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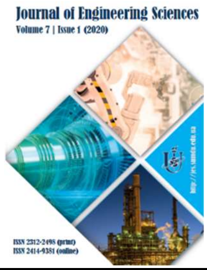

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Investigation of Parameters Affecting Underwater Communication Channel

Aydin S., Onur T. O.*

Zonguldak Bulent Ecevit University, 67100 Zonguldak, Turkey

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***Corresponding email:**
ozdincozge@gmail.com

Abstract. Underwater communication has become a widely studied area in recent years and showed great potential to be an area of research. Acoustic communication is often preferred in underwater communication due to its suitability for an underwater diffusion environment. However, in underwater communication, the physical and chemical properties of the water environment affect sound propagation. Therefore, determining and examining parameters affecting channel performance in underwater communication plays an essential role in inefficient communication. In this study, the effects of salinity, depth, noise, temperature, and frequency parameters for the underwater channel model are examined. By determining the effects of these parameters on spherical and cylindrical propagation, suitable propagation geometry and parameter values for an efficient channel are investigated. In light of the results obtained, in case of studying in a limited area, the path and absorption losses can be reduced by selecting cylindrical propagation as a geometrical propagation model, thereby an efficient channel model can be formed.

Keywords: cylindrical propagation, spherical propagation, underwater communication channel, acoustic communication, path loss, absorption loss.

1 Introduction

70 % of the world is covered with water, and most of this large area is still unknown [1]. The examination of underwater communication is important for the investigation of underwater ecosystems and underwater natural resources and defense purposes. Therefore, the interest in the underwater communication field is increasing day by day. Studies in the field of underwater communication began with the experiment of a physicist/engineer Jean-Daniel Colladon and a mathematician Charles-Francois Sturn in 1826. They obtained that the sound was transmitted in the water faster than in the air [2]. With the subsequent studies, this research area has become interesting, with the necessary knowledge base to examine underwater acoustic communication today.

2 Literature Review

In wireless underwater communication, acoustic waves are used more than radio waves, since they can propagate in seawater at very low frequencies (30–300 kHz) and show a serious weakening according to the ambient conditions [3]. Acoustic waves have very limited bandwidth. Therefore, they are used for communication at short ranges [4, 5]. The reason for using acoustic waves at a short-range is since the high data rate is less absorbed than radio waves in underwater [6]. Sound moves five times faster than the air in the water and propagates over very long distances. Therefore, acoustic signals are used in underwater communication [7].

There is a growing need for systems that can provide wireless data communication, control remote devices by a center, and allow vehicles or people who are in two different locations in underwater to communicate with each other. However, underwater communication systems are affected by many parameters, such as temperature, density, salinity, depth, pressure, path losses, etc. Different techniques and systems are used to minimize the problems that may occur in underwater communication. These techniques and systems are developed for the safe, quality, and rapid transmission of communication.

The performance of underwater communication channels varies depending on the environmental factors of the medium. The channel is influenced by many factors in terms of performances and characters. In order to transmit the signal correctly, with a low error rate, the noise, path losses, and absorption losses should be minimal. The propagation and absorption cause the signal to weaken.

Therefore, parameters that affect the physical and chemical properties of the medium should be selected appropriately to increase channel performance.

In this study, to improve the channel performance, the parameters such as salinity, temperature, depth, frequency, noise, etc. that affect the channel are examined, and optimum salinity, temperature, depth, and frequency values are investigated to ensure effective channel performance. The effects of these parameters for cylindrical and spherical propagations are compared.

3 Research Methodology

3.1 Underwater communication channel

The variables such as path loss, noise, propagation loss, and multipath effects mainly affect underwater communication [8]. All these factors determine the variability of the acoustic channel, limit the bandwidth of the channel, and make it dependent on distance and frequency [9].

The physical and chemical properties of the water environment affect the propagation of sound. An underwater acoustic signal will be weakened due to propagation and absorption. Underwater communication channels are affected by many parameters in terms of their characteristics. Some of these parameters are salinity, depth, temperature, frequency, noise, and pH of the water. These factors cause absorption and path losses. Channel performance can be made efficient by selecting these parameters correctly.

3.2 Propagation loss

The propagation loss occurs when the area covered by the same amount of acoustic signal energy increases as a wave moves out from the source. It depends on the area formed by the sound signal emitted geometrically from the source, dB:

$$PL_{propagation}(r) = k10\log(r), \qquad (1)$$

where r – distance, m; k – the propagation factor.

When the environment in which the signal transmission occurs is unlimited, the propagation factor is $k = 2$. In the case of limited propagation, this factor takes different values. For example, the value of k is taken as 1 for a cylindrical limit [10].

In studies conducted by Urick in 1967, it has been stated that global propagation can only occur in short intervals. Propagation loss has a logarithmic relationship with distance r, and its effect on the signal is essential at short ranges up to about 50 meters [11, 12].

3.3 Absorption

Absorption refers to energy loss in the form of heat due to viscous friction and ionic relaxation, which occurs as the sound wave travels out underwater. Absorption can be expressed analytically as given in equation (2), dB:

$$PL_{absorption}(r,f) = 10\log\{(a(f))r\}, \qquad (2)$$

where f – frequency, kHz; α – the frequency-dependent absorption coefficient.

The viscosity, ionic relaxation, and relaxation time of boric acid and magnesium sulfate molecules in seawater cause sound absorption. Viscosity affects the medium frequency range from 10 to 100 kHz. Boric acid effects are observed at low frequencies up to several kHz. In general, the absorption coefficient α increases with the increase in frequency and decreases with the increase in depth [13].

Absorption can be expressed in many ways by taking into account frequency, salinity, temperature, pH, and depth. According to the first studies conducted in the 60s, the absorption expression proposed by Thorp is given in equation (3) [14]. Equation (3) is valid for frequencies from 100 Hz to 1 MHz and is created for seawater with a salinity of 35 ppt, pH of 8, the temperature of 4 °C and depth of 0 m (atmospheric pressure), dB/km:

$$a(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 275\text{x}10^{-4} + 0.0033. \qquad (3)$$

Fisher and Simmons [15], as well as Francois and Garrison [16], have proposed different variations of the absorption coefficient. In particular, Fisher and Simmons have expressed the absorption coefficient depending on depth (pressure), frequency and temperature by examining the effect of boric acid relaxation in the absorption [15, 17], dB/km:

$$a(f,d,t) = \frac{A_1P_1f_1f^2}{f_1^2+f^2} + \frac{A_2P_2f_2f^2}{f_2^2+f^2} + A_3P_3f^2, \qquad (4)$$

Where t – temperature, °C; d – depth, m; A_1, A_2, A_3 – the effects of temperature; P_1, P_2, P_3 – ocean depth (pressure); f_1, f_2 – relaxation frequencies of boric acid and magnesium sulfate molecules, respectively.

These terms were later developed into simple equations by Ainslie and McColm. Viscous absorption and relaxation frequencies of boric acid and magnesium sulfate ions are simplified by equation (5)–(7) [18]. Viscous absorption is calculated by the following equation, dB/km:

$$\alpha = 0.00049f^2e^{-(\frac{t}{27}+\frac{d}{17})}. \qquad (5)$$

Boric acid and magnesium sulfate relaxation frequencies can be calculated as given in equations (6) and (7), respectively, kHz:

$$f_1 = 0.78\sqrt{\frac{S}{35}}e^{\frac{t}{26}}; \qquad (6)$$

$$f_2 = 42e^{\frac{t}{17}}, \qquad (7)$$

where S – salinity, ppt.

Ainslie and McColm have created equation (8), which includes total chemical relaxations [10], dB/km:

$$a = 0.106\frac{f_1f^2}{f_1^2+f^2}e^{(pH-8)/0.56} + 0.52\left(1+\frac{t}{43}\right)x$$
$$x\left(\frac{S}{35}\right)\frac{f_2f^2}{f_2^2+f^2}e^{-\frac{d}{6}} + 0.00049f^2e^{-(\text{t}/27+\text{d}/17)}. \qquad (8)$$

where pH – the degree of acidity or alkalinity.

Ainslie and McColm stated that acidity only affects low-frequency boric acid absorption, but salinity increases medium frequency absorption and decreases low-frequency absorption.

The temperature decreases absorption except when two relaxation frequencies are close [18–20].

3.4 Path loss

Total path loss is a combination of propagation and absorption losses. In 1967, Urick reasonably determined absorption and propagation losses through long-term observations [11]:

$$Path\ loss(r, f, d, t) = k10\log(r) + \alpha(f, d, t)r10^{-3}, \quad (9)$$

where k – the geometric propagation coefficient.

3.5 Ambient noise

Turbulence, ship traffic, thermal noise, and waves are the four main sources of ambient noise. These sources that form the noise are affected by the frequency and are dominant in different frequency regions. They can be calculated as follows, dB:

$$10\log N_t(f) = 17 - 30\log(f); \quad (10)$$

$$10logN_s(f) = 40 + 20(s - 0.5) + \\ +26log(f) - 60log(f + 0.03); \quad (11)$$

$$10\log N_w(f) = 50 + 7.5w^{\frac{1}{2}} + \\ +20logf - 40\log(f + 0.4); \quad (12)$$

$$10\log N_{th}(f) = -15 + 20\log(f), \quad (13)$$

where N_t – turbulence noise; s – the ship traffic noise factor; N_s – ship noise; N_w – wave noise caused by interaction with wind; w – wind speed, m/s; N_{th} – thermal noise.

The value of the ship traffic noise factor s, given in equation (11), varies between 0 and 1. The total noise can be calculated as [12], bB:

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f). \quad (14)$$

4 Results

The absorption coefficient is defined differently by Thorp and Ainslie and McColm as given in equations (3) and (8), respectively. In the absorption coefficient expression created by Thorp given in equation (3), salinity, pH, temperature, and depth are taken as constant, while these parameters are taken as a variable in the expression given by Ainslie and McColm in equation (8). The variation of the absorption coefficient, according to the frequency, is plotted using these two equations in Fig. 1. It is desired to have low absorption loss in order to provide efficient communication. Besides, frequency selection is also very important because of the absorption coefficient increases as the frequency increases. While the absorption coefficient found by Ainslie and McColm is less than that of Thorp in the 0–300 kHz frequency range, a greater increase in the absorption coefficient has been observed after 300 kHz.

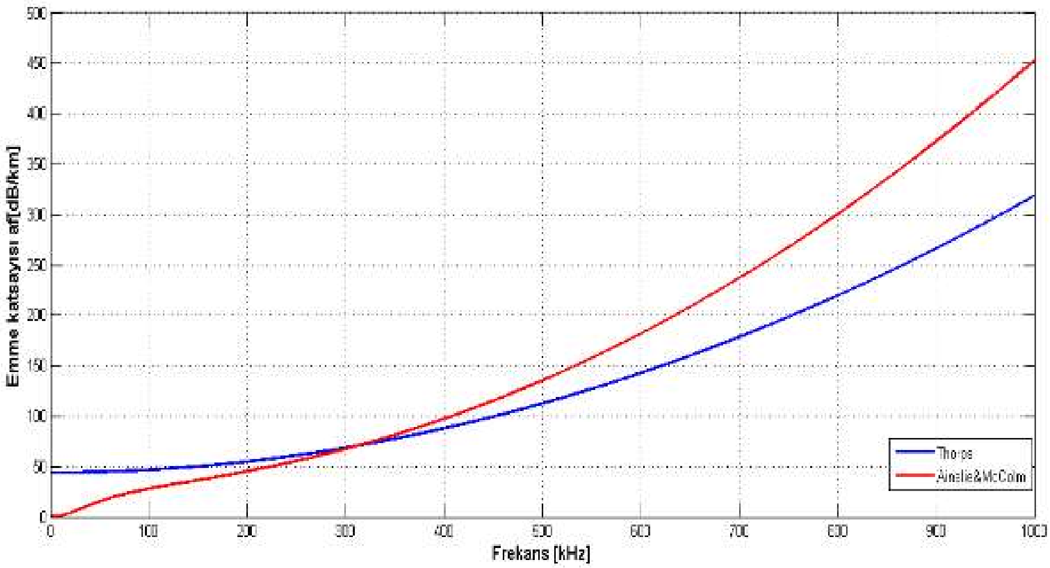

Figure 1 – Comparison of the absorption coefficient variation according to frequency by using Thorp and Ainslie, as well as McColm equations

In Fig. 2, the variation of the path loss according to the range in the cylindrical and spherical propagations is compared. As seen in equation (9), propagation loss occurs due to the geometrical propagation in path loss. While k value is taken 1 for cylindrical propagation, it is taken as 2 for spherical propagation [10]. Therefore, the path loss is higher in spherical propagation where environmental conditions are unlimited. As seen in Fig. 2, as the distance increases, the path loss in the spherical propagation increases more than the cylindrical propagation.

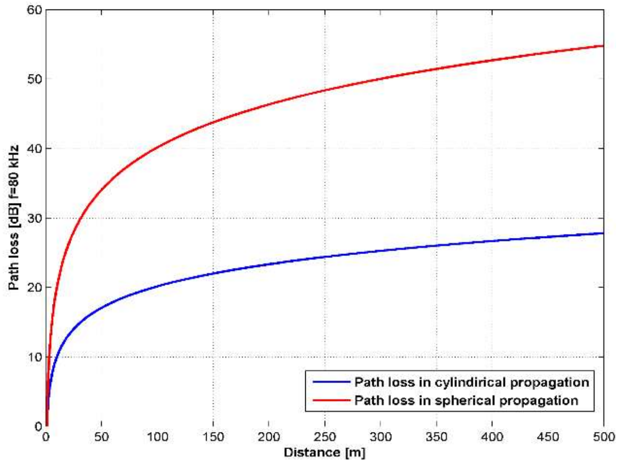

Figure 2 – Comparison of the path loss variation according to the distance in cylindrical and spherical propagations

In the graphic given in Fig. 3, the path loss arised by the salinity variation is examined. The path loss variation according to the distance in 5 ppt and 35 ppt salinity values with 80 kHz frequency, 8 pH value, and 4 °C temperature is plotted in Fig. 3. It can be seen in Fig. 3 that as the salinity value increases in cylindrical and spherical propagation, path loss increases. However, the difference is not so obvious. Because salinity value changes boric acid relaxation frequency. Boric acid relaxation frequency is also directly proportional to the square root of the salinity, as stated in equation (5). Therefore, as seen in Fig. 3, salinity has little effect on path loss.

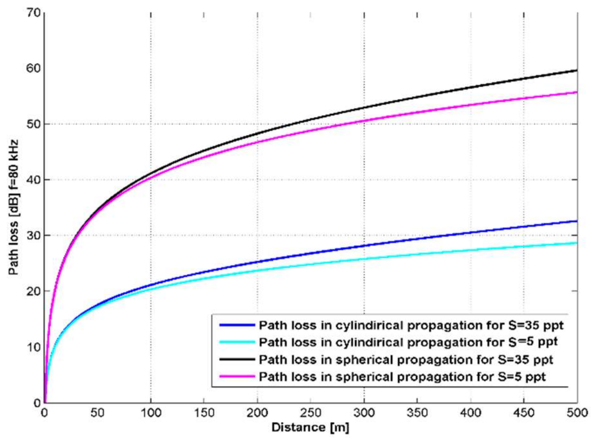

Figure 3 – Comparison of the path loss variation according to the different salinity values in cylindrical and spherical propagations

In Fig. 4, the path loss with temperature variation according to the distance in the spherical and cylindrical propagations is examined. It can be seen from Fig. 4 that the temperature value and path loss are inversely proportional. Temperature affects the relaxation frequency of boric acid and magnesium sulfate ions. As the temperature rises, relaxation frequencies increase. Absorption coefficient decreases due to this increase. For the reduction of the losses of the system channel, the temperature value should be selected high.

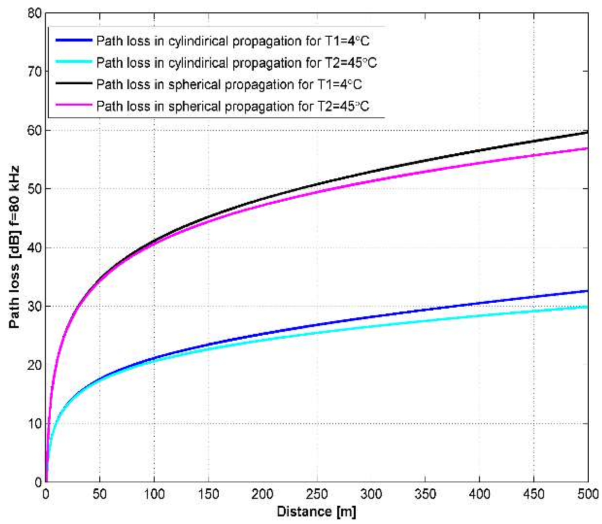

Figure 4 – Comparison of the path loss variation with different temperature values according to the distance in cylindrical and spherical propagations

The path loss is directly proportional to the square of the frequency. As the frequency value increases, path losses increase, too. In the graph given in Fig. 5, the variation of path loss in cylindrical and spherical propagations by distance is compared for 40 kHz and 120 kHz.

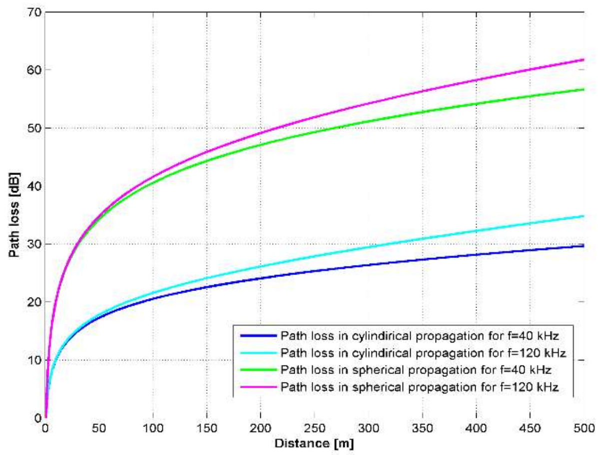

Figure 5 – Comparison of the path loss variation according to different frequency values in cylindrical and spherical propagations

It can be seen that the path loss occurred when cylindrical propagation is used, is less than spherical propagation. However, path loss in cylindrical propagation decreases at low-frequency values. One can see easily from the graphic given in Fig. 6, the path loss decreases as it is gone deeper. According to equation (8), depth and path loss are inversely proportional, anyway. In addition to this, in the graph given in Fig. 6, it is seen that the path loss is less when cylindrical propagation is preferred.

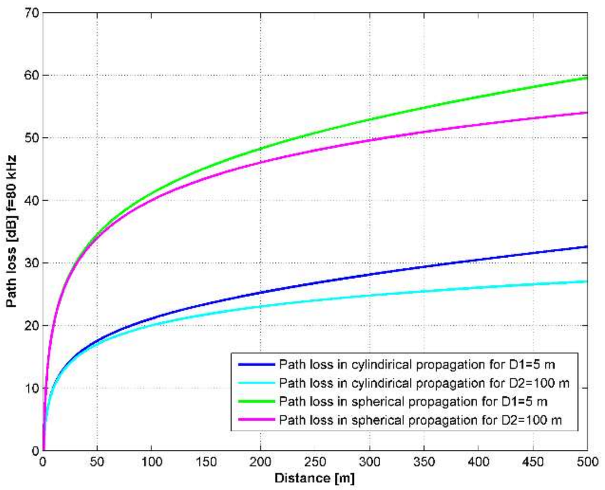

Figure 6 – Comparison of the path loss variation according to the different depths in cylindrical and spherical propagations

In the graphic given in Fig. 7, the noise types variation according to the frequency is examined. It can be said that the noise type, which is most affected by the frequency increase in ship traffic noise with reference to Fig. 7.

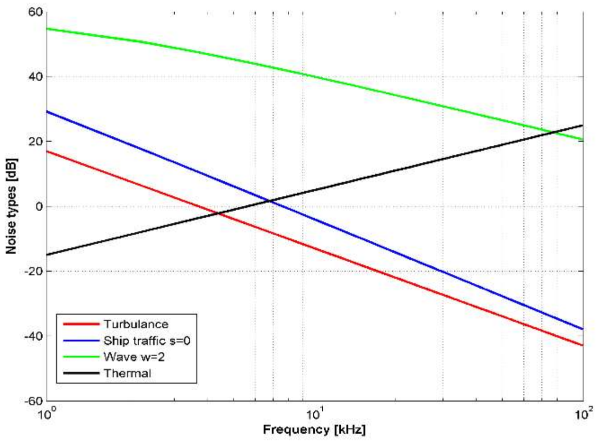

Figure 7 – The variation of the noise types according to the frequency

Ship traffic noise, turbulence, and wave noise decrease while thermal noise increases as frequency increases. However, when the noise affecting the channel is investigated, it can be seen that the noise decreases as the frequency increases due to the total noise.

In Fig. 8, the total noise, that is, the ambient noise given in equation (8), is given. It can be seen that the increase in frequency reduces noise. This positively affects the performance of the channel. Even though the increase of the frequency positively affects the noise, it is important to select the frequency region correctly because it causes absorption and path losses.

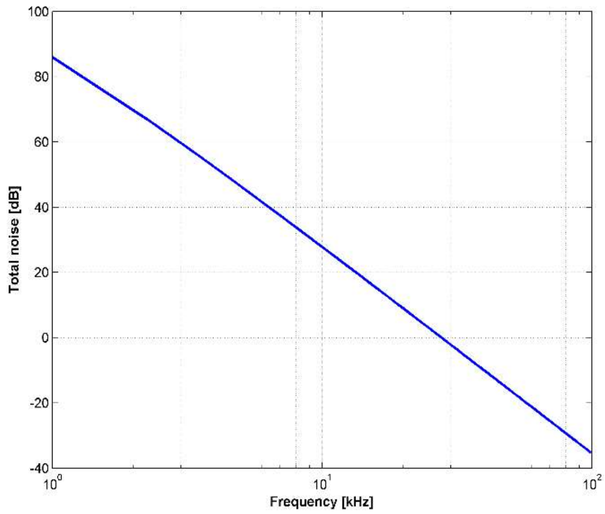

Figure 8 – The total noise variation by frequency

5 Conclusions

As a result of the simulation studies carried out, it has been observed that, in the case of a limited area, by selecting the cylindrical propagation model, the path and absorption losses will be less than the spherical propagation and an efficient underwater communication channel can be created.

In addition, the absorption coefficient expressions described in different ways by Thorp and Ainslie and McColm have been studied. While the expression of the absorption coefficient proposed by Ainslie and McColm, given in equation (8) is created, frequency, salinity, pH, and depth are based on.

As can be seen from the graphic given in Fig. 1, it is more appropriate to take the statement suggested by Ainslie and McColm for the absorption coefficient at frequency values between 0–300 kHz.

Salinity, temperature, frequency, and depth parameters affect the occurrence of path loss. In order to increase the efficiency of the channel, the absorption coefficient and path loss should be lower. Absorption coefficient and path loss decrease as temperature and depth increase. Path loss increases as salinity increases, but the effect of the salinity parameter is less than the other parameters. The square of the frequency and the path loss are directly proportional. It is observed that the path loss increases as the frequency increases.

Besides, it can be seen that the four main variables that make up the ambient noise are in different frequency regions. Turbulence noise only affects the very low-frequency region. If the frequency region is chosen in the range of 10–100 Hz, ship traffic noise will be dominant. The main factor that creates the noise in the 0.1–100 kHz frequency zone is the surface movement of the waves caused by the wind. In this study, since a 10–100 kHz frequency zone will be taken as reference, wave noise will have a dominant effect, and the thermal noise effect will not be seen because thermal noise acts in the frequency more than 100 kHz.

6 Acknowledgments

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References

1. Alkama, R., Cescatti, A. (2016). Biophysical climate impacts of recent changes in global forest cover. *Science*, Vol. 351, pp. 600–604, doi: 10.1126/science.aac8083.
2. Kirtskhalia, V. (2016). Correct definition of sound speed and its consequences in the task of hydrodynamics. *Journal of Fluids*, Vol. 2016, pp 1–9, doi: 10.1155/2016/4519201.
3. Akyildiz, I. F., Pompili, D. and Melodia, T. (2005). Under water acoustic sensor networks: research challenges. *Ad Hoc Networks*, Vol. 3(3), pp. 257–279, doi: 10.1016/j.adhoc.2005.01.004.
4. Stajanovic, M. (1996). Recent advances in high rate underwater acoustic communications. *IEEE Journal of Oceanic Engineering*, Vol. 21(2), pp. 125–136, doi: 10.1109/48.486787.
5. Catipovic, J. (1990). Performance limitations in underwater acoustic telemetry. *IEEE Journal of Oceanic Engineering*, Vol. 15(3), pp. 205–216, doi: 10.1109/48.107149.
6. Kilfoyle, D. B., Baggeroer, A. B. (2000). The state of the art in underwater acoustic telemetry. *IEEE Journal of Oceanic Engineering*, Vol. 25(1), pp. 4–27, doi: 10.1109/48.820733.
7. Zhichao, L., Jie, Z., Jiucai, J., Qi, L., Lanjun, L., Pengcheng, Z., Baoru, G. (2018). Underwater acoustic communication quality evaluation model based on USV. *Shock and Vibration*, Vol. 2018, pp. 1–7, doi: 10.1155/2018/2609073.
8. Akyildiz, I. F., Pompili, D., Melodia, T. (2005). Underwater acoustic sensor networks: research challenges. *Ad-Hoc Networks,* Vol. 3(3), pp. 257–279, doi: 10.1016/j.adhoc.2005.01.004.
9. Mendez, P. A., James, R. (2015). A comparative study of underwater wireless optical communication for three different communication links. *IOSR Journal of Electronics and Communication Engineering,* Vol. 10(3), pp. 40–48.
10. Hou, R., He, L., Hu, S., Luo, J. (2018). Energy-balanced unequal layering clustering in underwater acosutic sensor networks. *IEEE Access*, Vol. 6, pp. 39685–39691, doi: 10.1109/ACCESS.2018.2854276.
11. Urick, R. J. (1996). *Principles of Underwater Sound*, 3rd. ed., McGraw-Hill.
12. Chen, P., Rong, Y., Nordholm, S., He, Z. Q., Duncan, A. J. (2017). Joint channel estimation and impulsive noise mitigation in underwater acoustic OFDM communication systems. *IEEE Transactions on Wireless Communications*, Vol. 16(9), pp. 6165–6178, doi: 10.1109/TWC.2017.2720580.
13. Domingo, M. C. (2008). Overview of channel models for underwater wireless communication networks. *Physical Communication*, Vol. 1(3), pp. 163–182, doi: 10.1016/j.phycom.2008.09.001.
14. Thorp, W. H. (1967). Analytic description of the low-frequency attenuation coefficient. *Journal of the Acoustical Society of America*, Vol. 42(1), pp. 270–270, doi: 10.1121/1.1910566.
15. Fisher, F., Simmons V. (1977). Sound absorption in seawater. *Journal of the Acoustical Society of America*, Vol. 61, pp. 1–13, doi: 10.1121/1.2015423.
16. Francois, R R., Garrison, G. (1982). Sound absorption based on ocean measurements: Part 1. *Journal of the Acoustical Society of America*, Vol. 72(3), pp. 896–907, doi: 10.1121/1.388673.
17. Sehgal, A., Tumar, I., Schonwalder, J. (2009). Variability of available capacity due to the effects of depth and temperature in the underwater acoustic communication channel. *IEEE Oceans 2009*, pp. 1–6, doi: 10.1109/OCEANSE.2009.5278268.
18. Ainslie, M. A., McColm, J. G. (1998). A simplified formula for viscous and chemical absorption in seawater. *Journal of the Acoustical Society of America*, Vol. 103(3), pp. 1671–1672, doi: 10.1121/1.421258.
19. Wu, Y. C., Min, R. (2012). Joint channel estimation and data detection for multihop OFDM relaying system under unknown channel orders and doppler frequencies. *IEEE Communications Magazine*, pp. 97–102.
20. Lasota, H., Kochanska, I. (2011). Transmission parameters of underwater communication channels. *Hydroacoustics*, Vol. 14, pp. 119–126.
21. Coates, R. (1990). *Underwater Acoustic Systems*, Hong Kong: Macmillan.