (depth), and temperature.

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \tag{4}$$

3.4 Absorption Loss

The range-dependent absorption loss, which is computed using Eq. (5), indicates the energy loss of sound as a result of the conversion of energy into heat due to the chemical properties of viscous friction and ionic relaxation in the ocean.

$$L_{ab} = (\alpha \times R_t) \times 10^{-3} \tag{5}$$

3.5 Transmission Loss

Transmission loss [37], which is defined as the cumulative loss of acoustic strength caused by an acoustic pressure wave as it moves away from its source which is represented by using (6) & (7) for both shallow and Deep-sea water scenarios respectively.

$$TL_{shallow} = L_{CS} + L_{ab} \tag{6}$$

$$TL_{Deepsea} = L_{SS} + L_{ab} \tag{7}$$

4 Implementation Parameters

The parameters considered for analyzing the transmission loss, absorption loss, spreading loss and sound speed has been listed in Table 1.

Table 1. Implementation Parameters

Parameter	Range
Shallow water Depth	0–100 m
Deep water Depth	100–8000 m
Shallow Water Temperature	30–24°C
Deep Water Temperature	24°–4°C
Shallow Water Salinity	30–35 ppt
Deep Water Salinity	35 ppt
Frequency	100 Hz–100 kHz
pH	7.8
R_t	100 m

5 Simulation Results

The primary method of wireless data transfer in a marine environment is the acoustic medium. The most fundamental factor affecting achievable data rates, as well as network factors like latency and quality of service, is the speed of sound in an acoustic channel. Due to irregular variations in temperature, salinity, depth, and pH with respect to the season, time, and location of the ocean, the sound speed has unpredictable variations underwater. However, these irregularities have different profiles in the two divisions of the ocean such as shallow and deep water. In, shallow water the effect of temperature and salinity are predominant factor for abrupt change in sound speed, where as in deep water the effect of temperature and salinity on sound speed is insignificant due to constant values of temperature (4 °C) and salinity (35 ppt) in deep water. In deep water, the effect of pressure (depth) is significant on sound speed. The sound speed profile exhibits abnormal variations in shallow water because of drastic change in temperature gradients of the water column across the water depth (See Fig. 1). Whereas, the temperature is almost constant (4 °C) at the deep water scenarios, where the sound speed profile has minimal variations. It is clearly depicted in Fig. 1, that the sound speed is varying with temperature and depth. When the depth is extended to 100 m, the sound speed increases to 1542 m/s (see Fig. 1) from the initial value of 1539 m/s at a certain temperature and depth ($T = 27^{\circ}$C, $D = 100$ m).

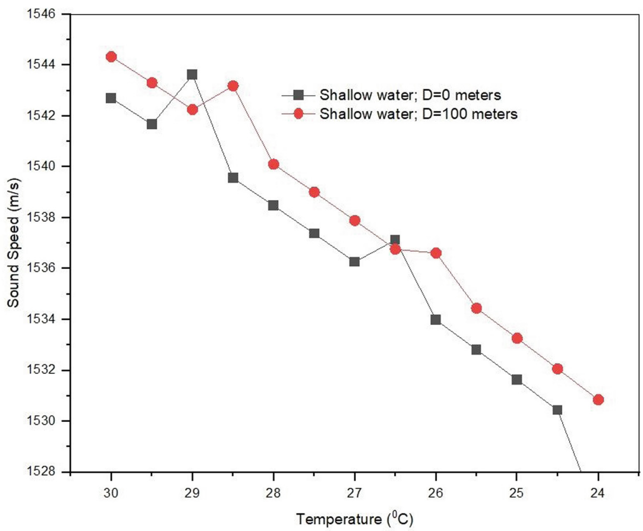

Fig. 1. Effect of temperature on sound speed in shallow water.

In the case of deep water, When the depth is extended to 8000 m and the temperature is lowered to 4°C, the sound speed increases to 1450 m/s (see Fig. 2) from the initial value of 1530 m/s at a certain temperature and depth ($T = 4^{\circ}$C, $D = 8000$ m).

Similarly, salinity of the ocean water increases along the depth, which also influences the sound speed in deep water. This is clearly depicted in Fig. 3, that the sound speed increases with increase in depth as well as salinity in shallow water. At a particular salinity (S = 33 ppt), the sound speed attained different profiles (varying from 1540 m/s to 1550 m/s) along the depth (see Fig. 3). Whereas, in deep water the salinity value is almost constant (s = 35 ppt), the sound speed has liner in nature, which is increases with depth (see Fig. 4).

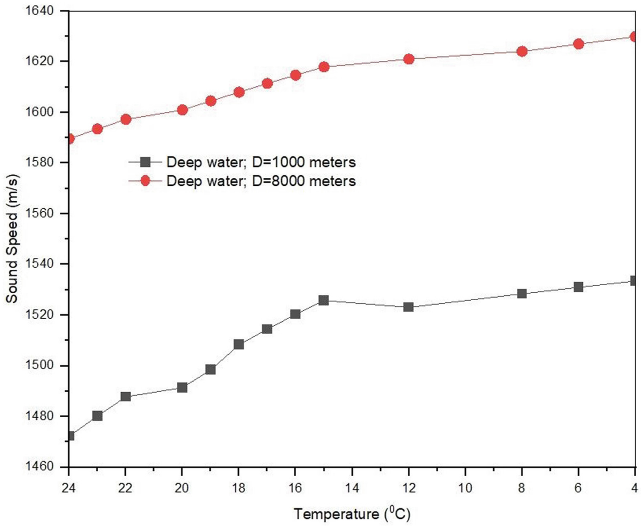

Fig. 2. Effect of temperature on sound speed in Deep water.

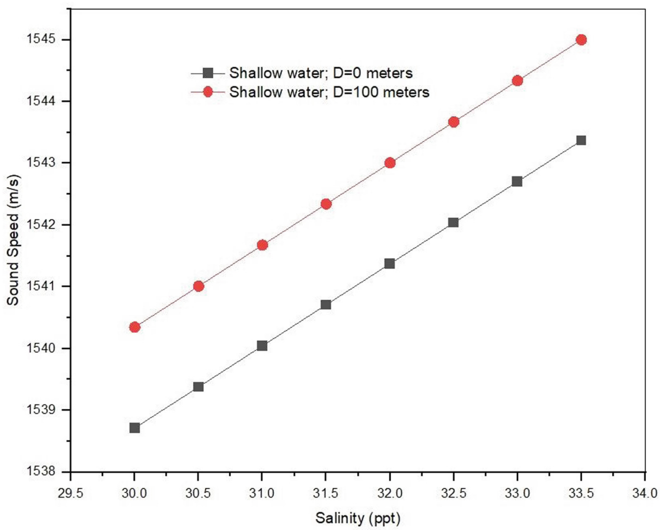

Fig. 3. Effect of salinity on sound speed in shallow water.

Absorption, which results from the transformation of acoustic energy into heat, is the principal cause of attenuation. As the distance and frequency rise, the attenuation grows. It is also obvious that the orders of magnitude vary widely and that attenuation rises sharply with frequency. For frequencies of 1 kHz and below, attenuation is less than a few hundredths of a dB/km; hence, it is not a limiting factor. Approximately 1 dB/km

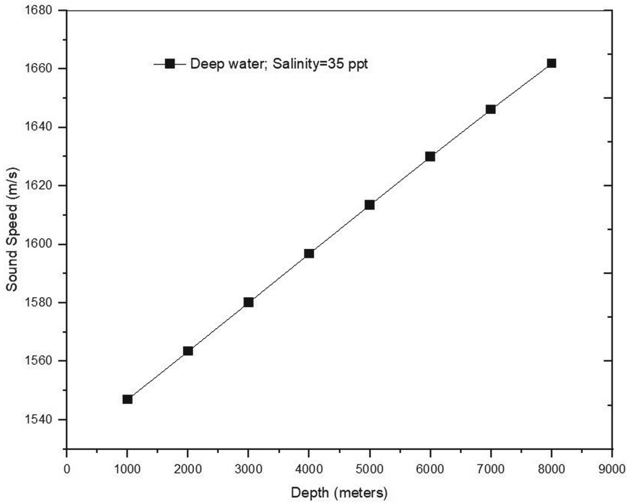

Fig. 4. Effect of salinity on sound speed in Deep water.

of attenuation occurs at 10 kHz, restricting ranges of more than a few tens of kilometres (see Fig. 5).

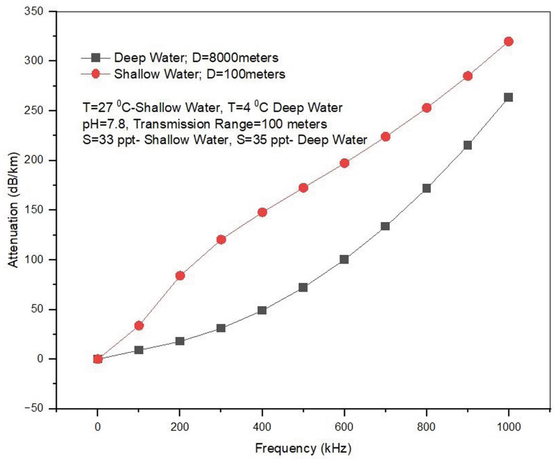

Fig. 5. Attenuation in shallow and deep water due to absorption.

The transmission losses are frequency and range dependent. According to Fig. 6, transmission losses increase as frequency increases, while transmission losses decrease as depth increases. The transmission losses are higher in shallow water when compared to deep water because of highly abnormal environment conditions in shallow water (see Fig. 6).

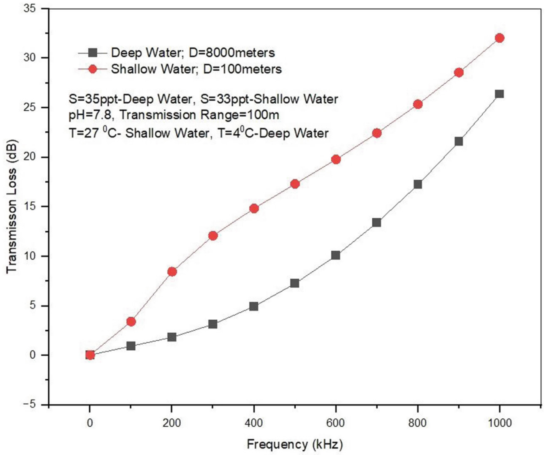

Fig. 6. Transmission losses with respect to frequency in shallow and deep water.

6 Conclusion

In order to examine the impact of underwater medium characteristics like temperature and salinity on sound speed, this study suggests an acoustic channel model for both ocean divisions. The suggested channel model analyses the influence of salinity and temperature at a given pH by adjusting different depths in shallow and Deep-sea scenarios. The effect of absorption resulting from various water chemical compositions with regard to the frequency of the acoustic signal is also investigated by the proposed channel model. Finally, with a fixed transmission range and various depths in shallow and deep water, the transmission losses have been evaluated. According to the simulation results, transmission and absorption losses depend on frequency. The frequency has grown proportionately to these two losses. In deep water, the sound speed rises as temperature and salinity gradually decrease with depth. Whereas, in shallow water the sound speed has been gradually decreased with respect to depth.

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