MULTICARRIER UNDERWATER ACOUSTIC COMMUNICATION- A SURVEY

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Abstract

Underwater communication has captured tremendous attention in the last few years. The varied applications ranging over commercial, scientific and military activities require efficient communication under water. Acoustic waves stand out as the best medium for communicating underwater. But underwater communication has to encounter effects of spreading loss, path loss, ambient noise, multipath propagation, Doppler effects etc. In this juncture, identifying suitable underwater acoustic channel model (UAC) is very important for minimum BER communication through underwater by considering water depth, frequency and range. Also the typical long delay spread and the resulting intersymbol interference inherent in underwater acoustic channels has to be dealt with. Multicarrier modulation is a solution to this problem. In this paper an analysis on the existing works related to underwater acoustic communication covering the channel modeling techniques and modulation schemes are presented and the best technique is proposed.

Keywords: *Underwater acoustic channel, Multicarrier modulation*

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1. INTRODUCTION

The varied applications of wireless underwater communication such as oil industry communications, environmental monitoring, scientific explorations beneath ocean, search and rescue missions, monitoring and controlling commercial activities, interactions between underwater acoustic vehicles, ocean floor mapping, etc requires communication techniques for transmission of data between two or more nodes located underwater. Radio, optical and acoustic techniques are suitable candidates for communicating underwater. Radio waves succumb extremely to the effects of attenuation. Only the lower frequency ranges can be used for communication and hence requires large antennas with high transmission power. Optical techniques are much affected by scattering than attenuation. High precision optical equipments are required to overcome scattering. As such acoustic techniques emerge as the best possible way to communicate underwater. Acoustic techniques in spite of being the best option for underwater communication face many challenges for efficient communication. The continuously varying nature of underwater medium poses many hurdles. The density and temperature of water varies over depth. Suspended particles of solid or gaseous matter result in the non-homogeneities of the water. The channel boundaries acts as reflecting layers and hence the acoustic signals travel along multiple propagation paths. This phenomenon, known as multipath propagation results in delay spread and ISI. Also the underwater medium is in a state of constant motion which will induce relative motion among the transmitter and receiver creating Doppler effects. The ambient noise associated with the channel is also a challenge as it varies with frequency. Addressing the effects of the above challenges into a channel model is the first phase for underwater communication. The second step is to devise a suitable modulation scheme which could provide better data rate for a favorable bit-error-rate (BER). Section 2 describes the current works regarding the various channel parameters followed by the modulation schemes used. In section 4 a solution based on the survey is proposed.

2. CHANNEL PARAMETERS

2.1 Sound Speed Modeling

Underwater medium consists of several thermo cline regions. Density and temperature of the medium change with depth. This results in variation of sound speed in water from the typical value of 1500m/s. Several models have been developed to account for sound speed variations in water for varying parameters. Medwin formula [1], one of the initial efforts to model sound speed takes into account the effects of temperature and salinity. Abdollah Doosti Aref et.al, 2011 has discussed the results of Medwin formula and has suggested a modification. The modified formula, models sound speed by a 10th order polynomial for varying depth, temperature and salinity. The results of the modified formula have been presented and have been shown to convolve with the experimental data obtained with reference to the Persian Gulf. Anuj Sehgal et.al, 2010 has used the McKinsey model to evaluate the sound speed variation. The variation in sound speed with temperature for different depths using the McKinsey model has been shown below. The temperature is taken in degree Celsius and depth is in meters.

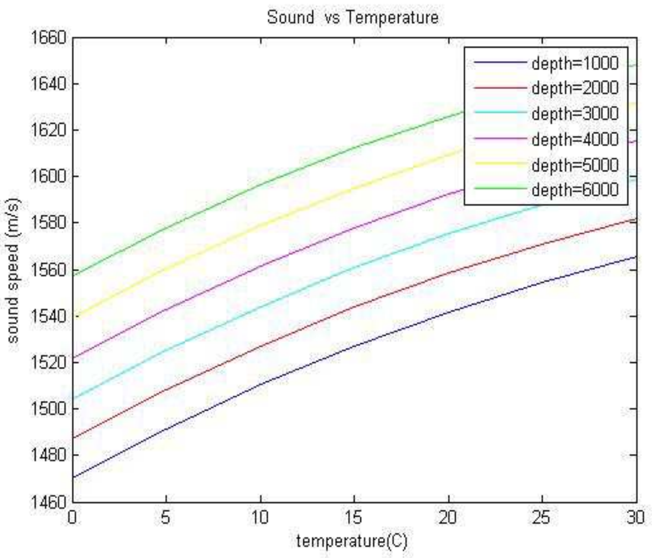

Fig -1: Variation of sound speed with temperature

Figure 1 shows the change in speed of sound with temperature. It can be observed that sound speed increases with both depth and temperature.

2.2 Path Loss Modeling

Acoustic signals incur losses over time during its propagation. The effects of spreading loss and absorption loss are collectively known as path loss. Acoustic signal spreads in the channel and the loss is observed along the transmission distance. The depth of the water column determines the nature of spreading. Acoustic signals spread spherically in deep water channels and cylindrically in shallow water channel. The spreading coefficient k denotes the nature of spreading i.e. it is assumed a value 1 for cylindrical and 2 for spherical spreading [3]. Generally spreading coefficient is taken as 1.5 so as to include the effects of both cylindrical and spherical spreading. Absorption loss, observed in the underwater channel is a frequency dependent parameter. Acoustic signals, over its course of propagation, lose energy due to this absorption. Many models have been developed to predict the absorption loss suffered by acoustic signals. Thorp model, one of the earlier techniques to obtain the absorption coefficient has been used by Chengsheng Pan et.al, 2012. Thorp model evaluates the absorption coefficient in terms of frequency. The works done by Anuj Sehgal et.al, 2009 has emphasized on this factor and suggests the Fisher and Simmons model over Thorp model as the former considers depth and temperature effects along with frequency to obtain the attenuation coefficient. They have depicted the attenuation coefficient as per both the models and have made a comparison in terms of accuracy.

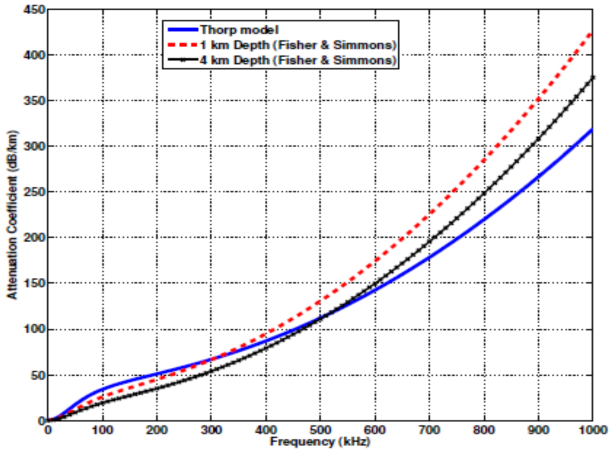

Fig -2: Absorption coefficient as predicted by the Thorp and Fisher & Simmons models at varying depths [5]

The coefficients were obtained for a temperature of 4 degree Celsius. It can be seen that Thorp model values have significant variation from Fisher and Simmons model. This variation is due to the inculcation of the effects of relaxation frequencies of Boric acid and Magnesium Sulphate in Fisher and Simmons model. Fisher and Simmons model assumes the Lyman and Fleming standard for water i.e. salinity = 35 and *pH* = 8 and is valid in the frequency range of 100 Hz to 1 MHz. Francois and Garrison model which is developed from Fisher and Simmons model can also be used to model the attenuation coefficient [6]. In the works done by Anuj Sehgal et.al, 2010, the Ainsley and McColm equation has been used to obtain the absorption coefficient considering the effects of salinity and pH as well. F. De Rango et.al, 2012 has used Schulkin and Marsh model. A choice can be made among the various attenuation coefficient models mentioned above based on the application requirements. The attenuation coefficient for a frequency range up to 1 MHz according to Fisher and Simmons model is shown below

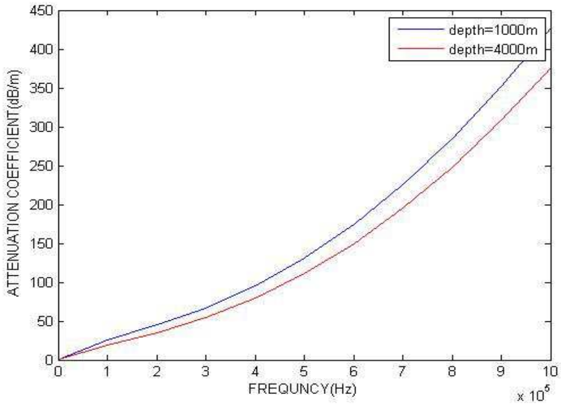

Fig -3: Attenuation coefficient for varying frequency

Attenuation for higher frequencies is more when compared to that of the lower frequency range as it is evident in the graph. Also a decline in attenuation is observed for increasing depth.

2.3 Multipath Modeling

In an underwater channel, multiple propagation paths are possible for a signal. The reflecting abilities of the channel boundaries and the refracting capability of the water medium result in this multipath propagation. Each of the propagation path acts as a low pass filter. The acoustic waves apart from the direct incident wave undergo multiple reflections along the channel boundaries. The signals travelling through these multiple paths have different gain values which vary over time. This variation observed in signal gain over time is due to the shifting of reflection points in the channel. This results in the time varying nature of the channel. The variation of signal gain can be modeled by various techniques. Some works suggests that the signal gain variation obeys the Rayleigh distribution [4]. Ray theoretical model is another approach to model the multipath effect. Different authors in their works [1,2] [6-9] have employed this model to simulate the multipath effects. Ray theoretical models include the physical properties of the channel. It provides the gain transfer function corresponding to each multipath in terms of cumulative reflection coefficient and path loss. Mandar Chitre, 2007 has suggested a method along with the ray theoretical model to bring out the time varying multipath effects. It can be inferred that ray theoretical model is a good technique to model the multipath effects.

2.4 Doppler Effect

An ideal channel model assumes the underwater channel to be in a state of rest. But in the real world scenario, the underwater medium is in a constant state of motion. This results in relative motion between transmitter and receiver. These movements can induce changes in the channel response through Doppler effects. Doppler effect is dependent on both the relative velocity of transmitter/receiver and the sound speed and is given through the Doppler factor which is the ratio of the above terms. Doppler effect will introduce frequency shifting and frequency spreading. In frequency shifting, a frequency offset depending on the Doppler factor is introduced. During frequency spreading, the signal is scaled in time by a factor proportional to the Doppler factor resulting in a change in the pulse duration. Due to the negligible speed of sound with respect to the speed of electromagnetic waves, motion-induced Doppler distortion is predominant in an acoustic signal and has to be considered. In a conventional approach to OFDM signal detection, each block is detected independently. This can be done by allocating null subcarriers for frequency offset estimation, and pilot subcarriers for channel estimation. Milica Stojanovic, 2008 has considered the Doppler effects on the signal and has explained an estimation technique for the Doppler factor.

2.5 Noise Modeling

The noise observed in underwater channel is different from that seen in the radio channel. Underwater noises are found to be frequency dependent. The primary noises are turbulence, shipping, wind and thermal. Each of these noises is dominant in certain areas of the frequency spectrum. Turbulence noise is prominent in the low frequency range. Shipping noise has its toll in the 10Hz to 100 Hz range whereas the wind noise is in the 100 Hz to 100 kHz range. Thermal noise appears only beyond 100 kHz. Anuj Sehgal et.al, 2009 has used the Wenz model to obtain the noise values. Chengsheng Pan et.al, 2012 has also depended on the Wenz model to account for the noise, but with a modification regarding the thermal noise. As a modification, the effects of noises produced by the receiver and transmitter are also included along with the thermal noise of the channel. Mandar Chitre, 2007 has considered the effects of snapping shrimp noise for warm shallow water channels and Yigit Mahmutoglu, 2013 has included the effects of rain also. It appears that Wenz model is capable of estimating the noises efficiently and noise curves obtained using the model is shown below.

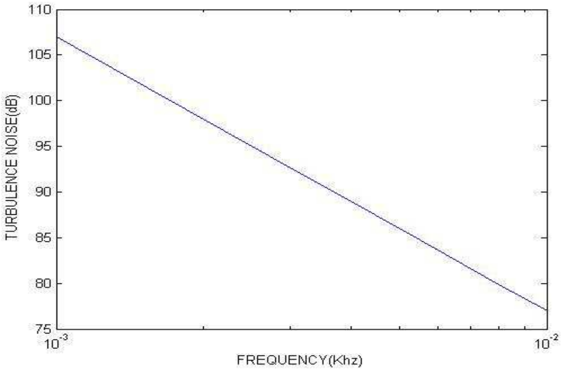

Fig -4: Turbulence noise

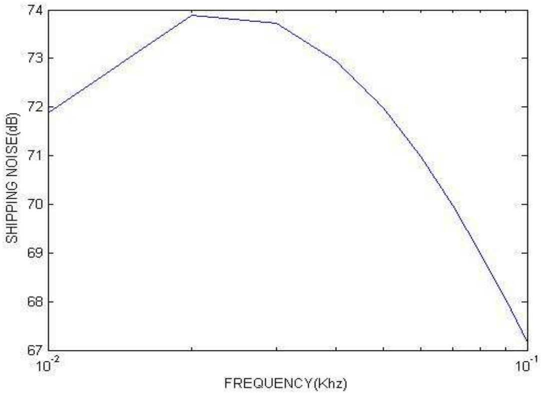

Fig -5: Shipping noise

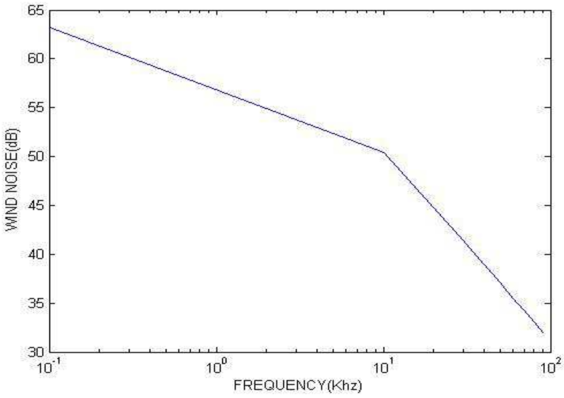

Fig -6: Wind noise

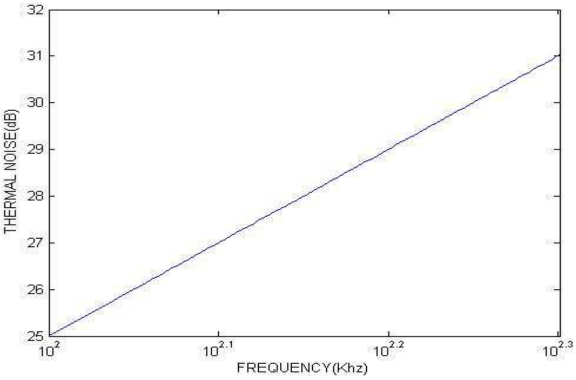

Fig -7: Thermal noise

3. MODULATION SCHEME

Along with the channel considerations, impeccable attention is to be made on the modulation scheme. Earlier underwater systems relied on single carrier modulation schemes. Such schemes trailed in terms of data rate and the adverse effects of ISI. Multicarrier modulation schemes emerged as a promising solution to these problems. OFDM, one of the best multicarrier schemes, has been used in many works [12,13,14,15] as it has many inherent advantages. In OFDM, the data is distributed over carriers that are spaced in frequency domain. This spacing provides orthogonality, which helps the demodulator in rejecting frequencies other than their own. OFDM splits the data and increases the symbol duration which will help in combating ISI [16]. Also existing modulation schemes such as BPSK, QPSK, DQPSK, QAM etc can be used as subcarrier modulation to better enhance the performance of the system. Geert Leus et.al, 2008 has used QPSK modulation scheme. Ram Pattarkine, has suggested the use of DQPSK signaling along with OFDM and concluded that it offers better data rate. Zahra Taheri Hanjani, 2012 has made a comparison between QAM and PSK in an OFDM system and observed that QAM can provide better data rate but with a compromise on bit-error-rate (BER). A suitable modulation scheme can be opted which will provide better performance with respect to the requirements.

4. PROPOSED SYSTEM

With the inferences drawn from survey, a standard channel model describing the above effects of the UWA channel can be developed. As it is observed that the McKinsey equation can successfully model the sound speed variation, the same can be adopted. Regarding the absorption loss, the Fisher and Simmons model can be preferred as it can yield comparable results within the constraints. The Ray theoretical model along with the time varying effects and the Doppler estimation technique described by Milica Stojanovic, 2008 can account for the time varying multipath UWA channel with Doppler distortions. As for the noise in the channel, Wenz model is an apt solution. The survey also highlighted the challenges regarding the modulation schemes that are used for underwater communication. OFDM for its inherent merits along with suitable subcarrier modulation schemes can enhance the performance in terms of BER and data rate. QAM and DQPSK are suitable candidates for subcarrier modulation schemes as it has been proved to have better outcomes regarding BER and data rate.

5. CONCLUSIONS

A universally applicable channel model incorporating all the UWA channel parameters along with a suitable modulation scheme is essential for the designing of new efficient systems. We are proposing an all-encompassing channel model along with the suggestion for the choice of a suitable modulation scheme.

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BIOGRAPHIES

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