MODELING OF A SHALLOW WATER ACOUSTIC COMMUNICATION CHANNEL

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Abstract— In these last years, many studies have focalized on the design of reliable underwater acoustic communication systems. However, the ocean acoustic communication channel exhibits strong amplitude and phase fluctuations and the phenomena of diffraction, refraction and reflection. Due to the complexity of environment, the motions of transducers, sea surface, etc., the underwater acoustic signals exhibit random temporal and spatial frequency fluctuations in both amplitude and phase. Therefore, it is very important to model a so complex channel. Acoustic propagation is characterized by three major factors: attenuation that increases with signal frequency, time-varying multipath propagation, and low speed of sound (1500 m/s). The background noise, although often characterized as Gaussian, is not white, but has a decaying power spectral density. The channel capacity depends on the distance, and may be extremely limited. In this paper, we propose a new multipath channel model for shallow underwater acoustic communications. In particular, our model takes into account the effects due to spreading loss, scattering and reflections.

Index Terms —Underwater communications, Acoustic channel, Underwater reflections, sound intensity loss, ambient noise.

I. INTRODUCTION

Underwater acoustic (UWA) communications have been used in military applications for a long time. Compared to radio waves, sound has superior propagation characteristics in water, which make it the favorite technology for this specific scenario. Underwater acoustic channels are generally recognized as one of the most difficult communication media in use today. The worst properties of radio channels—poor physical link quality of a mobile terrestrial radio channel and high latency of a satellite channel—are combined in an underwater acoustic channel[1]. At this time, there are no standardized models of the acoustic channel fading, and experimental measurements are often made to assess the statistical properties of the channel in particular deployment sites. However, the shallow-water acoustic channel is different from the radio channels in many aspects. The available bandwidth of the UWA channel is limited and it depends on both range and frequency. The acoustic signals are affected by timevarying multipath, which may create a severe inter symbol Interference (ISI) and large Doppler shifts and spreads[2].

These characteristics restrict the range and bandwidth for the reliable communications. The propagation speed in the UWA channel is five orders of magnitude lower than the speed of the radio wave. When designing a network protocol,
It should be given special attention to these aspects. These highly space, time and frequency dependent features pose numerous obstacles for any attempts to establish reliable and long-range underwater acoustic communications. Therefore, it is very important to model this complex channel[3]. The main goal of this paper is to modeling how environmental conditions affect underwater transmission. For this purpose a mathematical formulation taking into account the effects due to spreading loss, scattering and reflections, was presented. The paper is organized as follows: in Section II a brief introduction of underwater sound propagation, the underwater channel modeling is described in Section III, research methodology explain in section IV and Conclusions are summarized in section V.

**Figure 1: Aquatic Channel Block.**

**II. INTRODUCTION OF UNDERWATER SOUND PROPAGATION**

The variation of the speed sound c in the ocean is relatively small. Normally c assumes values between 1450 and 1540 m/s. However, even such small variations of c have a profound effect on the propagation of sound in the ocean. The sound speed can be directly measured or calculated using empirical formulas, if you know the temperature T, salinity S, and the hydrostatic pressure P or the depth z. The accuracy of the most comprehensive empirical formula is comparable to that of modern velocimeter measurements. However, the formulas that offer such accuracy are very complicated. A simple equation, but less accurate, to calculate the speed of sound in water, in m/s, is:

\[ c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016z \]

(1)

Where T is the temperature in °C, S the salinity in ppm, z the depth in meters and c the speed of sound in m/s[1]. The sound speed profile in underwater shown in Figure (2).

**Figure 2: Sound Speed Profile**
III. THE UNDERWATER CHANNEL MODELING

A. Path Loss: We now discuss the energy loss of channels. For any propagation wave, there are three primary mechanisms for energy loss: (i) geometric spreading, (ii) absorptive loss[4].

\[ PL_{\text{spreading}}(r) = k \times 10 \log(r) \text{ dB} \]  
(2)

Where \( r \) is the range in meters and \( k \) is the spreading factor.

\[ PL_{\text{absorption}}(r,f) = 10 \log(\alpha(f)) \times r \text{ dB} \]  
(3)

Where \( \alpha \) is absorption loss.

The total path losses are the combined contribution of both spreading and absorption losses:

\[ \text{PathLoss}(r,f,d,t) = k \times 10 \log(r) + \alpha(f,d,t) \times r \times 10^{-3} \]  
(4)

![Figure 3: Path Loss VS. frequency](image)

B. Multipath: An acoustic wave can reach a certain point through multiple paths. In a shallow water environment, where the transmission distance is larger than the water depth, wave reflections from the surface and the bottom generate multiple arrivals of the same signal[4].

![Figure 4: Path Loss VS. range with different frequency](image)
The impulse response of an acoustic channel is influenced by the geometry of the channel and its reflection and refraction properties, which determine the number of significant propagation paths, and their relative strengths and delays. Strictly speaking, there are infinitely many signal echoes, but those that have undergone multiple reflections and lost much of the energy can be discarded, leaving only a finite number of significant paths[2].

To put a channel model in perspective, let us denote by leap the length of the path propagation path, with \( p = 0 \) corresponding to the first arrival. In shallow water, where the sound speed can be taken as a constant \( c \), path lengths can be calculated using plane geometry, and path delays can be obtained as \( t_o = L_p/c[3] \). Large channel delay spread introduces time dispersion of a signal, which causes severe inter-symbol interference.

Consider a signalling scheme with a bandwidth of \( B = 4 \) kHz. Each symbol interval is about this = 0.25 ms In the presence of a channel with delay spread of 10 ms, each symbol will affect the subsequent 10/0.25 = 40 symbols due to waveform spreading. This brings grand challenges for efficient modulation and demodulation[4].

As shown in figure (6) When the distance between the sender and receiver long, time difference between the different paths will be small. In other words, the successive paths will converge in time.

C. Ambient Noise: Ambient noise is defined as “the noise associated with the background din emanating from a myriad of unidentified sources. Its distinguishing features are that it is due to multiple sources,
individual sources are not identified, and no one source dominates the received field”. The contributions of the major noise sources can be expressed through empirical formulae, which provide power spectral densities of each source relative to frequency $f$ [kHz] in [dB re $\mu$ Pa per Hz][3, 4].

Ambient Noise can be represented as Gaussian and having a continuous power spectrum density (psd). Background noise, although often characterized as Gaussian, is not white, but has a decaying power spectral density[3].

![Figure 7. power spectral density of ambient noise.](image)

**D. Doppler Effect:** Motion of the transmitter or receiver contributes additionally to the changes in channel response. This occurs through the Doppler effect, which causes frequency shifting as well as additional frequency spreading. The magnitude of the Doppler effect is proportional to the ratio $a = v/c$ of the relative transmitter-receiver velocity to the speed of sound. Because the speed of sound is very low compared to the speed of electro-magnetic waves, motion-induced Doppler distortion of an acoustic signal can be extreme[5].

For comparison, let us look at a highly mobile radio system. At 160 km/h (100 mph), we have $a = 1.5 \times 10^{-7}$. This value is low enough that Doppler spreading can be neglected. In other words, there is no need to account for it explicitly in symbol synchronization. The error 10,000 bits. In contrast to this situation, a stationary acoustic system may experience unintentional motion at 0.5 m/s (1 knot), which would account for $a = 3 \times 10^{-4}$. For an AUV moving at several meters per second (submarines can move at much greater velocities), factor a will be on the order of 10–3, a value that cannot be ignored[2].

**IV. RESEARCH METHODOLOGY**

To be a realistic Model Design must be to collect all the real and theoretical data and begin to analyze it scientifically to see and calculate all the variables in the channel, which has been described previously.

At first real data is collected and then analyzed using the MATLAB-program and get practical results and compare them with the theoretical results and then test the model of the channel in the communication system to test the validity of the Model. The channel model appear in Figure 8.
A mathematical model for the impulse response of a time-varying shallow water acoustic channel is proposed. The channel is modeled as a superposition of multiple propagation paths, whose lengths and relative delays are calculated from the channel geometry. Experimental signals will be collected and compare to mathematical models in Malaysian seas.
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