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A Study on channel modeling of underwater acoustic communication

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Abstract — The ability to effectively communicate underwater has numerous applications for researchers, marine commercial operators and defense organizations. As electromagnetic waves cannot propagate over long distances in seawater, acoustics provides the most obvious choice of channel. This research paper carries the study on acoustic channel modeling .In channel modeling, the attenuation due to the wave scattering at the surface and its bottom reflections for different grazing angles and bottom types, ambient noises such as shipping noise, thermal noise, turbulences are considered. Absorption coefficient in the channel with different established models like Thorp's and Fisher-simmons is also studied.

Key words- Acoustics provides, Channel Modelling, shipping Noise, Thorp's and Fisher-simmons - model.

1. Introduction

Wireless signals experience a variety of degradations due to channel imperfections [1], [2]. Just as electromagnetic signals are subject to a number of channel effects, including attenuation, reflections, and interference, underwater acoustic signals are subject to the same effects. One key difference between the RF and underwater acoustic channels is propagation speed. Acoustic signals in water are corrupted by interference from reflection and scattering at the water surface and bottom. For this reason, it is difficult to achieve high data rates in underwater channels. Sea water acts as acoustic waveguide and transmits sound signal in itself. Sound channel as a sound waveguide is a channel with random parameters [3]. But this subject does not have the meaning of its unpredictability. The most important characteristic of sea water is its inhomogeneous nature. In the whole classifications, its inhomogenity can be classified into two regular and random groups. Regular variations of sound speed in different layers of water leads to the formation of sound channel and this phenomenon causes the long distance sound propagation[. Random homogeneity causes the scattering of sound waves and sound fields variation.

The channel for communication here is water. Water can be deep or shallow, still or moving,, hot or cold etc. Here, each of these will be looked into and seen how it affects the communication process. For underwater communication has to be acoustical. Thus the role of ocean is that of acoustic medium. The single most important acoustical variable in the ocean is sound speed. The distribution of sound speed in the ocean influences all other acoustic phenomena. The sound speed, in turn, is determined by the density (or temperature and salinity) distribution in the ocean. Refraction of sound by fronts – eddies and other dynamic features can distort the propagation of acoustic signals.

2. Channel Modeling

In channel modeling, the attenuations due to the frequency absorption, ambient noises and loss due to the wave scatterings at the surface and bottom for deferent grazing angles and bottom types are considered. Also Ray theory is the basis of the mathematical model of multipath effects.

2.1 Loss Modeling

The acoustic energy of a sound wave propagating in the ocean is partly:

- Absorbed, i.e., the energy is transformed into heat
- Lost due to sound scattering by in-homogeneities.

2.2 Absorption

Underwater acoustic communication channels are characterized by a path loss that depends not only on the distance between the transmitter and receiver, as it is the case in many other wireless Channels, but also on the signal frequency. The signal frequency determines the absorption loss which occurs because of the transfer of acoustic energy into heat.

2.3 Attenuation

Attenuation, or path loss that occurs in an underwater acoustic channel over a distance L for a Signal of frequency f is given by equation 1 as

$$A(L, f) = A_0 L^k a(f)^L \quad (1)$$

Where A_0 is a unit-normalizing constant, k is the spreading factor, and a(f) is the absorption coefficient. Expressed in dB, the acoustic path loss is given by equation 2 as

$$10 \log A(L, f) / A_0 = k\ 10 \log L + L\ 10 \log a(f) \quad (2)$$

The first term in the above summation represents the spreading loss, and the second term represents the absorption loss. The spreading factor k describes the geometry of propagation, and its commonly used values are k = 2 for spherical spreading, k = 1 for cylindrical spreading, and k = 1.5 for the so-called practical spreading.

The absorption coefficient can be expressed empirically, using the established models like Thorp's formula [4], Fischer and Simmons model [5] which gives a(f) in dB/km for f in kHz. The loss according to the Thorp's model is shown in Fig 1

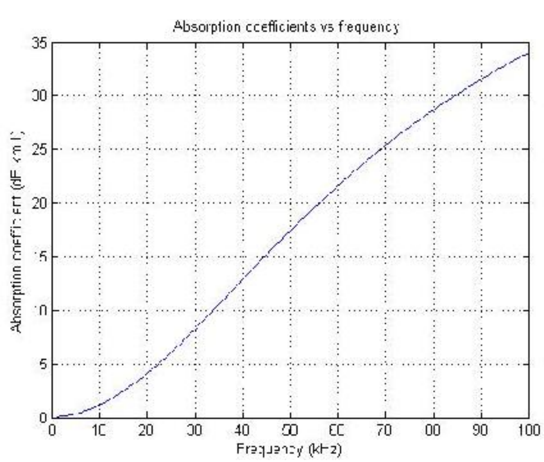

Fig 1: Absorption v/s frequency for Thorps Model

In Thorp's model, the attenuation is independent of temperature and the depth of the water body. This is taken into consideration in the next model of Fisher-Simmon's model.

The loss according to the Fisher-Simmon's model at t = 8 degree Celsius is shown in Fig 2

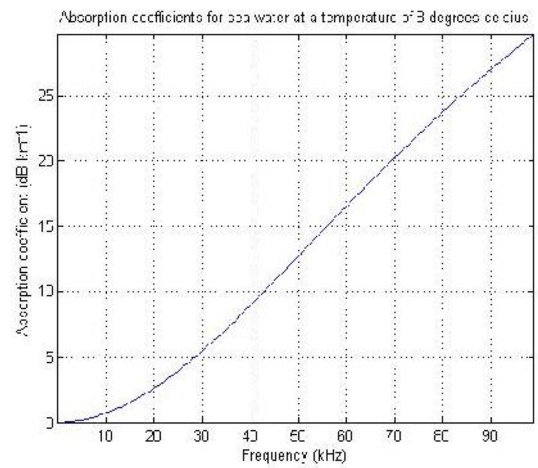

Fig 2: Absorption coefficient v/s frequency for Fisher and Simmons Model

2.4 Noise Modeling

The model considered for noise is the combination of Thermal noise, shipping noise, winds Noise. Figures 3 and 4 show the behavior of noise power versus frequency when they act individually and acting at the same time.

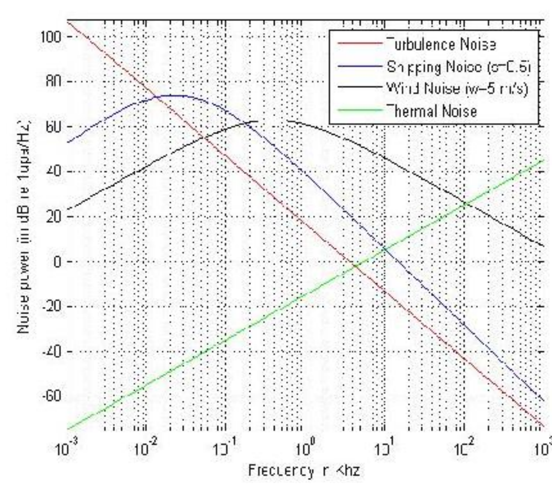

Fig 3: Individual Noise power v/s frequency

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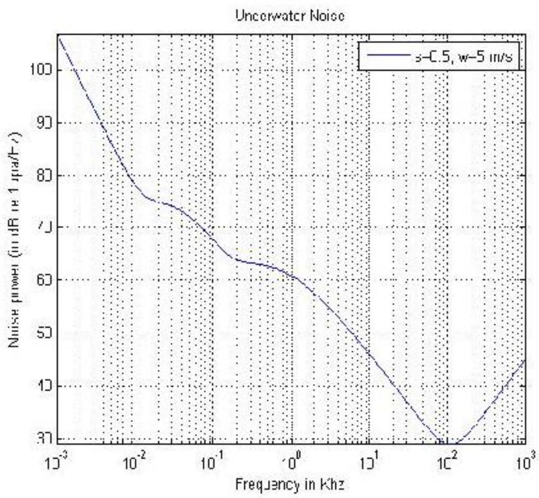

Fig 4: Noise Power v/s frequency at s = 0.5 and w = 5 m/s

2.5 Sound Attenuation in sediment

The sound attenuation in sediment mainly varies with the bottom type. Bottom type (bt), defines the sediment material of the ocean. Table 1 provides the values of bt for each sediment type.

Sediment type	value of bt
very coarse sand	0
coarse sand	1
medium sand	2
fine sand	3
very fine sand	4
very coarse silt	5
coarse silt	6

Table 1: Sediment Type

The following empirical formula is provided to find the sound attenuation in the sediment depending on the bt.

$$\alpha_s = \frac{1}{8.686} \mathrm{K} \left(\frac{f}{1KHz}\right)^n \frac{1}{m}$$

Where
α_s - attenuation of the sediment

The table 2 provides the values for K and n for four sediment types.

Sediment type	K	n
very fine silt	0.17	0.96
fine sand	0.45	1.02
medium sand	0.48	0.98
coarse sand	0.53	0.96

Table 2: K and n values for different Sediment Types

Fig 5 shows the attenuation based on different sediment types

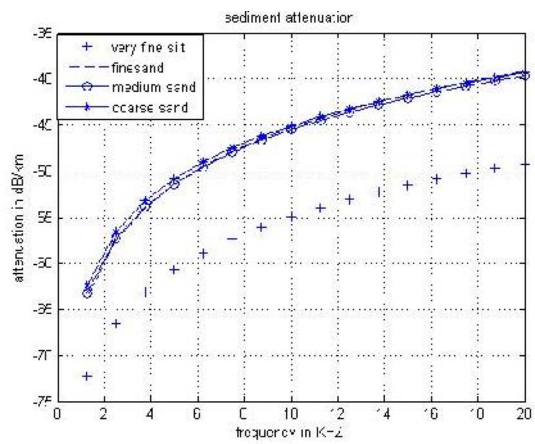

Fig 5: Sediment attenuation based on different sediment types

2.6 Scattering Modeling in the surface and bottom reflections

Scattering is a mechanism for loss, interference and fluctuation. A rough sea surface or seafloor causes attenuation of the mean acoustic field propagating in the ocean waveguide. The attenuation increases with increasing frequency. The field scattered away from the specular direction, and, in particular, the backscattered field (called reverberation) acts as interference for active sonar systems. Because the ocean surface moves, it will also generate acoustic fluctuations. Bottom roughness can also generate fluctuations when the source or receiver is moving. The importance of boundary roughness depends on the sound-speed profiles which determine the degree of interaction of sound with the rough boundaries.

Loss due to the wave scattering in the surface is given by [5]

$$R_G = Re^{(kh)^2 \cos^2 \varphi} \qquad (5)$$

It is based on the Gaussian normal distribution function for the surface displacement variable. Here k denotes wave number, h denotes the RMS height of the particle, phi is the angle of collision to the normal surface, R is the pressure reflection for the normal surface. Here R = -1 and h is obtained from the Neumann-Pierson spectrum.

Surface reflection coefficient loss for different wind speeds with a frequency of 25 kHz is shown in Fig 6 and 7. It can be observed that with an increase of grazing angle the scattering loss also increases. In the same way with the increase of wind speed, there is an increase in scattering loss.

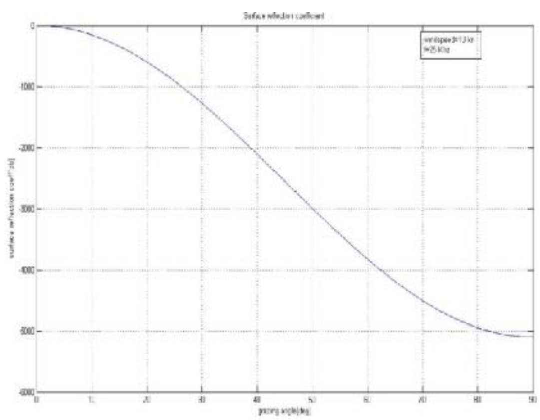

Fig 6: Surface reflection loss for wind speed 10 Kn, frequency=25 kHz

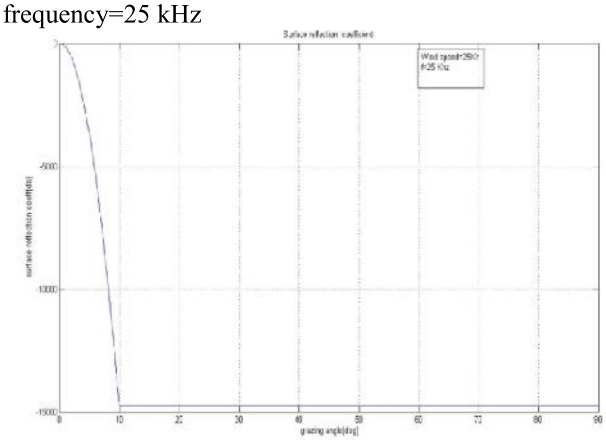

Fig 7: Surface reflection loss for wind speed 25 Kn, frequency=25 kHz

For the calculation of bottom reflection coefficient, bottom water type is selected using the Jackson pattern which is simulated based on the strait of Hormoz conditions and Hamilton-Bachmann Model.[6].

The Rayleigh reflection coefficient from medium 1 to medium 2 is

$$R = \frac{Z1 - Z2}{Z1 + Z2}$$

where Z_1 and Z_2 are the acoustic impedances of the first and second media, respectively (the Acoustic impedance is the product of the sound velocity and the density).

The bottom reflection coefficient for different sediment types are given in figures 8 and 9.

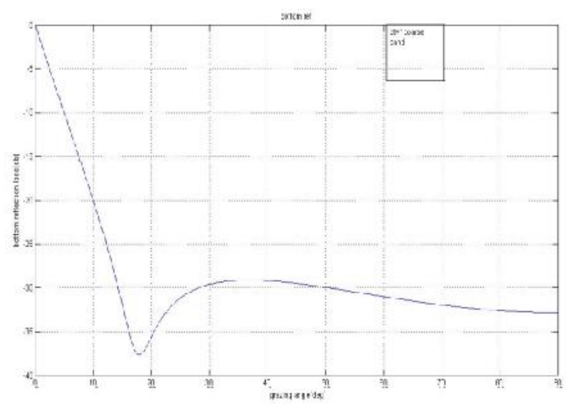

Fig 8: Bottom reflection coefficient loss for coarse sand

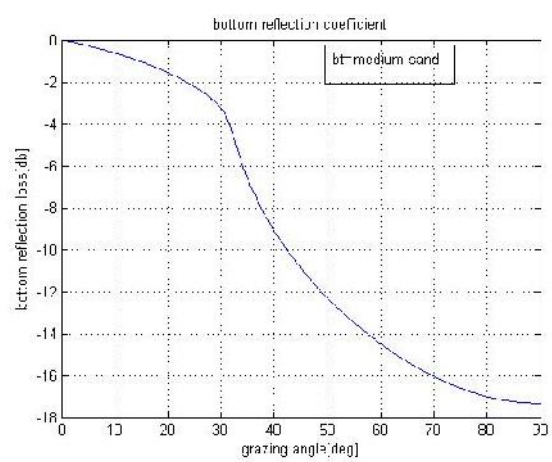

Fig 9: Bottom reflection coefficient loss for medium sand

3. CONCLUSION

Channel modeling is done considering the factors of absorption, attenuation and scattering losses. The absorption coefficient is simulated based on the Throp's and Fischer model. From the simulation results, surface and bottom reflection coefficients are calculated which also varies the acoustic attenuation. Future theoretical studies should investigate effects of attenuation on Multipath propagation and Doppler shift.

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