ON THE CHANNEL FREQUENCY RESPONSE IN SHALLOW SEAWATER

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Abstract: *The objective of this work is to analyze the channel frequency response in the coast of Arraial do Cabo, Rio de Janeiro, Brazil. The knowledge of the channel frequency response enables the communication to be established with reasonable power, since the system will operate in the frequency range in which the channel has minimum attenuation. Knowledge that the underwater acoustic channel is characterized by the large-scale fading due to path loss, and by small-scale fading caused by multipath fading, combined with the output provided by Bellhop ray tracing program in a proper way leads to somewhat representative channel model. The Bellhop program is used for performing the calculation of the channel amplitude, phase and delay responses for each frequency tone. The simulated scenario considered the sound speed profile, and the bathymetric profile acquired in the coast of Arraial do Cabo. In this environment, the maximum distance between transmitter and receiver is around 40 kilometers, in which the maximum depth is 130 meters, representing a shallow water environment. In addition to a model for the channel frequency response, we analyze the signal-to-noise ratio (SNR) by considering a variable signal power, the channel frequency response previously evaluated, and a model of the ambient noise. The work shows that some standard approaches for acoustic channel characterization leads to distinct attenuation results.*

Keywords: *Channel Frequency response, underwater channel modeling, underwater communication*

1. INTRODUCTION

In general the knowledge of a channel model allows the design of more efficient transceiver, leading to communication links with higher data rates. As a consequence, the characterization of the underwater acoustic channel is an actual concern. Some works model the channel stochastically [1], [2] while others characterize the channel using the attenuation due to path loss [3].

In [1], the channel is modeled stochastically using measurements collected in an experiment performed in Narragansett Bay, situated in the USA coast. This work concludes that the channel path gains follow Ricean fading models. In [2], a channel model for high-frequency in warm shallow water is developed. This model is tested with experimental data collected in Singapore where it has been found that the channel path gains follow Rayleigh fading models. These results show that there is not a unique appropriate channel model, meaning that the channel models might be site dependent.

In this work we analyze the channel frequency response in the coast of Arraial do Cabo. For a distance of 40 kilometers between transmitter and receiver, the maximum water depth is about 130 meters, meaning that our analysis will be focused in shallow water channel. The channel frequency response obtained in our work considers path loss and multipath fading. Besides, we analyze the signal-to-noise ratio (SNR) using the knowledge of the channel and of the ambient noise measured at the referred site.

Arraial do Cabo has underwater monitoring station of Brazilian Navy, being an important communication and monitoring site in Brazil South East coast. Information about the channel frequency response might improve the experiments performed at this site.

2. CHANNEL MODEL

Communication of a signal through a physical medium always faces power loss. The objective of this section is to describe some types of loss that occur in the transmission medium, i.e., the acoustic channel, and that are taken into consideration in the analysis of the channel frequency response. The loss or fading can be classified as small-scale fading and large-scale fading. The large-scale fading occurs due to path loss, and the small-scale fading is caused by multipath. In the following section, a brief description of these fading types is provided.

2.1. Path Loss

The path loss is a combination of the following phenomena: spreading loss, absorption loss and scattering loss. The spreading loss occurs in the propagation of the acoustic wave: a greater distance to the source leads to a larger area occupied by the wave front [4], so that a lower amount of energy will reach the receiver. The absorption loss is the transformation of the energy transmitted in the acoustic wave into heat. The scattering is the modification of the acoustic wave direction due to irregular surfaces or obstacles. The path loss is modelled in dB as [3]:

$$10\log A(l,f) = 10\log A_0 + k10\log l + l\alpha(f) \quad (1)$$

in which l is the distance (in meters) between transmitter and receiver, f is the wave frequency in kHz, $10\log A_0$ is a normalization factor related to the inverse of the transmitted power, k is the spreading factor, and $\alpha(f)$ is the attenuation coefficient (in dB/m). The spreading factor assumes the value 1 for cylindrical spreading and 2 when the spreading is spherical. In shallow water, generally the spreading is considered to be cylindrical [5]. The attenuation coefficient $\alpha(f)$ can be expressed as [5]:

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

where f is the frequency (in kHz). The coefficients f_1, f_2, A_1, A_2, A_3, P_1, P_2 and P_3 are functions of the salinity, temperature, water depth and of the pH of the water. The complete formulation of these coefficients can be found in [5].

2.2. Multipath Fading

The transmitted signal travels through different paths before reaching the receiver. These phenomena of multiple arrivals of the same signal is called multipath fading. Notice that these signals may arrive at close time instants such that the reflections can be unresolvable, and the combination of all these reflections gains compose the path gain. These phenomena will be reproduced in the channel model with the help of the Bellhop program, that provides as output all the rays that arrive at the receiver at all time instants.

2.3. Ambient Noise

The knowledge of the noise power spectral density (PSD) and of the channel frequency response can be valuable for the design of efficient transceivers. A measurement of the ambient noise was performed using the hydrophone ITC-8073C. These measurements were transmitted through a cable whose length is 700 meters. As the cable is modeled as a lowpass filter with cutoff frequency around 70 kHz, we consider that the frequency response is flat in the range $0 < f < 20$ kHz. Besides, the hydrophone sensitivity is approximated as flat, whose value is considered to be the midband: -167 dB //1V / μ Pa.

3. CHANNEL FREQUENCY RESPONSE USING BELLHOP

Bellhop is a program that performs ray tracing for a given scenario. The scenario setup may include sound speed profile or sound speed field, bathymetric profile, and surface profile. Some possible outputs are travel time and the amplitude of each arriving ray.

Thus, for computing the channel frequency response, we use the Bellhop program for each frequency of interest with the selected scenario. As we have as output the travel time and the amplitude of each ray, we perform the phasorial sum of amplitudes of the arriving rays. This procedure is repeated for a frequency range. Notice that, using this simulator, both path loss and multipath fading effects are considered in the channel frequency response. As ray theory has restrictive assumptions in shallow water for frequencies under 500 Hz [6], the channel frequency response might not be accurate in this frequency range.

4. SCENARIO – ARRAIAL DO CABO

The site we are interested is located in Arraial do Cabo coast, situated in Rio de Janeiro state, Brazil. For performing the calculation of the channel frequency response, we used a Bathymetric profile, a surface profile, and a sound speed propagation profile acquired in Arraial do Cabo. The bathymetric map of Arraial do Cabo is shown in Fig. 1. The bathymetric profile considered in this work is the black line of Fig. 1. The maximum depth is about 130 meters, representing a shallow water environment.

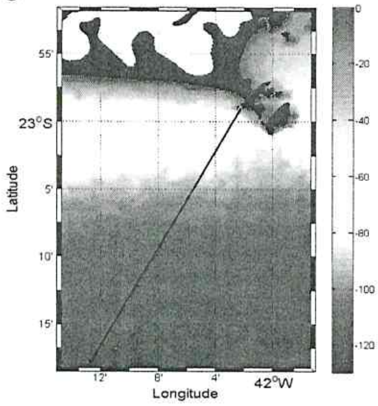

Fig.1: Arraial do Cabo coast bathymetric map.

As the sea bottom of the interested location is composed mostly by fine sand, the measured sound speed at this seafloor was 1684 m/s, the bottom density was 1.99 g/ cm^3 and the bottom attenuation was 0.6 dB/ λ . These geoacoustics data were collected in a previous work [8].

5. SIMULATION RESULTS

As our objective is to find the frequency range with the minimum channel attenuation, we analyzed the channel frequency response due to path loss as in [3] and also the channel frequency response provided by the Bellhop simulator.

The channel frequency response was calculated for the following transmitter/receiver distances: 1, 5, 10, 20 and 40 kilometers. For each distance, the receiver was placed in 5 different depths in order to minimize the effect of constructive or destructive interference. The channel gain $G(l, f)$ is obtained by averaging the results of these 5 experiments. The channel gain of each experiment is calculated using the Bellhop program. Table 1 shows the receiver depths for each transmitter/receiver distance. The transmitter is placed at 16 meters of depth and the source aperture was 90°. The simulation setup is depicted in Fig.2.

Fig. 3 shows the channel frequency response for all the distances between transmitter and receiver. This figure depicts the channel characterized only by the path loss, as described in [3], and the channel obtained using Bellhop program. Considering the same frequency, the channel has higher attenuation for longer distances between transmitter and receiver. Also, for the same distance between transmitter and receiver, the channel attenuation is lower for lower frequencies. Besides, when considering the multipath effects, i.e. using Bellhop program, the channel gain is lower than the case where the channel is characterized with only path loss.

Tx/Rx distance (Km)	Receiver Depth (m)				
1	10	15	20	25	30
5	15	20	30	40	50
10	15	30	40	50	60
20	15	30	50	70	85
40	15	30	50	70	90

Table 1: Receiver depth X distance.

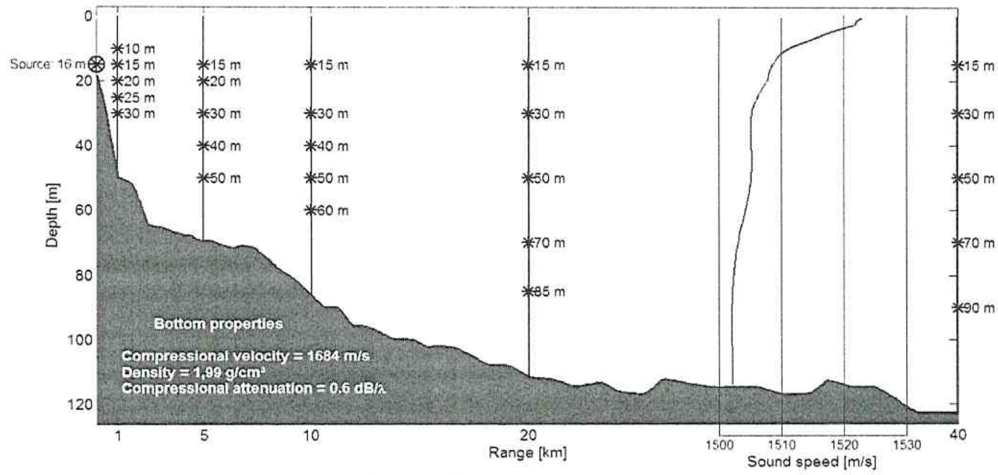

Fig.2: Simulation setup.

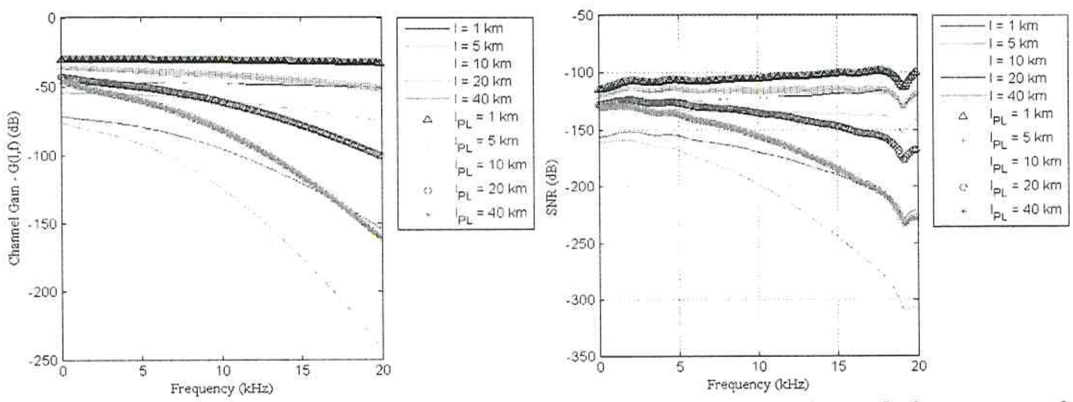

Fig.3: Channel frequency response (left) and SNR (right) for a channel characterized only by the path loss (legend with subscript PL) and for a channel obtained using Bellhop.

Besides the channel frequency response, we analyzed the signal-to-noise ratio (SNR) using the knowledge of the channel and of the ambient noise measured at the site probed. The SNR is given by

$$SNR(l,f) = \frac{PG(l,f)}{N(f)} \tag{3}$$

where P is the signal transmission power, that will be considered as unitary, $G(l,f)$ is the channel gain, and $N(f)$ is the noise power spectral density. Notice that the SNR depends on the signal frequency, and on the distance between transmitter and receiver.

Fig. 3 depicts the SNR for each frequency considering the two characterization of the channel frequency response. For all cases, longer distances leads to higher attenuation. Once more, the SNR is lower in the case where the channel is characterized with only path loss. We can notice that there is an attenuation near the frequency 19 kHz for all SNR curves. The noise around this frequency presents an unexpected characteristic in this region that is under investigation.

6. CONCLUDING REMARKS

In this work, we analyzed the channel frequency response and the SNR in Arraial do Cabo coast. The channel frequency response is characterized by the large-scale fading and small-scale fading, that were calculated using the Bellhop program. The simulated scenario considered measurements acquired at the site. As expected, the results show that lower frequencies leads to lower attenuation when transmitting signals over longer distances.

7. ACKNOWLEDGEMENTS

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REFERENCES

[1] **P. Qarabaqi, M. Stojanovic**, Statistical modelling of a shallow water acoustic communication channel, In *Proc. Underwater Acoust. Meas. Conf.*, Nafplion, Greece, pp. 1341-1350, Jun. 2009.

[2] **M. Chitre,** A high-frequency warm shallow water acoustic communications channel model and measurements, In *J. Ac. Soc. Amer.*, vol. (122), pp. 2580-2586, Nov. 2007.

[3] **M. Stojanovic**, On the relationship between capacity and distance in an underwater acoustic communication channel, In *SIGMOBILE Mobile Computing and Communications Review*, volume (11), n. 4, pp. 34-43, Oct. 2007.

[4] **S. Zhou, Z. Wang**, *OFDM for Underwater Acoustic Communications*, Wiley, 2014.

[5] **M. C. Domingo**, Overview of channel models for underwater wireless communication networks, *Physical Communication J. Acoust. Soc. Amer.*, vol. (1), pp. 163-182, 2008.

[6] **P. C. Etter,** *Underwater Acoustic Modeling and Simulation*, Spon Press, 3rd Ed., 2003.

[7] **M. C. Domingo**, Overview of channel models for underwater wireless communication networks, *Physical Communication J. Acoust. Soc. Amer.*, vol. (1), pp. 163-182, 2008.

[8] **I. Simões, F. Xavier, L. Barreira, L. Artusi, H. Macedo, Y. Alvarez, R. Romano, J. P. Hermand**, Medições geoacústicas em sedimentos marinhos da plataforma continental próxima a Arraial do Cabo-RJ - Brasil, In *2as Jornadas de Engenharia Hidrográfica*, Lisbon, Jun. 2012.