An Extensive Review on Underwater Acoustic Channel

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Abstract- Underwater acoustic communication is more challenging than terrestrial communication. UWAC have various useful application including military use ,discovering of new resources, remote control in off-shore oil industry, monitoring pollution in ecological systems, efficient collection of scientific data recorded at stations located at sea bed, communication among divers also underwater vehicles and mapping of the sea bed for detecting objects and so forth. The signals that are used to carry digital information through an underwater channel are acoustic waves, which could propagate over long distances. Some are the factors affects communication like background noise, the multipath propagation, attenuation and low speed of the sound. The channel capacity is the highest data rate that could be supported by acoustic channel for source and receiver. The baseband signal might be in the form the data, voice, wave or information. In this survey paper we introduce the properties of acoustic propagation in seawater and different underwater acoustic channel characteristics and consider analysis of bandwidth, the frequency, loss, study the various properties of the acoustic channel and finally, we compared the characteristics n previous work of each model from different aspects.

***Keywords-* Acoustic communications, Acoustic channels, Propagation effect, Multipath propagation, signal to noise ratio.**

I. INTRODUCTION

Underwater acoustic channels are generally recognized as one of the most difficult communication media in the use today. Acoustic propagation is most excellent supported at low frequencies and the bandwidth (BW) available for communication is extremely limited. For example, an acoustic system may operate in a frequency range between 10 and 15 kHz. Although the total communication bandwidth is very low (5 kHz), the system is in fact wideband as the bandwidth is not negligible with respect to the center frequency. Sound propagates underwater at a very low speed of approximately 1500 m/s, and propagation occurs over multiple paths. However, several problems present ongoing challenges for UWA communication. Signals reflects from shallow and deep water both so that the multipath propagation occurs [1]. This multipath environment causes signal fading and inter symbol interference (ISI). Previously different field experiments have performed for measuring impulse responses of a shallow-water acoustic channel and variation of the propagation channel [2] etc.

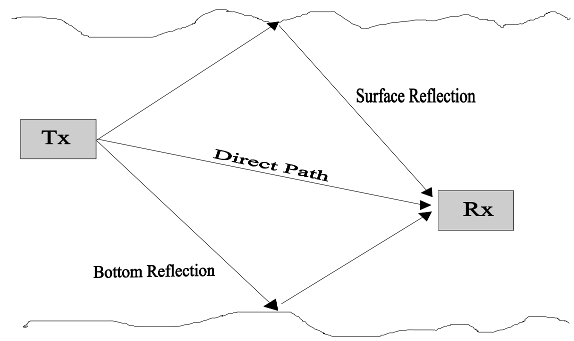

Fig. 1: Shallow water multipath propagation: in addition to the direct path of the signal propagates via reflections from the surface and bottom.

The transmission of acoustic signal from T_X to R_X is categorized in three ways (Fig. 1) by direct path, reflection through water surface and bottom reflection. Transmitter-receiver motion also is quite challenging in underwater acoustic communication due to the extreme sensitivity to Doppler resulting from the relatively slow propagation speed [3]. In this paper we aim to provide a brief overview of the key developments, both theoretical and practical. We also hope to provide an insight into some of the open problems and challenges facing in this field in the near future. The survey of all research in the field but the concentrate on ideas and developments that are likely to be the keystone of future underwater communication networks.

Applications: In the Marine research, oceanography, commercial operations, the offshore oil industry, defense, speech transmission between divers, gathering information without human interference, control over Autonomous underwater vehicles (AUV).

II. SYSTEM MODEL

The system model of underwater acoustic signal consists of 3 main processes-

(1) Signal transmission
(2) Channel estimation and
(3) Signal reception

Signal transmission is the process to encode and transmit the signals in which meaningful information is present, it could be in the form of data (telemetry) , voice (speech), control and video etc. channel is important in the design and simulation of underwater acoustic communication system. Channel is the medium by which the signal propagation takes place. Acoustic waves are used for long distance and high speed transmission. When it is compared to electromagnetic propagation that flows through the atmosphere, underwater acoustic signals' propagation is characterized significantly by frequency causing disturbances and relatively quite slower speed of propagation. Signal receiver receives and decodes the transmitted signal coming from channel.

At high frequencies appropriate for shallow water communications, ray theory describes the framework for determining the coarse multipath structure of the channel (Bjerrum-Niese etal. 1996). A ray theory-based multipath model, where as the individual multipath arrivals are modeled as Rayleigh stochastic processes, has been given to describe the medium range very shallow water channel accurately (Chitre, 2007). Channel modeling in the surf zone is particularly very difficult because of the large impact of the rapidly time-varying surface on the acoustics. The scattering of acoustic signals off shoaling surface gravity waves results in a time-varying channel impulse response (Preisig and Deane, 2004). Further work in this area is needed to help improve performance of communication systems in surf zones[12]. An additive Gaussian noise assumption is used commonly in the development of most signal processing and communication techniques. capacity of a channel increases linearly with the minimum of the number of transmit and receive antennas. This increase in capacity translates to a corresponding increase in achievable data rate through the use of multiple input multiple output (MIMO) processing technique, with MIMO underwater acoustic capacity provide capacity estimation using simulation and through the use of experimental data.

III. CHANNEL CHARACTERISTICS OF UWAC

Propagation under water is primarily determined by transmission loss, absorption loss noise, range, bandwidth, and SNR.

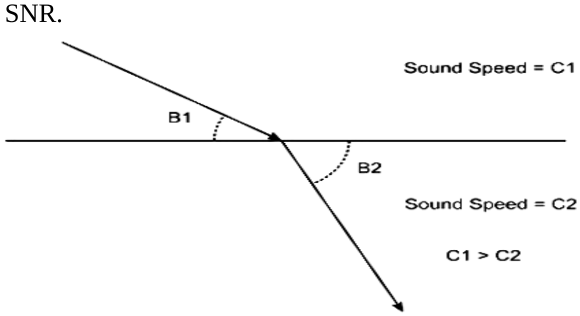

Fig 2: Diagram of the refraction of sound rays

The attenuation mechanisms that impacts underwater acoustic signal could be viewed principally as the sum of these three terms: the spreading loss, absorption loss and reflection loss. The spreading losses are due to the flow and hence the expansion of the fixed amount of transmitted energy over a larger area as the signal slowly propagates away from its source. The energy decays at a rate of $l^{(-k)}$ where l is the distance and k is the spreading factor depending upon the geometry of propagation.

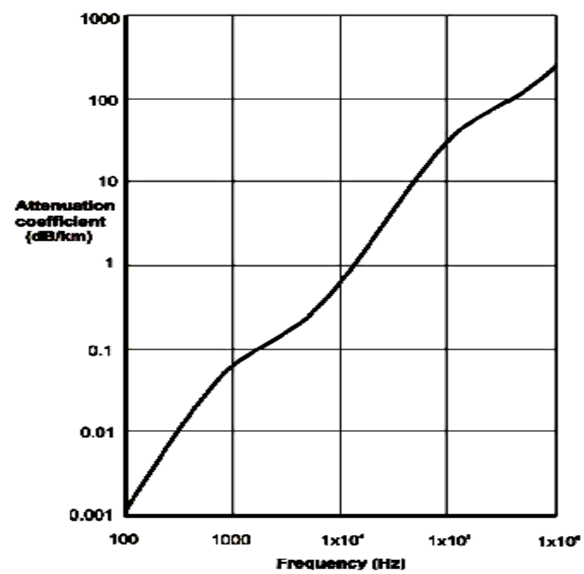

Fig 3. Absorption of sound in sea water (20°C).

$$(TL = 20 \log (R) + aR)$$

where a is the absorption in dB per meter.

The effect of this absorption of sound energy is that the fall in sound pressure level due to spherical spreading is increased by an additional loss for every kilometer the sound travels. This additional absorption loss is small to negligible for frequencies less than 1kHz. Attenuation is a term means the obstacle in between the communication of acoustic signals. It depends on frequency of the signal. Attenuation is the function of the distance. Noise is the unwanted signal that produces in between the communication process and gives the lossy output at the receiving end. Noise includes the environmental noise, emission receiver noise, discrete ship noise, disturbance noise, and etc. The size of environmental noise directly affects Signal-to- Noise Ratio (SNR) of the receiver. Noise in an acoustic channel consists of ambient noise and site-specific noise. Ambient noise is always present in the background of the quiet deep sea. Site-specific noise, on the contrary, exists only in certain places. Signal-to-noise ratio (SNR) varies over the signal bandwidth. Total path loss that occurs in a under-ocean acoustic channel could be computed by the equation:

$$\Gamma_p / \sqrt{A(l,f)}$$

where $A(l, f)$ is the sum of spreading and absorption loss:

$$10\log A(l,f) = k.10 \log l + l.\ 10 \log\alpha (f)$$

MULTIPATH: The underwater channel results in paths of multiple propagation from each source to receiver. The multi path depends in the transmission link configuration. Multipath formation in the ocean is governed by two effects: sound reflection at the surface, bottom and any objects, and sound refraction in the water[13]. The latter is a consequence of sound speed variation with depth, which is mostly evident in deep water channels. Ray bending occurs differently in shallow and deep water. The definition of shallow and deep water is not a rigid one, but it is generally assumed that shallow water stands for a water depth less than 100 m. Multipath propagation introduces ISI (inter symbol interference).

DOPPLER EFFECT: The Doppler effect is a change in frequency of emitted waves produced by movement of an emitting source relative to an viewer. Action of the transmitter or receiver contributes additionally to the changes in channel response. This happened 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.

IV . MULTICARRIER MODULATION

Multi-carrier modulation is an attractive substitute to a broadband single-carrier communication system. By dividing the available bandwidth into a number of narrower bands, (OFDM) orthogonal frequency division multiplexing systems could perform equalization in frequency domain, thus eliminating the need for complex time-domain equalizers. orthogonal frequency division multiplexing modulation and de-modulation could easily be implemented using fast Fourier transforms (FFT). In shallow waters, an experiment was conducted to compare the performance of OFDM with direct sequence spread spectrum (DSSS), in this good OFDM performance (BER < $2x10^{-3}$) at ranges up to 6 km[12].

OFDM equalization is simplified greatly if a guard interval longer than the delay spread is allowed between successive OFDM symbols. This guard period is usually implemented as a cyclic prefix to maintain orthogonality of the sub-carriers. Though, when the delay spread is long, the prefix length could become undesirably long and affect the efficiency of transmission significantly. In future OFDM systems to reduce the prefix length and improve bandwidth effectiveness. When using coded OFDM, consecutive symbols are often striped across sub-carriers to reduce the error correlation resulting from fading. However, impulse noise present in some environments could affect multiple sub-carriers simultaneously and hence generate correlated errors. Make a use of channel interleaver with coded OFDM allows symbols to be distributed over a frequency-time plane, therefore allowing the code to make maximal use of frequency and time diversity offered by OFDM.

V. PREVIOUS WORK

By the different researchers studies of UWA communication and related parameters I did review of their work:

Tadashi Ebihara and Koichi Mizutani in “Underwater Acoustic Communication With an Orthogonal Signal Division Multiplexing Scheme in Doubly Spread Channels” [1] states that in the field of communication, underwater acoustic communication is an ongoing challenge because of multipath propagation and Doppler effect. In this paper they propose orthogonal signal-division multiplexing scheme for measuring multipath profile and compare the performance of OSDM and existing communication schemes. Authors found that OSDM with a multichannel receiver is attractive in terms of communication quality; it achieved a far better bit error rate (BER) performance compared to various input signal to noise ratio (SNR). OSDM could provide a highly reliable communication environment for UWA communication with multipath and Doppler spread, same as in shallow water.

Sea-Moon Kim, Sung-Hoon Byun, Seung-Geun Kim, and Yong-Kon Lim in “The Effect of Source Power on Statistical Characterization of Underwater Acoustic Communication Channel in Shallow Water” [2] states that in underwater acoustic communication only statistical channel modeling has been studied because of experimental approaches of ocean for estimating of communication channels. In this paper authors numerically analyze the probability density functions for various SNR conditions. The outcomes show that small SNR induces inaccurate statistical channel model when narrow-band signal is used for transmitting sound waves. Field experiment also shows similar results but further difficulties are there and should be make overcome.

Hee-Chun Song in “Long-range Acoustic Communication in Deep Water Using a Towed Array: Beam Diversity” [3] states that vertical arrays are involve in underwater acoustic communication but if elements are separated channel fading and inter symbol interference occurs. Coherent long-range acoustic communication (200- 300 Hz) is feasible in deep water over ~550-km range between a source and a horizontal towed array. In this paper demonstration shows that beam diversity with a larger horizontal array (~200 m aperture) could be exploited to further improve the communication performance, and achieving an error-free data rate of 50 bits/s for BPSK modulation at ~550-km range.

Joe Borden in “Long Range Acoustic Underwater Communication with a Compact AUV” [4] states that in comparison to radio frequencies, underwater communication with respect to Autonomous Underwater Vehicle (AUV) offers more discrepancies. Radio frequencies could not propagate well in seawater. In this paper author describes a method of employing underwater acoustic modems to exchange data and information between a submerged AUV and the operator.

Table 1: Summary of Literature Review

Year	Author	Title	Methodology	Outcomes
2013	Tadashi Ebihara and Koichi Mizutani	"Underwater Acoustic Communication With an Orthogonal Signal Division Multiplexing Scheme in Doubly Spread Channels"	Orthogonal Signal Division Multiplexing Scheme	Highly reliable communication environment Obtained
2012	Sea-Moon Kim, Sung-Hoon Byun, Seung-Geun Kim, and Yong-Kon Lim	"The Effect of Source Power on Statistical Characterization of Underwater Acoustic Communication Channel in Shallow Water"	Underwater Acoustic Communication Channel in Shallow Water	Obtained Small SNR Induces statistical channel model
2012	Hee-Chun Song	"Long-range Acoustic Communication in Deep Water Using a Towed Array: Beam Diversity"	Towed Array: Beam Diversity	Beam diversity with (~200 m aperture) horizontal array Exploited
2012	Joe Borden	"Long Range Acoustic Underwater Communication with a Compact AUV"	Compact AUV	Represent a significant improvement in observed, practical, performance
2012	Lan Zhang , Xiaomei Xu , Wei Feng and Yougan Chen	"HFM Spread Spectrum Modulation Scheme in Shallow Water Acoustic Channels"	HFM Spread Spectrum Modulation	This is the advancement of the lake experiment performed.
2008	Mandar Chitre, Shiraz Shahabudeen, Lee Freitag, Milica Stojanovic	"Recent Advances in Underwater Acoustic Communications & Networking"	research over the years has resulted in improved performance and robustness	Improvement in bandwidth, extended multi-path, refractive properties of the medium

Underwater acoustic modems could employ low frequency (9 to 13 kHz) acoustics to achieve effective extremely long range communication. In this research paper author discusses the results of field tests and demonstrates the improvement seen by application of the Band C modem as compared to other acoustic modem systems. the results are meaningful to a growing compact AUV user community but does not challenge theoretical understanding of acoustic communications. As the results derive from the combination of two commercially available products, represent a considerable improvement in practical, performance.

Lan Zhang , Xiaomei Xu , Wei Feng,and Yougan Chen in "HFM Spread Spectrum Modulation Scheme in Shallow Water Acoustic Channels" [5] states that to reduce the effect of multipath propagation and Doppler effect in underwater acoustic communication uses the modulation scheme name as HFM spread-spectrum modulation to improve the performance of channel but introduces some amount of narrow band noise. The affects of many factor investigated by experimental model in shallow water. This is the advancement of the lake experiment performed in 2011.

Mandar Chitre, Shiraz Shahabudeen, Lee Freitag and Milica Stojanovic in "Recent Advances in Underwater Acoustic Communications & Networking" [6] states that In last 2 decades attention is improved in underwater acoustic communications. Continued research over the few years has resulted in improved performance and robustness as compared to the initial communication systems. Research has extended from point-to-point communications to include underwater networks as well. This paper presents an overview of developments both theoretical and practical. Some of the problems and challenges in the future have also discussed. As electromagnetic waves propagate poorly in sea water, acoustics provides the nearly all obvious medium to enable underwater communications. High-speed communication in underwater acoustic channel is challenging due to limited bandwidth, expanded the multi-path, refractive properties of the medium.

VI. Conclusions And Future Scope

In this paper, we studied the basic system model of underwater acoustic channel communication in which the transmitter, channel capacity and estimation, receiver, main characteristics of acoustic channel losses in underwater acoustic communication as transmission loss, absorption, attenuation noise(ambient & Gaussian). Low frequency is less than 500 Hz and high frequency is more than 500 Hz. The importance of each effect for system design depends on both its impact on communication performance and frequency of occurrence. We should take more values reported propagation effects and channel characterizations should be adopted as being typical for underwater acoustic communication channels.

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