Robust Encrypted Underwater Communication with LPI/LPD

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A dissertation submitted to Pakistan Navy Engineering College National University of Sciences and Technology (NUST), Islamabad. A thesis submitted in partial fulfillment of requirements for the

Degree of

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Abstract:

In recent decades, underwater acoustics communication (UWAC) has attained much attention of researchers due to their applications in both military and commercial sectors including gathering oceanographic information, monitoring the environmental conditions and coastal defense.

The objective of our research is to develop a robust underwater telephone system for shallow water fading channel for short range communication, requirement of our underwater communication system is to have reliable high data transmission security using encryption. Direct Sequence Spread Spectrum (DSSS) System is used providing data encryption in underwater communication with low detection probability (LPI/LPD) in presence of ambient noise. To provide data robustness is based on the channel condition multiple modulation techniques can be applied e.g. ASK, BPSK, FSK, and QPSK to increase complexity.

To model multipath short range shallow underwater acoustic channel, a comprehensive model is used named BELLHOP, where the ray tracing is based on multipath effects. Doppler Effect and the transmission losses due to reflection and refraction at surface and the bottom aren't being considered for BER Calculation.

Acknowledgement:

I am very grateful to Allah for his faithful provision throughout my life, my mother and my husband for their support and the sacrifices they made during my studies. I would like to thank my advisor, Dr. S Sajjad Haider Zaidi for their guidance and patience, and many others who gave their advice and input into numerous stages of this study.

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Project Summary

Encrypted communication is crucial in numerous situations, varying from secret military operations and the organization of social turbulence, to privacy security for consumer especially of underwater wireless communications.

The motivation and interest in both sensor and vehicular technology using wireless underwater communication is creating enormous applications varying from environment surveillance to gather oceanic data, aquatic archeology, sea rescue operation and many more. The signal we are using to carry the digital information in underwater environment is neither radio nor electromagnetic wave but acoustic signal. As the radio and electromagnetic wave have short propagation distance with high signal attenuation, where acoustic signal are able to carry information for long distance compared to other techniques.

Underwater telephony system is one of the applications that are primarily used for through water communication (TWC). By the recent decades system is shifted toward the wireless underwater communication using acoustic signals.

However, non-detection is being the primary task of most submarine operations, existing system only provide underwater telephony for short ranges with significant reduction in fading channels. Proposed system offers an integrated approach that combines voice communication with digital data transfer. Proposed system uses direct sequence spread system (DSSS) modulation structure for reliable communication through low probability of interception (LPI)

and low probability detection (LPD) especially in fading shallow water channel. System utilizes end to end encryption to provide signal transmission security and to identify and isolate the voice data information in underwater environment for low bit error (BER), different modulation techniques is applied to choose adequate BER for selected underwater propagation channel.

Contribution

In last three decades, underwater acoustic communications have gained the interest of many researchers since there are numerous applications and these applications is now shifting from military purpose toward the commercial. In underwater channel digital communication is far more different and complex as compared to the other mediums, due to the multipath, time varying spatial variability and high propagation delay are some of the channel conditions of underwater environment. Since the signal is used for underwater communication is acoustic signal, data is transmitted by an acoustic signal which has limited bandwidth with small data rate.

Requirement of underwater communication system is to have reliable data transmission with security using encryption. Direct Sequence Spread Spectrum system is implemented to provide robustness while communicating in underwater with LPI/LPD in presence of ambient noise. To provide secure data transmission multiple modulation techniques are implemented.

In this thesis, the channel we have designed is incoherent which means that output file ignored the interference by phase differences. The simulation is implemented using BELLHOP tool and MATLAB software []. BELLHOP is a ray tracing tool used to determine the acoustic pressures, transmission loss, eigenrays and transmission delays. The delays and acoustic pressures calculated by BELLHOP are converted to arrival file (.arr). Arrival file which is also the impulse response of the selected underwater channel, for every arrival the travel time, amplitude, and phase of arrival is provided. Additional information is also included of ray take-off angle of source and at receiver, also the top and bottom bounces. For this simulation we only considered the traveled time and amplitude for channel impulse response. Since the underwater channel is so complex that the effect of channel varies by geological location and environmental conditions such as, sea traffic, underwater animals, and weather condition, so in our simulation we compared the BER curves based on different modulation techniques to select better option for signal modulation.

Chapter 1

Introduction

To transmit and receive message underneath water is called underwater communication [1]. In Underwater acoustic communication, high frequencies acoustics waves' propagation has more attenuation with high transmission losses over long ranges, which make them less-effective propagating tool. Various methods can be design for underwater acoustic communication. This study and experimental is based on the deployment of underwater networks has been rising. [2]

Acoustic waves aren't the only means for establishing an underwater communication channel, radio waves, optical and other can also be used for the channel modeling but these mediums have their own limitations. As for the radio the range of waves is between 30Hz to 300Hz which require a very large antenna to establish a communication path in underwater, on the other side optical communication has low attenuation but it can easily scattered, and the electromagnetic waves can easily attenuate in underwater communication. Among all these approaches acoustic waves are more convenient and efficient.

Project description can be distributed into three parts in this thesis. First part based on underwater communication background, including best choices for underwater communication and explanation of underwater channel as utmost challenging channel, where second part containimplementation of modulations using simple principles. Third part focused on results and conclusion of simulation using MATLAB.

1.1 Relevance to National Needs

Underwater acoustic communication channel is an inconsiderate environment, making it hard to transmit data without any error. Due to the high absorption of electromagnetic energy, neither optics nor radio waves are suitable for long range transmissions in underwater channel. Although high attenuation in higher frequency range is a great deal of noise in the lower end [22], high propagation delay and limited bandwidth, where acoustics is the most suitable method to carry information underwater. The problems acknowledged above makes attaining a robust and reliable network communication hard and tough, and require a set of communication protocols.

Because of the requirements of security issues of UWA communication channel. In this thesis we have discussed the applicable security algorithms that are suitable for UWA channel [24], and the focus of our research is to design an end to end encryption system of underwater acoustic communication which is quite new research field, especially for Arabian Sea. Achieving robust encrypted over underwater acoustic communication channel, which is very challenging owing to limited bandwidth obtainability [2]. Underwater networks encryption over wireless communications have an extensive variety of applications. All these applications contain mine-field controlling, networking of surface, submarines, and unmanned underwater vehicles. With drive to construct such networks in such a challenging environment, with reliable wireless underwater communication is significant for Navy.

1.2 Goal of the Thesis

Research on underwater acoustics communication security remains to be in promising stages with numerous restrictions. Still, requirement of security technology for underwater communication is rising quickly [10]. Here, we have described current research on underwater acoustics and technologies related to security.

To address the underwater communication security issues we first analyzed the characteristics of underwater acoustic channel, since we can't implement normal communication protocols over underwater communication channel due to the factor of multipath, channel fading, delay and low data rate. Therefore, it requires security protocol intended for underwater communication that that could be appropriate for underwater challenging environment.

Due to the characteristics of underwater acoustics communication channels, they are more exposed to attacks. Covered security systems has restriction against these blended attacks, in order to conquer these limitations, proposed security mechanism is necessary. If we imply network's traditional techniques for instance cipher or message digest, the size of message will be increased. To solve these problems of a cryptographic matching set for underwater communication channel it require data modulation methods such as DSSS, OFDM, PSK, or DPSK.

The objective of our research was to identify digital voice data transmission techniques having low bit error rate (BER). DSSS modulation scheme will be used to provide robustness and low detection probability in the presence of ambient noise. End to end encryption is used to secure data transmission.

1.3 Literature Review

In last three decades, underwater acoustic communications have gained the interest of many researchers since there are numerous applications and these applications is now shifting from military purpose toward the commercial. In underwater channel digital communication is far more different and complex as compared to the other mediums, due to the multipath, time varying spatial variability and high propagation delay are some of the channel conditions of underwater environment. Since the signal is used for underwater communication is acoustic signal, data is transmitted by an acoustic signal which has low bandwidth and low data rata rate. To efficiently make the use of bandwidth of the channel and to make transmission and reception encrypted different modulation schemes has been implemented.

Table 1: Work already done

Sr. no	Title	Modeling Technique	SNR	BER	Data rate	Bandwidth
1.	High Reliability Direct-Sequence Spread Spectrum for Underwater Acoustic Communications	DSSS	24db	10-3	1920bits	10kHz
2.	Low probability of detection underwater acoustic communications using direct-sequence spread spectrum (2008)	DSSS PSK	-10db to 30db	10-6	8bps	4kHz
3.	Direct-sequence spread-spectrum modulation for utility packet transmission in underwater acoustic communication networks (2009)	DSSS BPSK	33db	10-5	100bps	9 to 14kHz
4.	Reliable underwater communication system for shallow coastal waters (20)	DSSS PSK FSK	1.44db	10-2 to 10-3	1kbps	10 to 100kHz
5.	Analysis of channel effects on direct-sequence and frequency-hopped spread-spectrum acoustic communication (2001)	DSSS PSK	25db	10-2	320bps	10kHz
6.	Study on the Structure of an Efficient Receiver for Covert Underwater Communication Using Direct Sequence Spread Spectrum (2017)	DSSS PSK			187.5bps	16kHz
7.	Discrete sequence spread spectrum based modem for underwater acoustic communication and channel measurements (1999)	DSSS	30db		200bits	30kHz

8.	Design consideration For Wireless Underwater Communication Transceiver (2008).	QPSK	19db	10-3		10kHz
9.	Adaptive Technique for Underwater Acoustic Communication (2012).	MFSK and OFDM	2db, 25db	10-4	3400bps	200Hz, 3kHz
10.	Adaptive OFDM Modulation for Underwater Acoustic Communications: Design Considerations and Experimental Results (2013)	QPSK and OFDM	24db	10-2–10-3		25k to 35kHz
11.	Modulation and Error Correction in the Underwater Acoustic Communication Channel (2009).	PSK and 16QAM	20db	7.32x10-3	40kbps	10khz
12.	Design and Simulation of a Secure and Robust Underwater Acoustic Communication System in the Persian Gulf (2011)	QPSK and QAM	1.5-3db	2x10-6	2.4kbps	5k to 27kHz
13.	Direct-sequence spread-spectrum modulation for utility packet transmission in underwater acoustic communication networks (2002)	DSSS and BPSK	-24db	10-4	80bits	5k to 24kHz
14.	Efficient encoding and decoding schemes for wireless underwater communication systems (2014).	PSK and OFDM	84to94db	10-3		18k to 34kHz
15.	Performance Evaluation of Modified OFDM for Underwater Communications (2013).	WHSOFDM DFTOFDM DCT-SOFDM CI-OFDM	20db-15db	4e-4 8e-5 2e-6	1e6 bits	10kHz
16.	Non-binary LDPC Code for Non-coherent Underwater Acoustic Communication and Its Experiment Results (2013)	Non binary LDPC code	2-3db	0.2 to 0.14	357bps	6 to 10kHz
17.	Performance analysis of IRA codes for underwater acoustic OFDM communication system (2009).	OFDM	14 to 16db	10-3 to 10-5	1024bits	5kHz

1.4 Report structure

This report is ordered as follows. Chapter 1 provides introduction of project with literature review of underwater acoustic channel and work that already has been done over the past years. Chapter 2 described why we chosen acoustic signal for underwater wireless communication. Chapter 3 includes the methodology of project. In Chapter 4 described the theory of underwater channel. Chapter 5 modulation techniques are discussed, in Chapter 6 we discussed the Bellhop tool in detail where in chapter 7 focused on the simulation and results.

Chapter 2

Optimal Option for Underwater Communication

To transmit data wirelessly in underwater channel, we have multiple options for instant electromagnetic wave, optical wave, radio waves and acoustics or sound waves. Each means of transmission has their pros and cons in underwater channel. We have discuss some of them in this chapter.

2.1 Electromagnetic waves

In underwater communication electromagnetic waves can be used in RF range for wireless channel. In underwater speed of electromagnetic wave is four times faster than sound waves, which can greatly reduce the latency of the channel [3][4]. Moreover, the effect of reflection and refraction is much lower in EM in shallow water, also them waves has very small effect of suspended particles. But EM waves are highly attenuating in underwater due to water conductivity. For example, the typical conductivity of seawater is 4S/m which cause high losses.

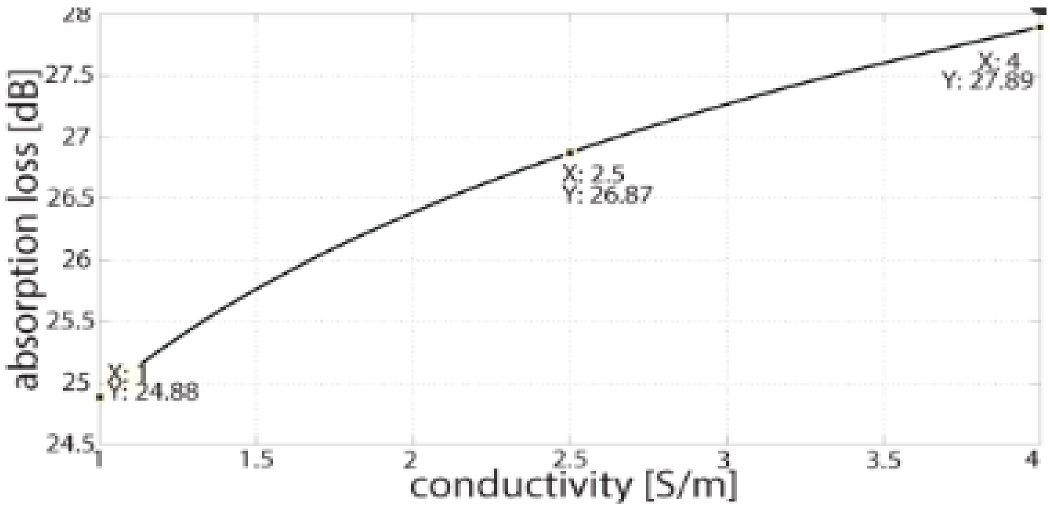


Figure 1: Abortion loss of EM waves in Seawater

2.2 Radio waves

Radio wave can propagate any distance in underwater channel, is has low attenuation, effect of reflection and refraction is also low in radio waves. But there is one drawback in using radio waves in seawater is, it require high transmission power and large antennas are the frequency range of radio waves are to low (30-300Hz), Since the bandwidth is too small the data rate of transmission is 300bits per second.

2.3 Optical waves

Optical waves can provide high speed data rate in underwater channel with low latency but the range of optical waves are very limited, as they suffer scattering, they are too delicated for reflection and refraction which cause high attenuation.

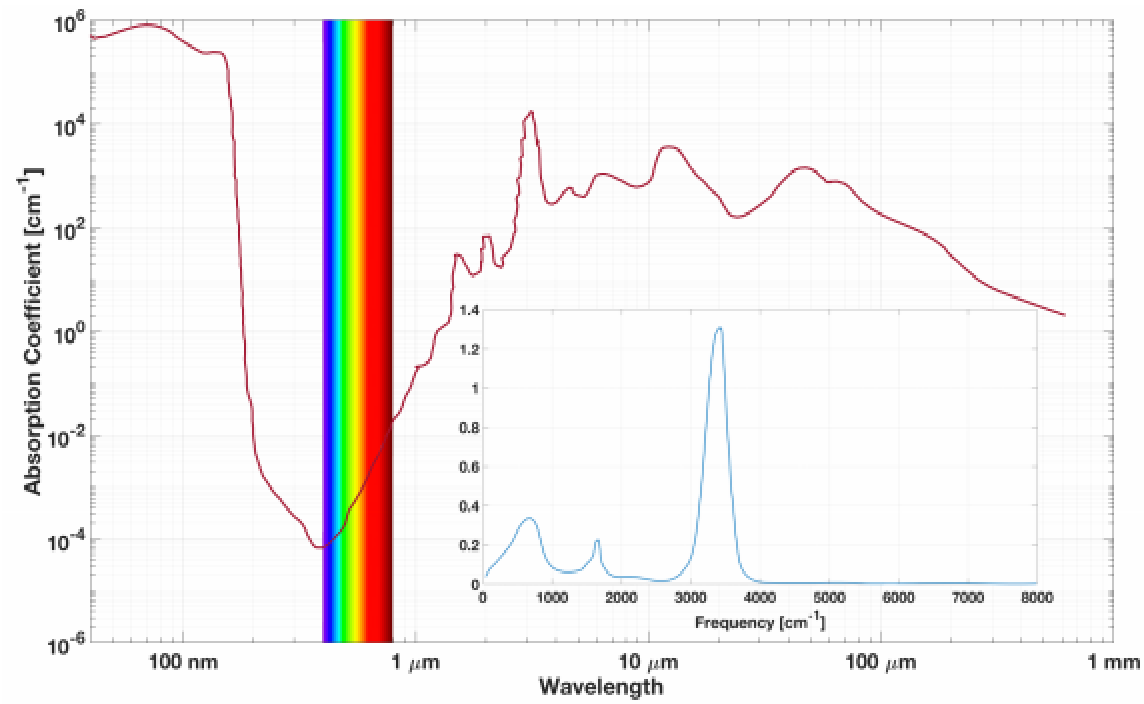


Figure 2: Attenuation of optical waves in underwater

2.4 Acoustics waves

In underwater channel, acoustics or sound waves are more suitable for wireless communication. The acoustic wave propagation is reliant on following factors: as frequency of signal increases attenuation increases gradually, multipath propagation, time varying property, and speed of sound that is about 1500m/s [5][6]. The signal attenuation in underwater channel is also depended on the distance, Long distance cause the effect of spreading and absorption loss. The bottom and surface of the ocean can reflect and scatter acoustic waves [21], which origin multipath propagation. Multipath effect creates the intersecting of consecutive pulses results inter symbol interference (ISI), which increase bit error rate in received signal. Hence, underwater communication systems has low data rates [5,6].

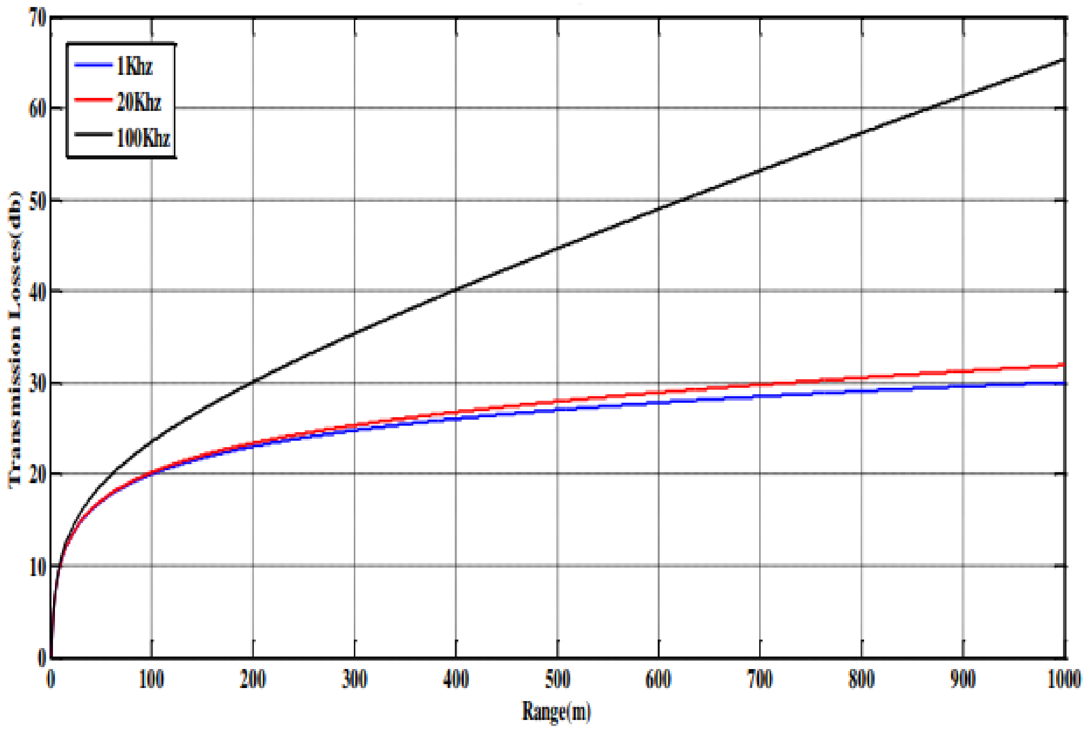


Figure 3: Transmission losses of acoustic waves in underwater channel

Table 2 describe the comparison of multiple underwater communication techniques, which shows for very short range communication optical waves can be used for transmission with following parameters, for transmission under 100m RF wave can be used and for more than 100m transmission acoustic waves can be used for transmission.

Table 2: Comparison of wireless underwater communication

Parameters	RF waves	Optical waves	Acoustic waves
Transmission Distance	100m	10to 30m	Up to 20km
Attenuation	Frequency and conductivity dependent	Distance	Distance and frequency dependent
Speed	2.255x10^8m/s	2.255x108m/s	1500m/s
Transmit Power	Hundreds of watts	Few Watts	Few tens of watts
Cost	High	Low	High
Data rate	Up to 100Mbps	Up to Gbps	In Kbps
Antenna size	0.5m	0.1m	0.1m
Latency	Moderate	Low	High

Table 2 shows comparison of multiple communication techniques used for underwater transmission where acoustic wave characteristics in underwater channel shows much better performance in terms of long range transmission with low losses compared with others, but the speed of sound is only 1500m/s which resultant more time requirement for data transmission also the data rate would also be low.

Chapter 3

Methodology

Project simulation can be divided into two main parts in first part we designed underwater acoustic communication channel using bellhop ray tracing tool, and in second part we simulated the effect of underwater channel over the transmitting data with the help of impulse response.

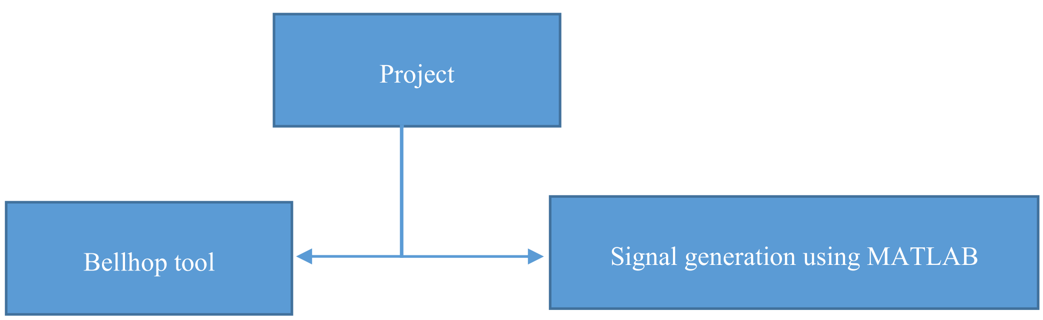


Figure 4: Basic Diagram of Project

3.1 Generation of Underwater channel using Bellhop tool

Underwater channel noise is non Gaussian. Different sources experience different noises changing rapidly over graphic location and time. Hence, designing an identical or true statistical noise is tough. 50 Hz or below frequency dominate the underwater turbulence, where noise less than 600Hz effect by the graphical location. For frequencies between 600 Hz to 60 kHz, the sea surface effect noise spectrum. Where surface of sea level is roughness is linked with the wind speed. Lastly, frequencies more than 60kHz effects by both thermal noise and motion of surface.

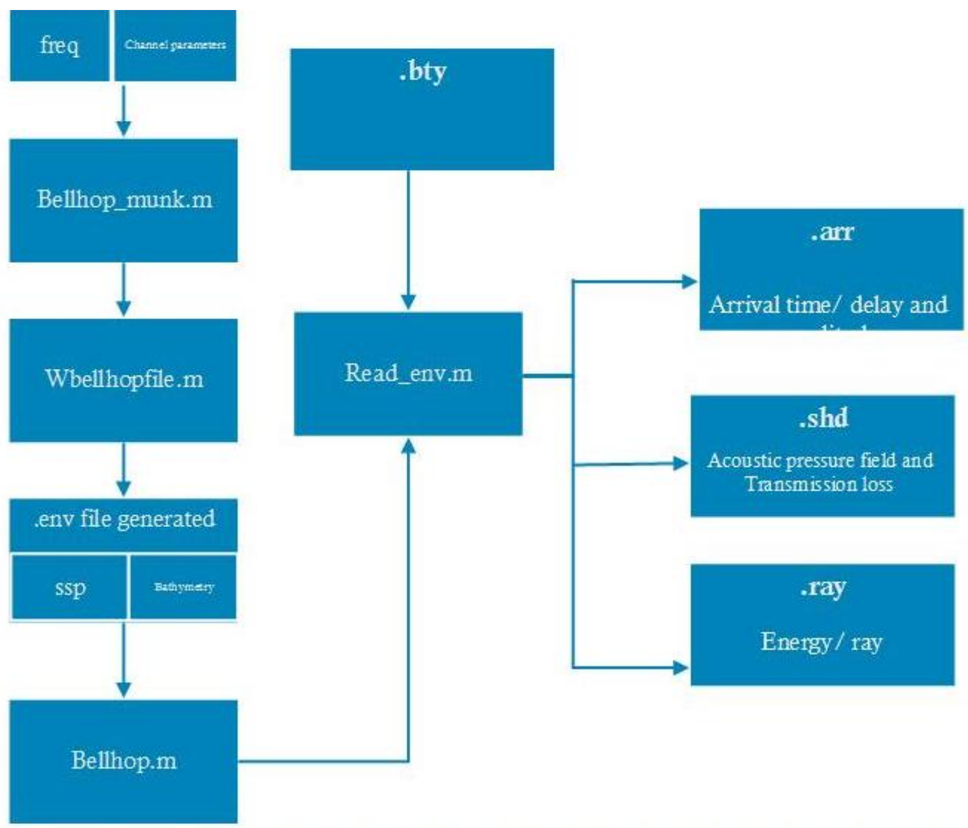


Figure 5: Block diagram of Bellhop Ray tracing tool simulation

3.2 Process of transmitting signal over channel

In software simulation we modeled two channel, where one is underwater channel and the other one is AWGN to relate the simulation results with theoretical performance of digital modulations. For simulation we didn't consider Doppler Effect.

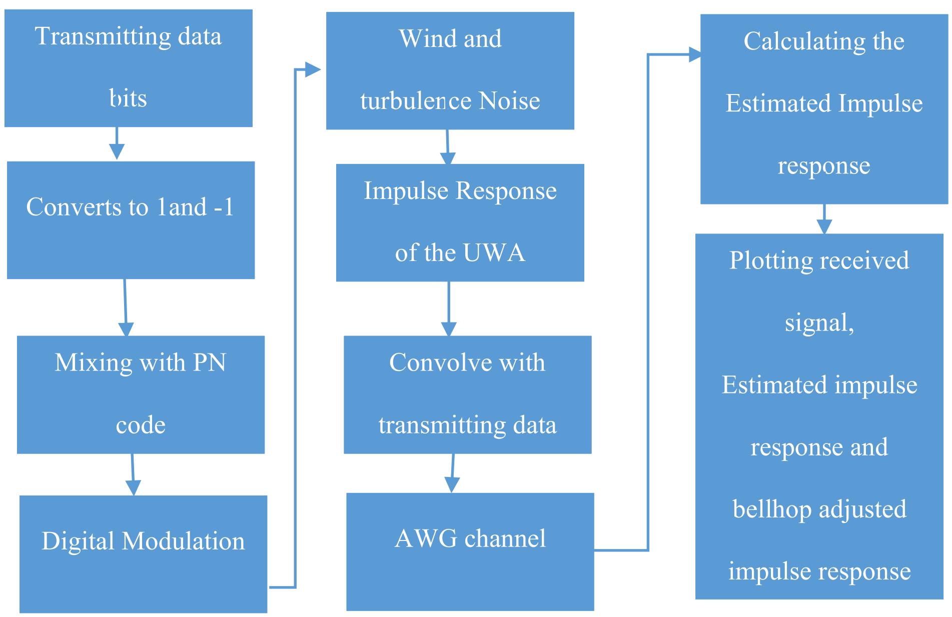


Figure 6: Block diagram of signal simulation over channel impulse response

3.2.1 AWGn Channel

AWGN channel only consider the noisiness of the channel no multipath propagation is taken into account [23].

$$y(t) = x(t) + n_{snr}(t)$$

Where y is the AWGN channel, x is the message signal and n is the noise based on SNR.

3.2.2 Noises based on wind speed

Following are the noise we have used for signal transmission as the frequency we have selected is ranged in 16 kHz;

- Turbulence Noise

$$ANturb_{db} = 17 - 30 * \log 10\left(\frac{f_c}{1000}\right)$$

- Wind driven ambient noise in dB

$$ANwind_{dB} = 50 + 7.5 * sqr(windspeed) + 20 \log 10\left(\frac{f_c}{1000}\right) - 40 * \log 10\left(\frac{f_c}{1000} + 0.4\right)$$

- Thermal noise in dB

$$ANtherm_{dB} = -15 + 20 * \log 10\left(\frac{f_c}{1000}\right)$$

Chapter 4

Underwater Channel

In last decades, underwater wireless communication has received more attention as the rapid growth of underwater applications has shift from navy to commercial area. As the requirement of underwater communication has increased [2][25], that has also increased the need of underwater data security, owing to the underwater environment. Since underwater channel differ from air media, signal digression in water medium caused by multiple factors such as propagation losses, Doppler Effect, multipath propagation, reflection refraction and time delay property of channel [22]. This chapter includes underwater channel condition and its effect over the signal.

In wireless underwater communication transmission range has important role. Selection of transmission range directly effects the energy efficiency and bandwidth utilization [13]. In table 3 we have shown the relation between the transmissions rang and bandwidth require for transmission;

Table 3: Underwater acoustic channels rang vs. bandwidth

Types	Transmission Range (km)	Bandwidth(kHz)
Very short	0.1	<1000
Short	0.1-1	20-60

Medium	1-15	10
Long	15-100	2-6
Very long	1000	<1

For simulation of our project we selected a short-range shallow water acoustic channel. Mathematical modeling of multipath effects is grounded on ray tracing, attenuations due to wave scatterings and reflections.

4.1 Background of UAW channel

4.1.1 Ray Theory

To solve wave equation, ray theory is the alternative theoretical approach for high frequency underwater acoustic propagation modeling. To drive ray tracing it involves integration of differential equations called ray equation, which also describes the ray trajectory [3]. These equations can be drive from the initial conditions of the path to trace the ray propagating path form the source. Through cross section of ray tube we can determine the amplitude of the ray, the drawback of this ray tracing is presence of shadow zones from where no ray can pass through the pressure field of the zone is zero in them.

But in practical situation there is some diffraction of acoustic waves in shadow zone which creates discrepancy in calculated results and exact results. For high frequency propagation modeling ray tracing is useful too, to mathematical drive the ray equation time delay of ray from source to receiver is calculated through deriving the ray, ratio of pressure amplitude on the preferred location to the reference point, and transmission loss. These are the parameters used to construct a ray tracing.

4.1.2 Acoustic Waves

Acoustic waves can more easily propagate through liquid or solid as compared to electromagnetic wave which can travel through air or vacuum. These sound waves are generated through vibration of mechanical machine which creates movement of partials. These movements of partials cause pressure in the medium and results a acoustic wave. The propagation direction of the wave is similar to the direction of vibration.

4.1.3 Acoustic Wave Equation

Acoustic wave equation can be deriving from adiabatic and hydrodynamic relation between density and pressure in an ideal fluid. The Euler's equation, conservation of mass and adiabatic equations are as follow:

$$\frac{\partial \rho}{\partial t} = -\nabla . \rho v,$$

$$\frac{\partial v}{\partial t} + (v.\nabla)v = -\frac{1}{\rho}\nabla p(q),$$

$$p = p_0 + \rho' [\frac{\partial p}{\partial \rho}]_s + \frac{1}{2}(\rho')^2 [\frac{\partial^2 p}{\partial \rho^2}]_s + \cdots$$

For simplification of equation 2 we will write this equation as,

$$c^2 = [\frac{\partial p}{\partial \rho}]_s$$

In equation 3, c is speed of sound of an ideal fluid, p is the density of the equation, v particle velocity and P is the pressure with S thermodynamics partial derivative with constant entropy.

4.1.4 Underwater Acoustic Channel

In wireless communication approach the signal has to face these environmental factors such as temperature, pressure and salinity due to these factors it creates signal spread, high attenuation as per distance increase, time- variant multipath propagation, path loss, slow rate transmission and low bandwidth range. The range of bandwidth in underwater acoustic channel is limited 10 kHz to 20 kHz with a total of 10 kHz of bandwidth. Bandwidth of the channel mainly depends upon both frequency and the range of the channel. Limited bandwidth affects the time varying multipath, which creates spread and Doppler shift [18].

For the better understanding of mathematical modeling of underwater acoustic communication we will review some affecting parameters of underwater acoustic channel, by taking care of those parameters into account that are used in modeling underwater acoustic communication channel.

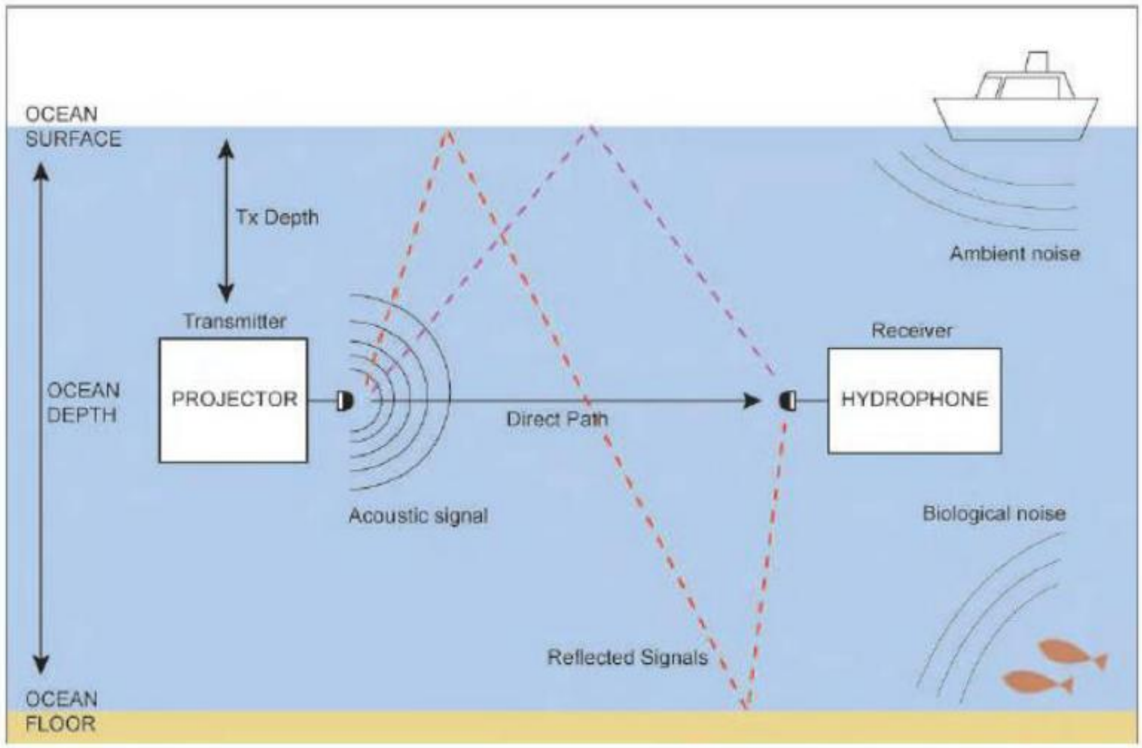


Figure 7: Underwater Acoustic Channel

Associated to electromagnetic waves which travel over vacuum, where some medium is required for acoustic waves to propagate. A mechanical vibration can initiate acoustic wave is, where piratical move due to vibration, this origins pressure variations occurs inside medium that outcomes in the sound wave. The sound wave propagation direction is same as vibration, for example the longitudinal waves are acoustic pressure waves. The studying of vibrations and density changes are connected to movement of spatial position and mass in time.

4.1.5 Acoustic Propagation in Deep Water

In Deep Ocean temperature of sea is almost same, but the pressure of the ocean increases by the increase in depth which directs the speed of sound, while in shallow water the speed of sound is almost constant [3][8]. As per the depth of the ocean the sound wave will hit bottom of the sea which will reflect wave, if the depth is sufficient enough then sound will penetrates toward the depth where sound speed has increased drastically. Then rays will start to bend back towards the shallow depth which slower the sound speed. In Deep Ocean sound speed must be equal to source sound speed for refracted mode of transmission. Near the surface the rays of sound are horizontal and become horizontal again while in the depth of sea a bands upwards. The starting angle of the rays are required to be steeper for deep water with high sound speed to become horizontal then return back to surface.

This process is repeated again, if the sound rays transmitted close to the surface the sound will return towards the surface without touching the bottom. If the temperature of the surface is higher water must be deep for the deep sound speed to equals the surface speed.

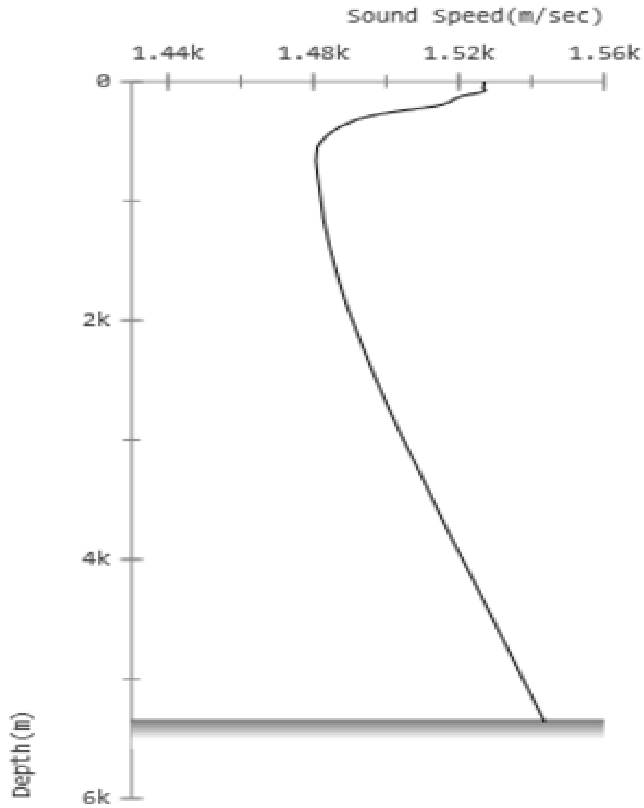


Figure 8: Sound speed in deep water

4.1.6 Acoustic Channel Characteristics

Underwater environments with Noise, speed of sound, multipath, time variability and Doppler Effect, These factors can be determined by environmental conditions, signal to noise ratio and propagation losses. In analysis of the data these environmental conditions has an important impact on performance of the communication. In this research we focused on shallow water acoustic propagation from source to receiver these signals interact with surface and bottom boundaries, which increases the rise of channel conditions, attenuate and scattered the received signal.

4.1.6.1 Sound Speed

To build an accurate channel model and better understanding of underwater sound propagation we need to have a good knowledge of wave propagation. The speed of sound is approximately 1440 to 1550 m/s in underwater propagation and the variations in it are very small, whoever these small variations has a great impact on underwater acoustic propagation. Pressure, temperature and salinity are the factors that affect the underwater sound speed. The most effect of temperature and pressure is in shallow and deep water on sound propagation. Through following equation we can determine the speed of sound with the factors the effects its speed,

$$C = 1449.2 + 4.6T - 0.055T2 + 0.00029T3 + (1.34 - 0.01T)(S - 35) + 0.016z$$

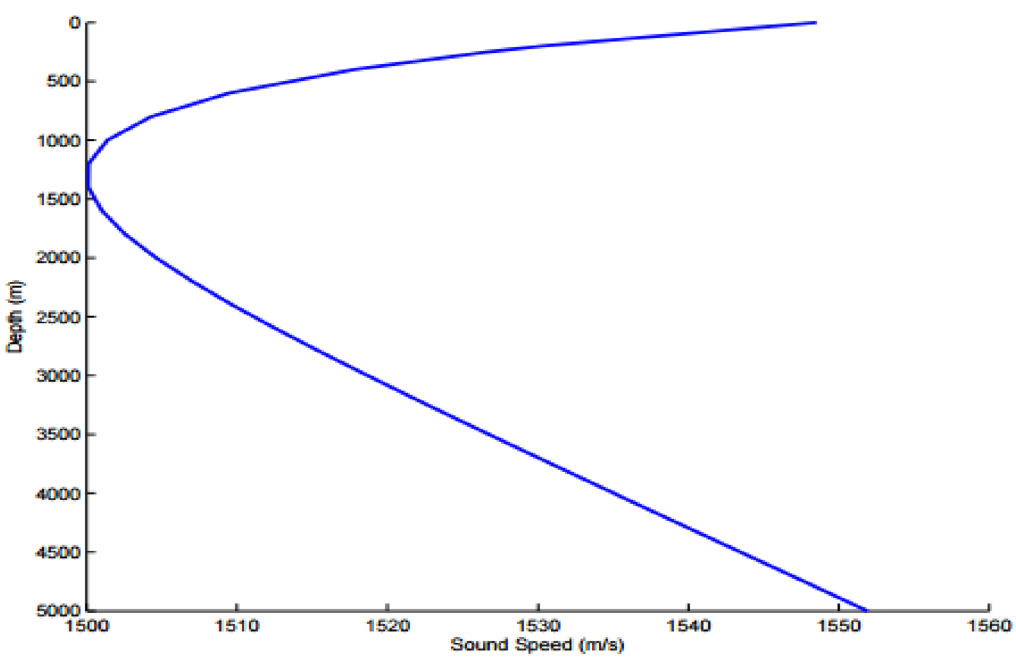


Figure 9: Underwater Speed of Sound

Where C is speed of sound, T is the sea temperature S in salinity and z is the depth of the sea. Salinity's effect on sound is much negligible. But this theory fails under high shore of the sea.

Slow propagation of sound speed highly affects the overall system performance, which creates the delay in system's propagation. This delay can be calculated by the following simple equation,

$$t = \frac{d}{c}$$

Where t is the time delay, d is the distance b/w nodes and c is the speed of sound.

4.1.6.2 Signal path loss and Absorption in sea

Energy of acoustic signal transfer to heat due to the absorption, which affect signal's frequency and leads to path losses cause amplitude degradation of the signal. Spread loss is also a factor experienced by the signal; spread loss is increased as the distance increases. The spread is spherical so the spread loss is proportional to the square of the distance,

$$A(L, \mathrm{f}) = \mathrm{L}^{\mathrm{k}} \,.\, \alpha(\mathrm{f})^{\mathrm{L}}$$

Where L is the distance, f is the frequency of the signal; k is the spread loss and α is the absorption coefficient which can be determined by the following relation,

$$\alpha = 0.11\left(\mathrm{f}^2(1 + \mathrm{f}^2)\right) + 44\left(\frac{\mathrm{f}^2}{(4100 + \mathrm{f}^2)}\right) + 2.75 * 10^{-4}(\mathrm{f}^2 + 0.003)$$

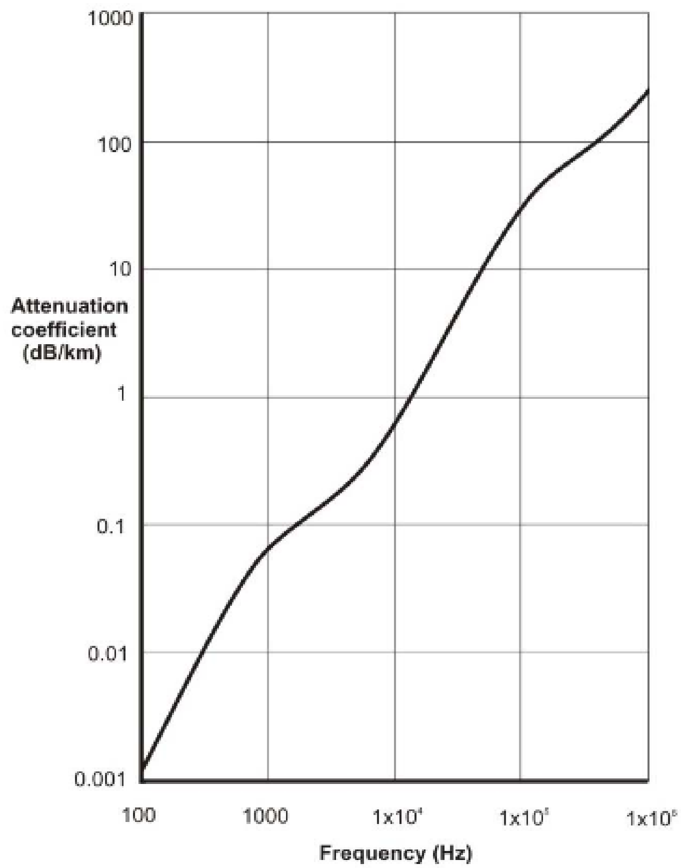


Figure 10: Transmission loss in underwater channel

Acoustic channel path loss depends upon the signal frequency and the channel rage this dependency is due to the absorption as the relation is given above.

4.1.6.3 Noise

During acoustic communication different noises add in original signal such as environmental noise, disturbance noise and system noise etc. Signal to noise ratio (SNR) is directly affected by the environmental noise [17] [14].

Environmental noise divided into two categories ocean ambient noise and site specific noise. Ambient noise is changeable and complex noise it depends upon the weather and area of sea and also on the frequency of the signal. Ambient noise always presented as Gaussian noise, but it isn't a white noise. Signal to noise ration can be expressed by the following expression,

$$SNR\ (l, \mathrm{f}) = \frac{\mathrm{Sl(f)}}{\mathrm{A(l,f)N(f)}}$$

Where Sl(f) is power spectral density, which can be adjust according to the distance. For a particular distance SNR is a function of frequency. The bandwidth and the power needed to achieve a pre-specified SNR over some distance can be approximated as

$$B(l) = b.l - \beta,$$

$$P(l) = p.l\,\Psi$$

Where $\beta \epsilon (0, 1)$, and $\Psi \geq 1$.

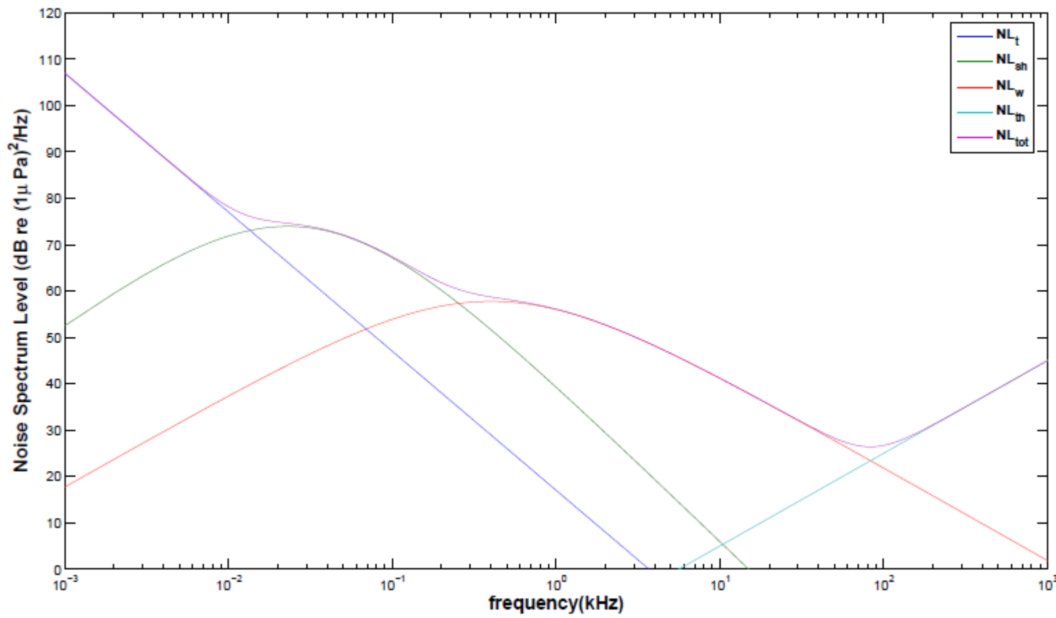


Figure 11: Underwater acoustic Noise at different frequencies

4.1.6.4 Time Variability

During the acoustic communication there are two factor that affect variability of the time, change in propagation medium due to the inherent changing property caused by the change in temperature, and other is surface scattering as it contributes a lot in time variability which is caused by the surface wave, more stable the surface wave less will be the reflection point displacement.

4.1.6.5 Transmission Loss

Transmission loss is decrease in the intensity of sound cause due to the propagation of sound wave form sender to receiver. Transmission loss (TL) [10] is normally is represented through the ratio of intensity of the sound at the reference range of about one meter distance from center of acoustic wave source which is represented as I0, the intensity of the sound at receiver end is I1, now the equation of the transmission loss can be represented as,

$$TL = 10\ Log\ \left(\frac{I0}{I1}\right) dB$$

We can classify the spread loss, absorption loss and multiple paths as major reason that added to total transmission loss.

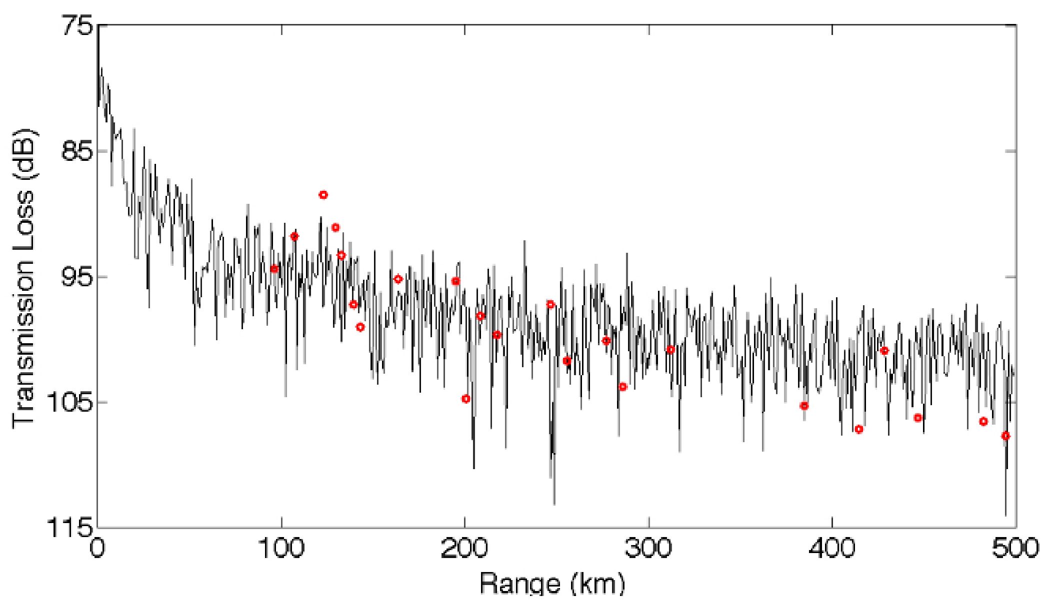


Figure 12: Underwater Transmission loss

4.1.6.6 Doppler Effect

In acoustic channel Doppler Effect is caused by the surface waves, motion of platform, the environmental condition and movement of transmitter and receiver [14] [17]. During the modeling of the acoustic channel we consider all these factors for better communication. Doppler Effect can be estimated through frequency average and demodulation techniques. During acoustic communication any object between the transmissions can cause Doppler Effect as it will scatter the signal. If Doppler factor changes randomly then the Doppler spread will be random.

4.1.6.7 Multipath

Time spread occurs when numerous amount of transmitting signal receive at receiver end, which is also known as multipath propagation. Multipath channels due to the reflection from surface of the sea and the reflection caused by different objects, Intentional or unintentional motion of transmitter and receiver also one of the factor of multipath. Multipath creates difficulties in the transmission of communication [10].

In ocean two factors that govern the multipath formation: reflection of sound at the surface and bottom also by any objects, and refraction of sound in water. Temperature, salinity and pressure are the factors that effects the speed of sound depends on the temperature, pressure, and salinity, which vary with depth and location; and a ray of sound always bends toward the region of lower propagation speed, obeying Snell's law. At the surface temperature and pressure are normally constant, as is the speed of sound.

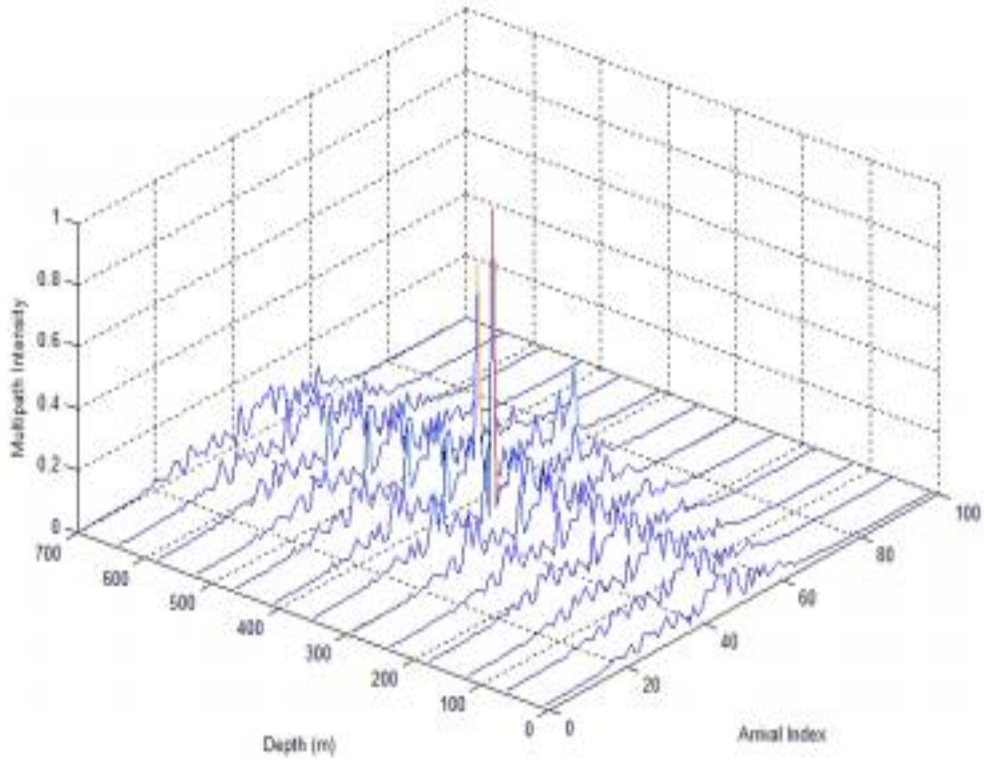


Figure 13: Multipath propagation of sound wave in underwater

In moderate environment temperature reduce as depth increase, where pressure variation doesn't effect on sound speed. After some increase in depth, temperature become constant at 4°C, sound speed increases pressure. When beam of rays launches source, every ray will track a marginally different path, and receiver placed at certain distance to detect multiple signals.

Chapter 5

Modulation for underwater communication

With various restrictions over security of wireless underwater communication it is the promising stage for researchers since the requirement of secure technology is very quickly growing. To address issue of underwater communication security we first understand the underwater channel characteristics, which have discussed in detail in chapter 4, since normal communication protocol can't be implemented over underwater channel. Underwater communication channel is a complex channel in terms of transmission multipath propagation, Doppler effect, low bandwidth, delay and high transmission losses are some of the factors that effects the transmitting signal. Therefore, a layered security technique is required to limit the effect of underwater environment. Normal network methods like message digestion or chipper will increase the message size, to address the issue data modulation such as ASK, PSK or FSK is required.

For transmission of data efficiently in underwater environment numbers of modulation techniques has been proposed. Particularly, for multipath propagation and diversity of time delay Direct Sequence Spread-Spectrum (DSSS) is implemented, DSSS is also capable of tackling the issue of unwanted intrusion.

5.1 Quadrature Amplitude Shift Keying

QAM based on the digital signal. For 16QAM, each four bits of input data amplitude and phase of carrier driven to sixteen modulation states [29][30], it offers substantial benefits above the data transmission. As for 16QAM to 64QAM, 64QAM to 256 QAM transition and so on, using QAM higher data rate can be attained at the cost of noise. Higher the order more noise will affect the data.

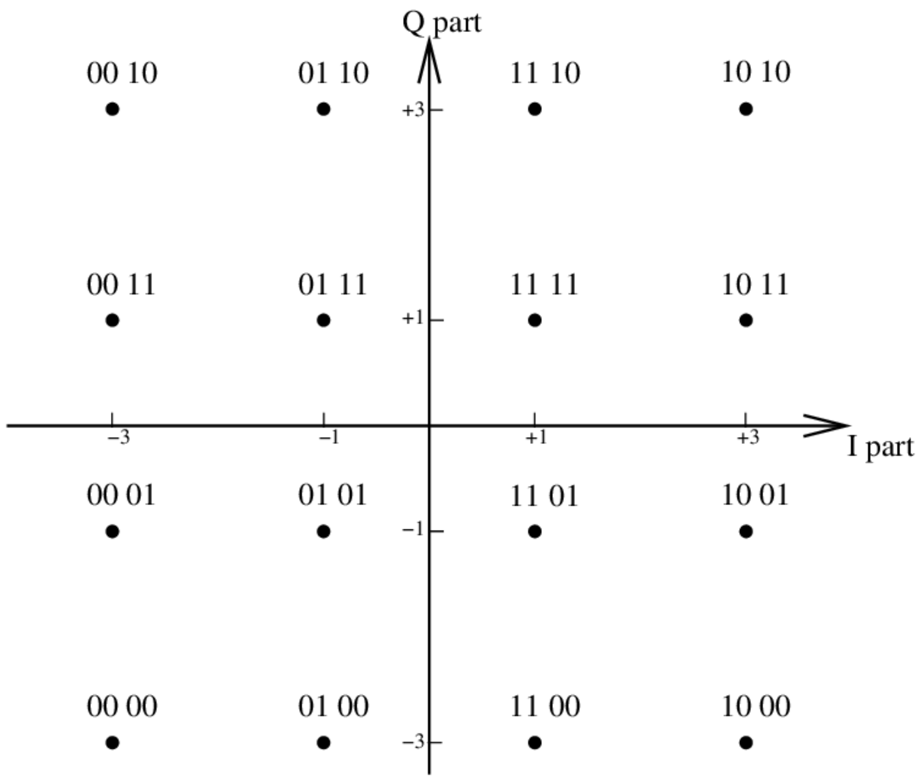


Figure 14: Bits distribution for 16QAM

Above diagram is represents the data bits arrangement for carrier signal, that is described below,

symbols $\begin{Bmatrix} \pm1+\pm1j, & \pm1+\pm3j, \\ \pm3+\pm3j, & \pm3+\pm1j \end{Bmatrix}$,

$$C(t) = A_c.\cos(2\pi.f_c.t + \pi/2) + A_c.\sin(2\pi.f_c.t + \pi/2)$$

The QAM wave is modulating signal m(t) multiplied by carrier wave C(t), and is expressed as a formula as follows [31].

$$S_{ask}(t) = m(t).C(t)$$

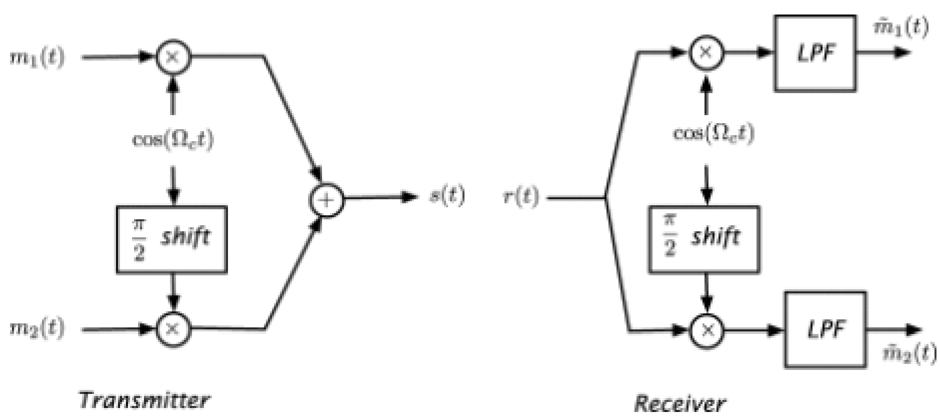


Figure 15: QAM description of transmitter and receiver

For demodulation, signal is multiplied by the carrier signal and shift by $\pi/2$, as shown in figure 15.

$$Y(t) = r(t).C(t + \pi/2)$$

$$\therefore C(t) = A_c.\cos(2\pi.f_c.t)$$

The probability of error for 16QAM is,

$$P_E = \frac{3}{2} erfc \sqrt{\frac{E}{10\eta}}$$

Where E is bit energy. This expression is relevant for coherent detection, for non-coherent detection simple envelope recognition can be used in receiving end. The synchronous detection gives approximately 1dB improvement per envelope detection. Maximum theoretical bandwidth efficiency of ASK is 1bps/Hz.

5.2 Binary Phase Shift Keying

Binary Phase shift keying is type of modulation where the Phase of the carrier signal varies according to the message signal. For example if the input signal bit is shifting from high to low or the signal state is changing the modulated signal will change 180 degree accordingly.

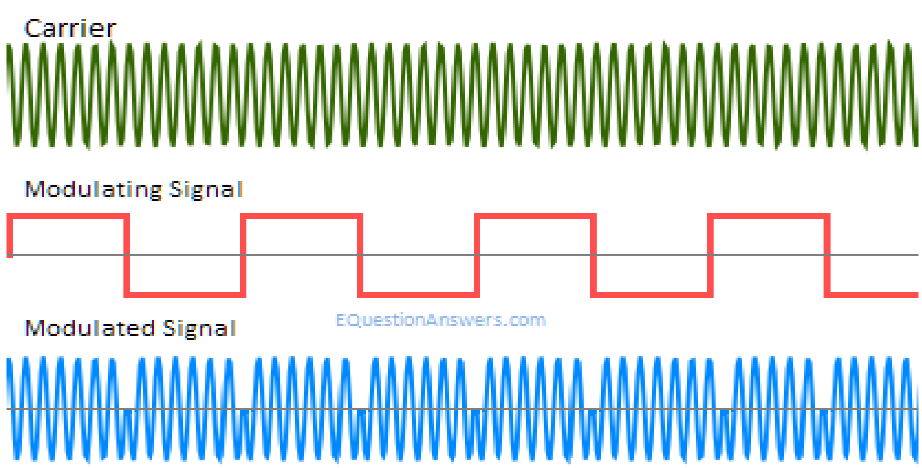


Figure 16: BPSK modulation

$$m(t) = A_m \cos(2\pi . f . t)$$

Where m(t) is the message signal, A_m is the amplitude and f is the frequency.

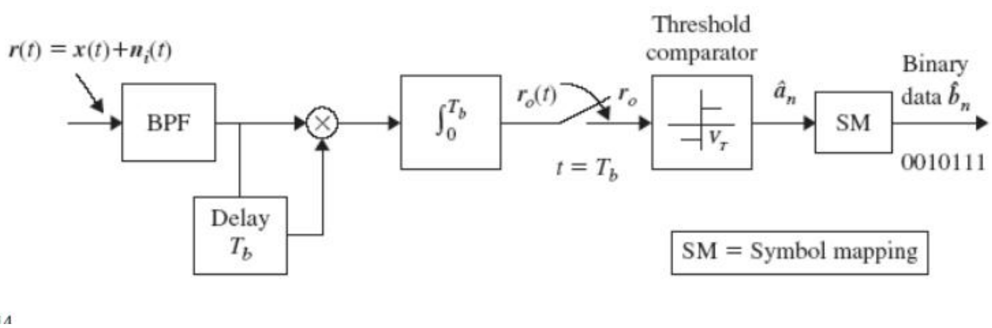
$$C(t) = A_c \cos(2\pi . f_c . t + (xA_m))$$

Where C(t) is the carrier signal, A_c the carrier amplitude and f_c is the carrier frequency xA_m is the following degree corresponding to the message signal.

$$P(t) = A_c \cos(2\pi . f_c . t) \quad \ldots\ldots for\ bit\ 1$$

$$P(t) = A_c \cos(2\pi . f_c . t + \pi) = - A_c \cos(2\pi . f_c . t) \quad \ldots\ldots for\ bit\ 0$$

For demodulation



The probability of error in BPSK is

$$P_E = \frac{1}{2} erfc \sqrt{\frac{E}{\eta}}$$

Where E is the energy per bit, which shows low transmission power.

5.3 Quadrat Phase Shift Keying

QPSK modulation is based on binary signal, which produce four combinations of different input: 00, 01, 10, and 11. Hence, in QPSK modulation input data is joined into clusters of two bits. The modulator generates the four possible output phases (+45°, +135°, -45°, and -135°) for input bits.

Carrier signal for QPSK modulation,

$$A_c \sum_{n=-\infty}^{\infty} \boldsymbol{a}_n^I v(t-nT)\cos(2\pi f_c t) = A_c \boldsymbol{I}(t)\cos(2\pi f_c t)$$

Modulated signal using QPSK,

$$\begin{aligned}\boldsymbol{x}(t) &= A_c\left[\boldsymbol{I}(t)\cos(2\pi f_c t) - \boldsymbol{Q}(t)\sin(2\pi f_c t)\right] \\ &= A_c \sum_{n=-\infty}^{\infty}\left[\boldsymbol{a}_n^I v(t-nT)\cos(2\pi f_c t) - \boldsymbol{a}_n^Q w(t-nT)\sin(2\pi f_c t)\right]\end{aligned}$$

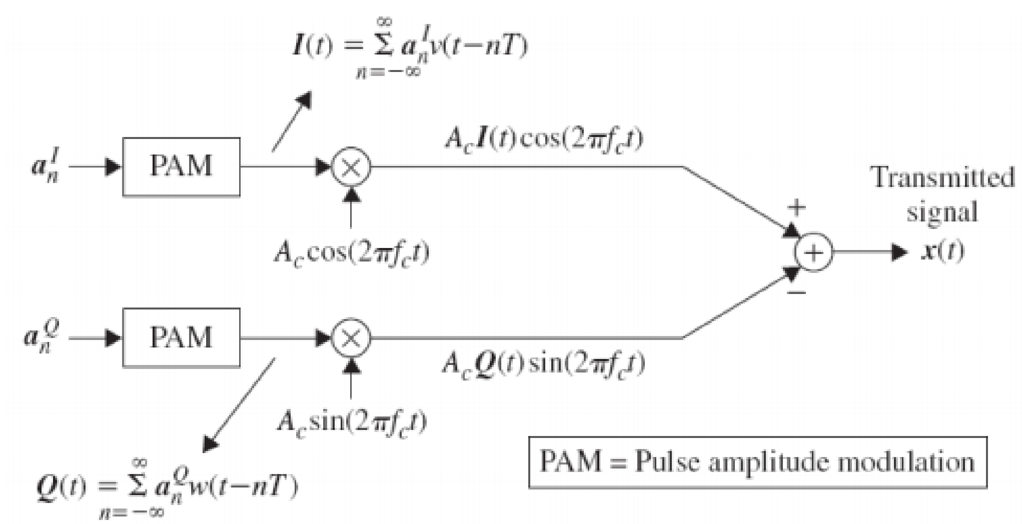


Figure 17: QSP modulation description

In phase QPSK modulated data can be recovered by, multiplying received signal x(t) with 2cos(2π fc t) and 2sin(2π fc t) and then Low Pass filtering .

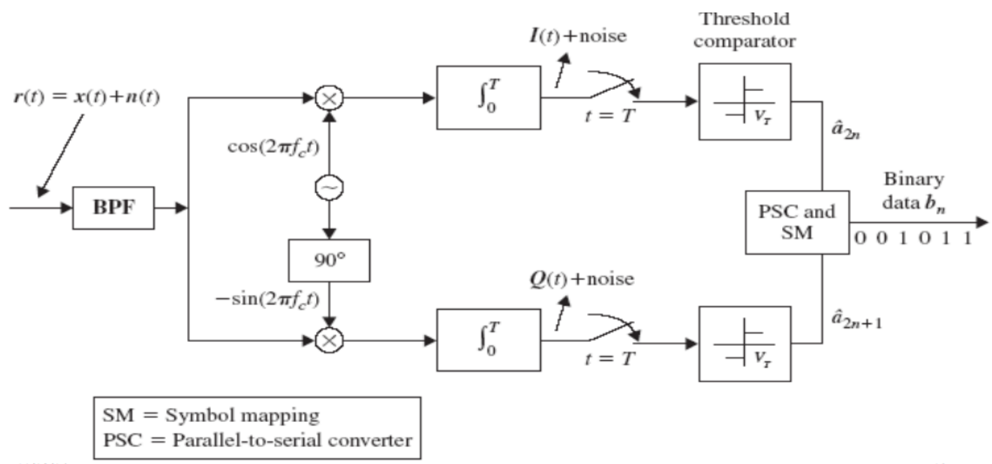


Figure 18: Demodulation of QPSK signal

The probability of error in QPSK is

$$P_E = erfc\sqrt{\frac{2E}{2\eta}}$$

5.4 Discrete Sequence Spread Spectrum

DSSS modulation technique is commonly used for digital signal transmission to develop a difficult to detect wideband signal so it can resist jamming attacks [2][6]. The information signal is divided into small pieces, where each piece is integrated with a frequency channel over the spectrum [8]. Signals at transmission point are homogenized with a higher data rate bit sequence called pseudo noise (PN), which divides data based on a spreading ratio.

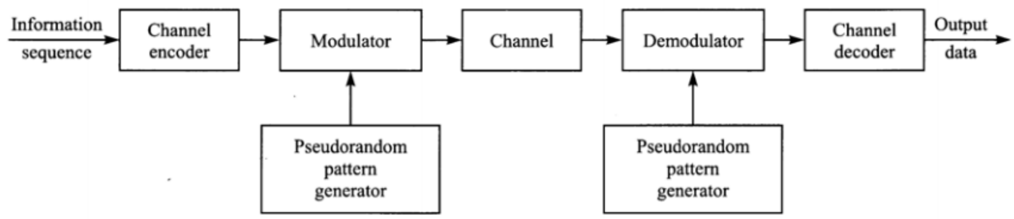


Figure 19: Block diagram of DSSS Modulation

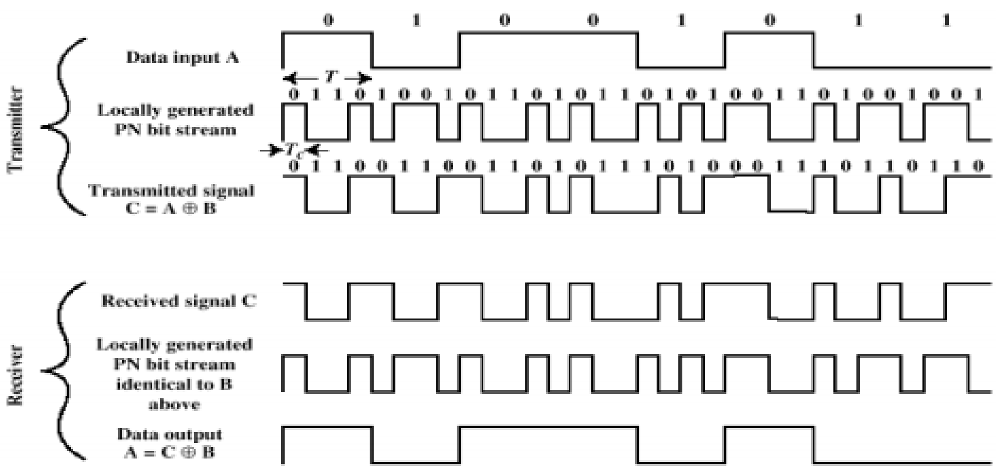


Figure 20: Signal diagram of DSSS modulation

Chapter 6

Bellhop Tool

In our research we have used BELLHOP beam tracing model for underwater acoustic channel modeling, as BELLHOP is a Gaussian beam tracing tool used for modeling transmission losses of an underwater channel [27]. BELLHOP model was developed in 1987 by Porter and Bucker, the model is able to produce ray tracing, source to receiver eigenrays, and impulse response of channel and transmission losses plots.

Bellhop ray tracing model is being developed as source of a vibrant simulation. This code allows us to calculation propagation for water surface range dependent and bottom profiles. This range dependent water surface allows consecutive static surface profile to be replicated. In 'geometric' form Bellhop models the ray propagation of ray-'tubes' which traces the path of points normal to propagating wave. Ray-tubes which group the receiver point signify sound transmission path, and are used to calculate the source level at receiver. Amplitude at receiver end is calculated by the divergence of the ray tube borders. Net phase change from border connections are pathway for each ray path as is the amount of surface and bottom reflections, and total time for source to receiver, also referred to the path delay.

The AcTUPℓ (Acoustic Toolbox User-interface & Post-processor) program, created by Maggi and Duncan of Curtin University of Technology in Perth, Australia [26] [28], provides the front-end support for the version of Bellhop3D is used in this analysis.

6.1 Introduction of Bellhop

In our research we have used BELLHOP beam tracing model for underwater acoustic channel modeling, as BELLHOP is a Gaussian beam tracing tool used for modeling transmission losses of an underwater channel [27]. BELLHOP model was developed in 1987 by Porter and Bucker, the model is able to produce ray tracing, source to receiver eigenrays, and impulse response of channel and transmission losses plots.

Bellhop ray tracing model is being developed as source of a vibrant simulation. This code allows us to calculation propagation for water surface range dependent and bottom profiles. This range dependent water surface allows consecutive static surface profile to be replicated. In 'geometric' form Bellhop models the ray propagation of ray-'tubes' which traces the path of points normal to propagating wave. Ray-tubes which group the receiver point signify sound transmission path, and are used to calculate the source level at receiver. Amplitude at receiver end is calculated by the divergence of the ray tube borders. Net phase change from border connections are pathway for each ray path as is the amount of surface and bottom reflections, and total time for source to receiver, also referred to the path delay.

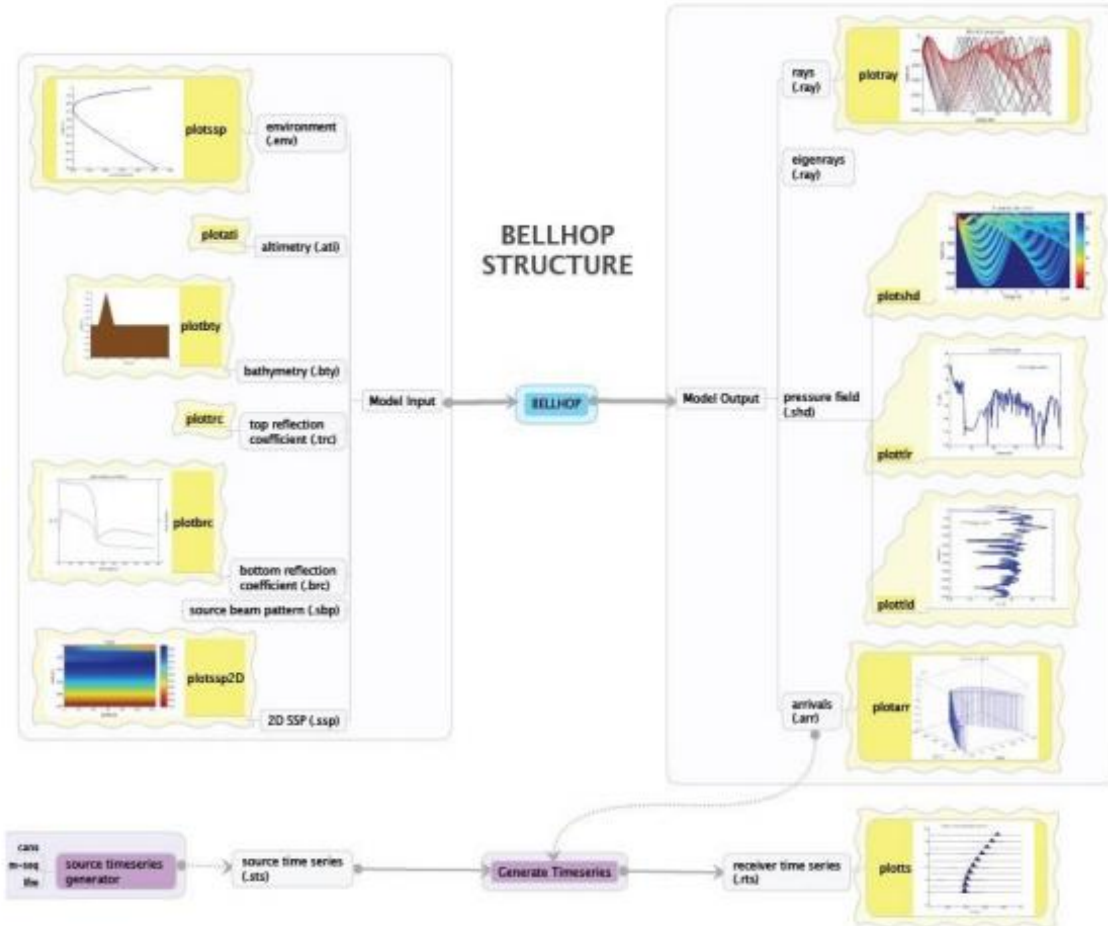


Figure 21: Bellhop input and output file structure

6.1.1 Bellhop Ray Equation

Ray equations solution required for the Bellhop ray tracing for determination of coordinates of acoustic wave. For the solution of dynamic ray equation acoustic pressure and amplitude is required which is well descried in [13]. Bellhop tool is incorporated with the data update from world database that measures the sound speed profile. The ray's trajectories are also calculated through ocean wave motion, using the selected environmental parameter and the sound speed profile it generate a propagating model that is close to the experimental acoustic propagation in underwater environments. For cylindrical symmetric system the ray equation can be as follow:

$$\frac{dr}{ds} = c\xi(s),$$

$$\frac{d\xi}{ds} = -\left(\frac{1}{c^2}\right)\left(\frac{dc}{dr}\right)$$

$$\frac{dz}{ds} = c\xi(s), \frac{d\xi}{ds} = -\left(\frac{1}{c^2}\right)\left(\frac{\partial c}{\partial z}\right)$$

Where r(s) and z(s) represents the cylindrical coordinates of ray and arc length of the ray is s; pair c(s) *[ξ(s), ζ(s)]* shows the normal verso along ray. Initial conditions for *r(s)*, *z(s)*, *ξ(s)* and *ζ(s)* are,

r(0)= rs , z(0)= zs , ξ(0)= cos θs / cs , ξ(0)= sin θs /cs

Where ϑs represent launching angle, (rs, zs) is source position, and cs is sound speed at source position. The coordinates are sufficient to obtain ray traveled time:

$$\tau = r \int \frac{d(s)}{c(s)}$$

It is calculated along curve.

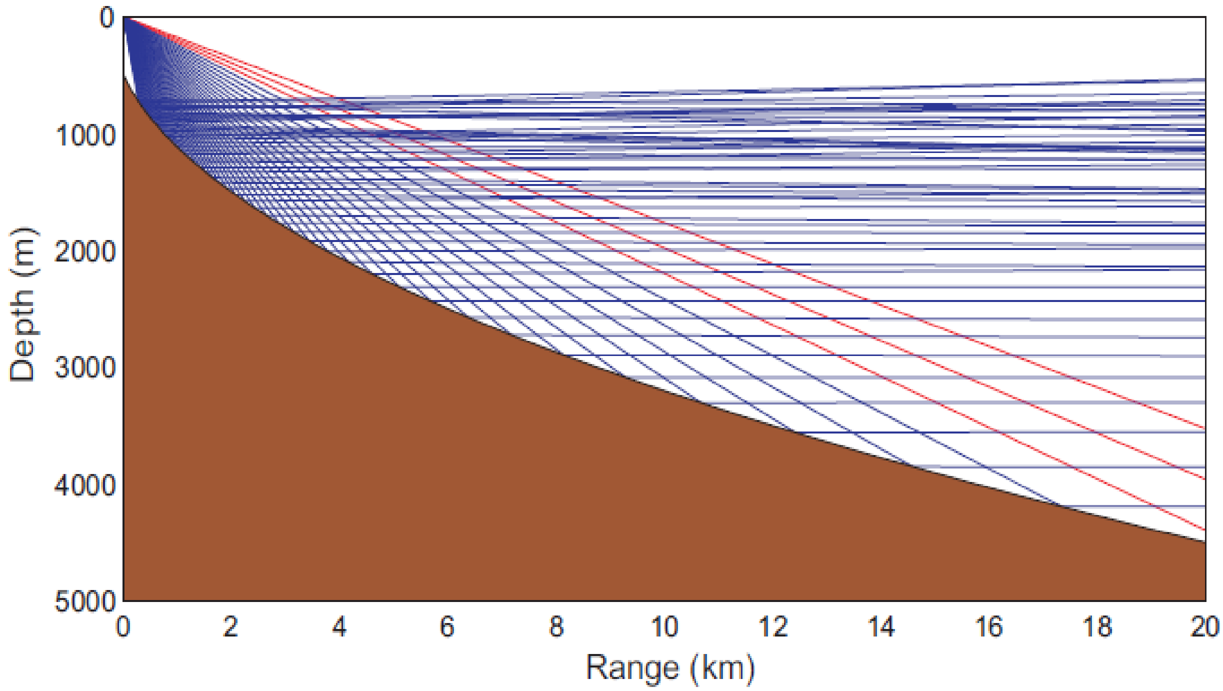


Figure 22: Bellhop ray tracing

6.1.2 BELLHOP Input

To generate Bellhop ray tracing it requires a variety of files to define the environment and the geometry of source and receiver. Which is referred as an environmental file, also include the sound profile and the ocean information about the bottom. Bottom can be rang dependent or independent, for range dependent bottom one has to add bathymetry file and for the range independent one has to add SSP file with sound speed. Normally acoustic source is considered as an omni directional to specify the source beam pattern one has to add source beam pattern file with amplitude angle. These files are read by the BELLHOP depending on selected options it traces the rays and display each input files.

```
'Munk profile' ! Title
41225.0        ! Source frequency
1              ! Num of media
'CVW'          ! Type of media
51  0.0   5000
   0.0 1523.4 /
 200.0 1513.2 /
 400.0 1506.6 /
 600.0 1502.6 /
 800.0 1500.6 /
1000.0 1500.0 /
1200.0 1500.5 /
1400.0 1501.7 /
1600.0 1503.5 /
1800.0 1505.8 /
2000.0 1508.3 /
2200.0 1511.1 /
2400.0 1514.0 /
2600.0 1517.1 /
2800.0 1520.3 /
3000.0 1523.5 /
3200.0 1526.7 /
3400.0 1530.0 /
3600.0 1533.4 /
3800.0 1536.7 /
4000.0 1540.1 /
4200.0 1543.5 /
4400.0 1546.8 /
4600.0 1550.2 /
4800.0 1553.6 /
5000.0 1557.0 /
'A*' 0.0
5000.000000 1600.000000 0.000000 1.800000 0.800000 / ! Bottom properties
1                ! Number of Source
100.00   0.00 / ! Source depths
201              ! Number of Receiver depths
   0.0 5000.0  /! Receiver depths
501              ! Number of Receiver ranges
   0.0  100.0  /! Receiver ranges
'C'
1400             ! Number of rays
 -40.0   40.0 / !Source angle
0.0 5000.0 1000.0 ! Box
```

Figure 23: Input for Bellhop .env file

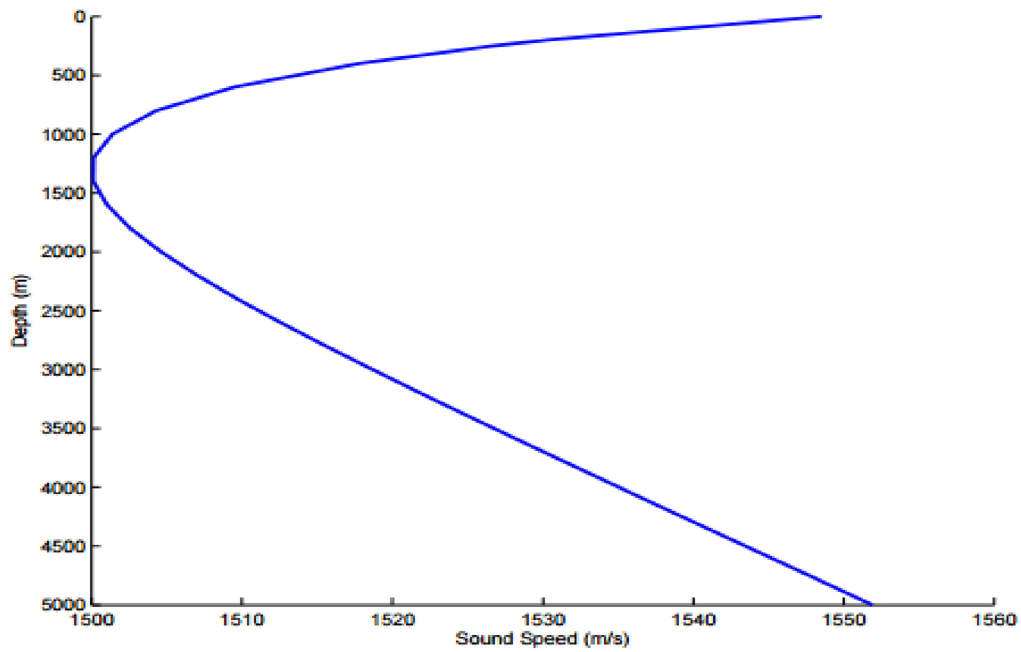


Figure 24: SSP profile for Bellhop

6.1.3 BELLHOP Output

Bases on the files and option selected in the environmental file BELLHOP generate different outputs.

6.1.3.1 Ray tracing

Ray tracing option produces an output containing number of rays originating from source. Ray tracing are used to know how the energy propagates in channel. To display the ray energy propagation plotray file is used.

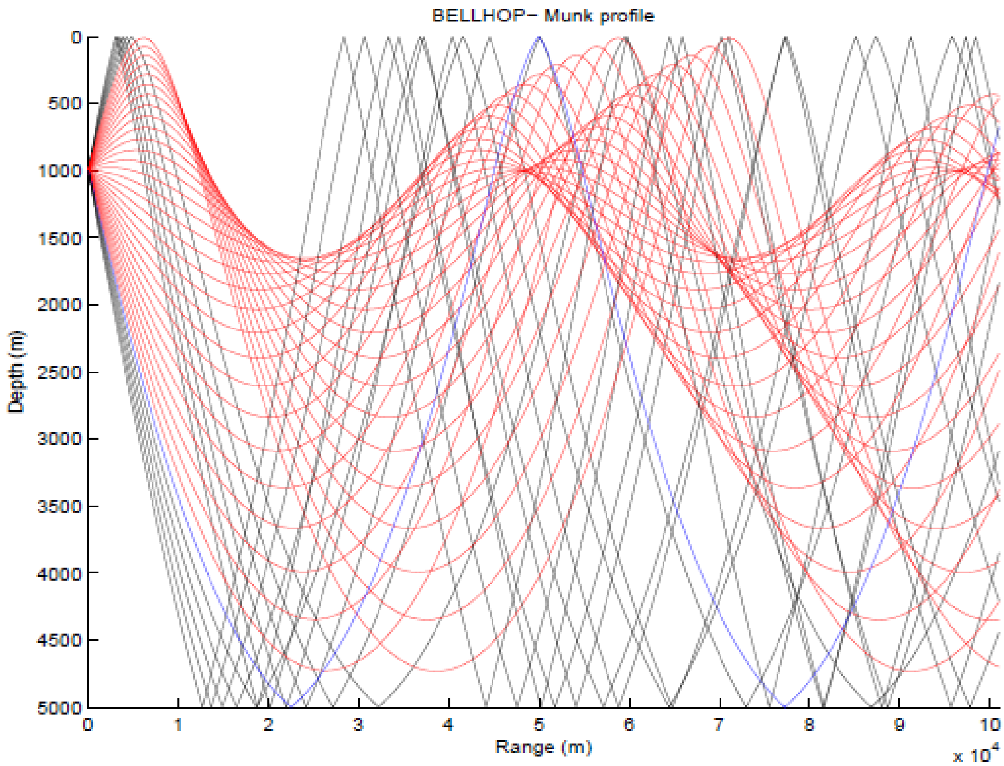


Figure 25: Eigenrays for Munk sound speed profile

6.1.3.2 Acoustic pressure field

To calculate the transmission loss for source, shade file is used which displays 2D surface using plotshd file. The number of beams, NBeams, should normally be set to 0, allowing BELLHOP to automatically select the appropriate value. The number needed increases with frequency and the maximum range to a receiver. To understand this one may imagine a point source in free space. The beam fan expands as we go away from the source.

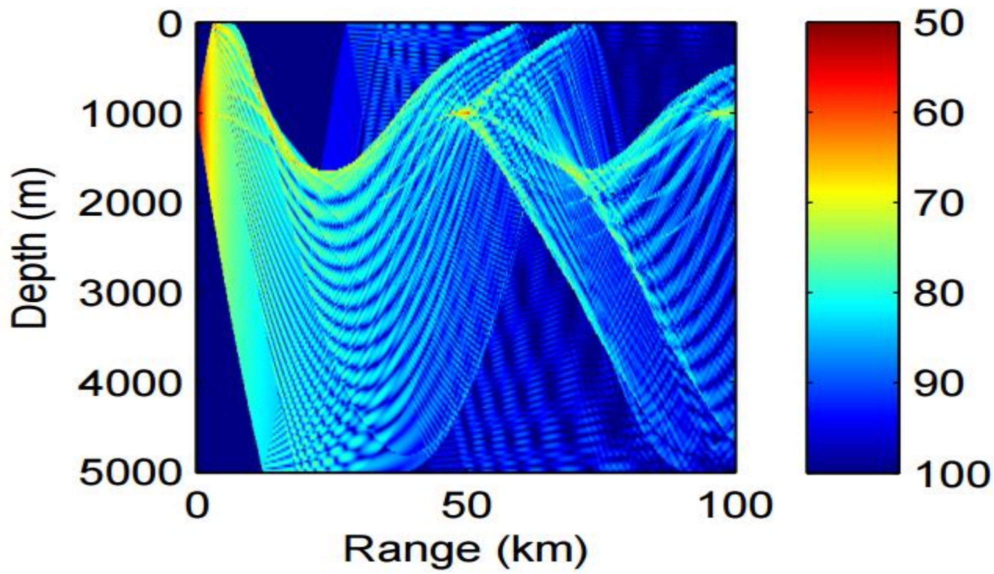


Figure 26: Transmission loss for the Munk sound speed using Gaussian beam

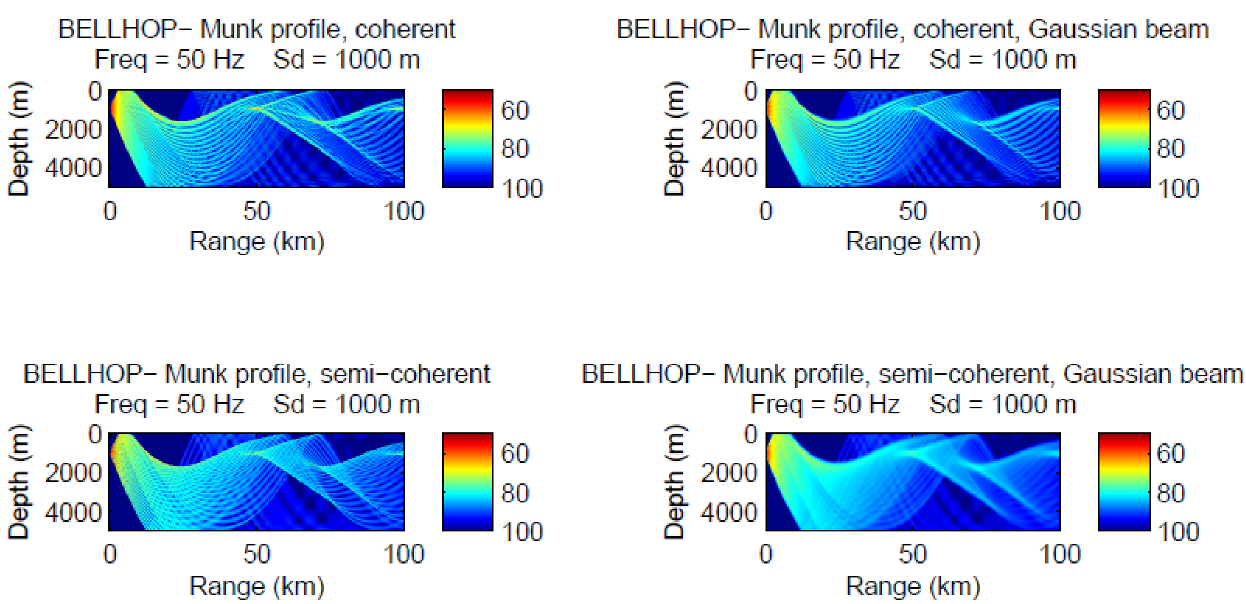


Figure 27: Transmission loss for Munk sound speed profile

6.1.3.3 Arrival time series

To generate intensity of total source with entire time series arrival calculation is selected which produce arrival file with amplitude delay pairs what defines the loudness and delays for each echo of the channel, which can be plotted by using plotarr. Then again it can be passed through the convolver to sum up all the echoes for particular source or receiver time series

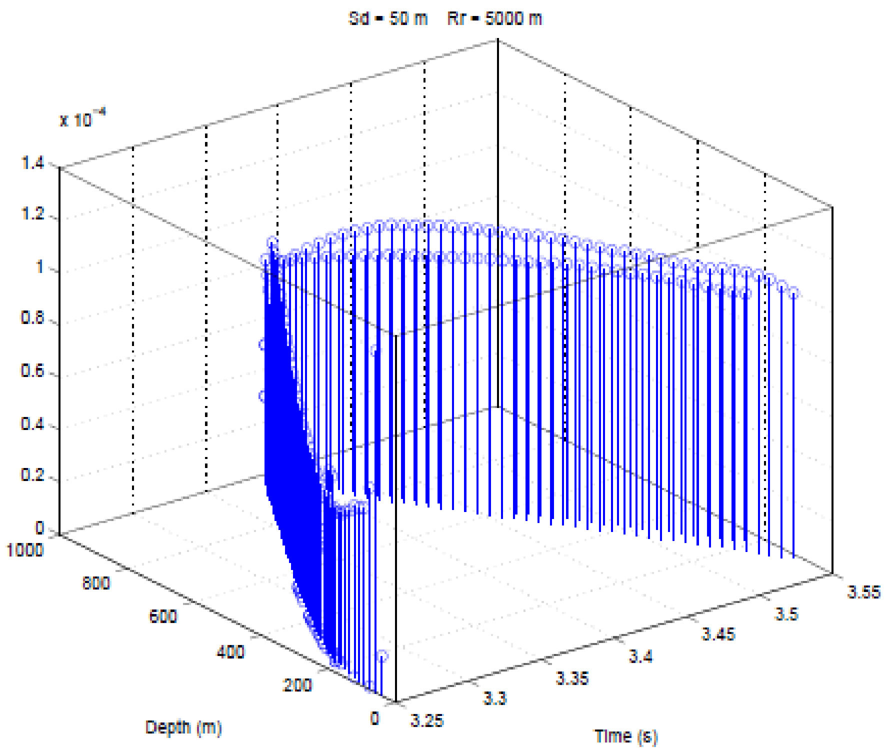


Figure 28: Impulse response as a function of depth

Chapter 7

Simulation and Results

This section presents the results acquired with the simulation of underwater communication channel discussed in Chapters 4 along with ambient noise. BER obtained using different modeling techniques are compared.

Since underwater acoustic channel is too complex, all simulations are done using MATLAB and BELLHOP tool. BELLHOP calculates received delays and acoustic pressures. MATLAB acquires the values from output files by BELLHOP.

Simulation is divided into two major parts one is underwater acoustic channel simulation using Bellhop tool and second estimating the effect of selected underwater channel over the modulated data.

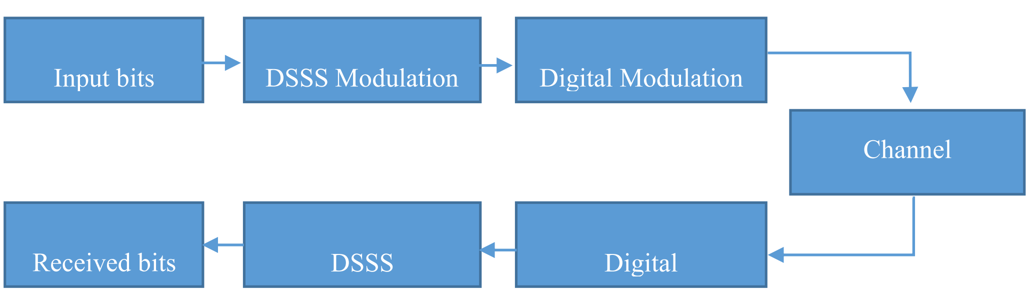


Figure 29: Project flow diagram

7.1 Signal analysis using Bellhop tool

Bellhop is high efficient tool to depict the underwater environment; it used the speed profile c(z) to race the acoustic rays [6][20][21]. Output options contain transmission loss, ray coordinates, channel impulse response using time series, eigenrays, and acoustic pressure using the input environmental file (.env). Table 1shows the channel parameters used to develop environmental file for Bellhop tool [15].

To select transmission frequency for underwater communication geographical location plays a vital role as well as the transmission rage. For selecting any underwater channel parameters is considered very carefully for efficient communication.

Table 4: Underwater channel Parameter using Bellhop

Parameter	Value
Frequency	15kHz
Source angel	70
Num of sources	1
Num of rays	1400
Type of medium	"CVW"
Run type	"A*"
Beam type	"C"
Source depth	10m
Num of receivers ranges	201
Receiver range	2.5Km
Num of receiver depths	501
Receiver depths	90m

In this section we have described the effect of underwater acoustic channel over the analog modulated data [11][13]. As the efficient bandwidth for communication in underwater environment are from 30Hz to 30 kHz above that range frequency experiences severe transmission losses. In this simulation we have used 15 kHz frequency for signal transmission. Figure 10, 11 and 12 are the simulating results of Bellhop ray tracing tool for the given frequency and environmental parameters that we have shown in Table.

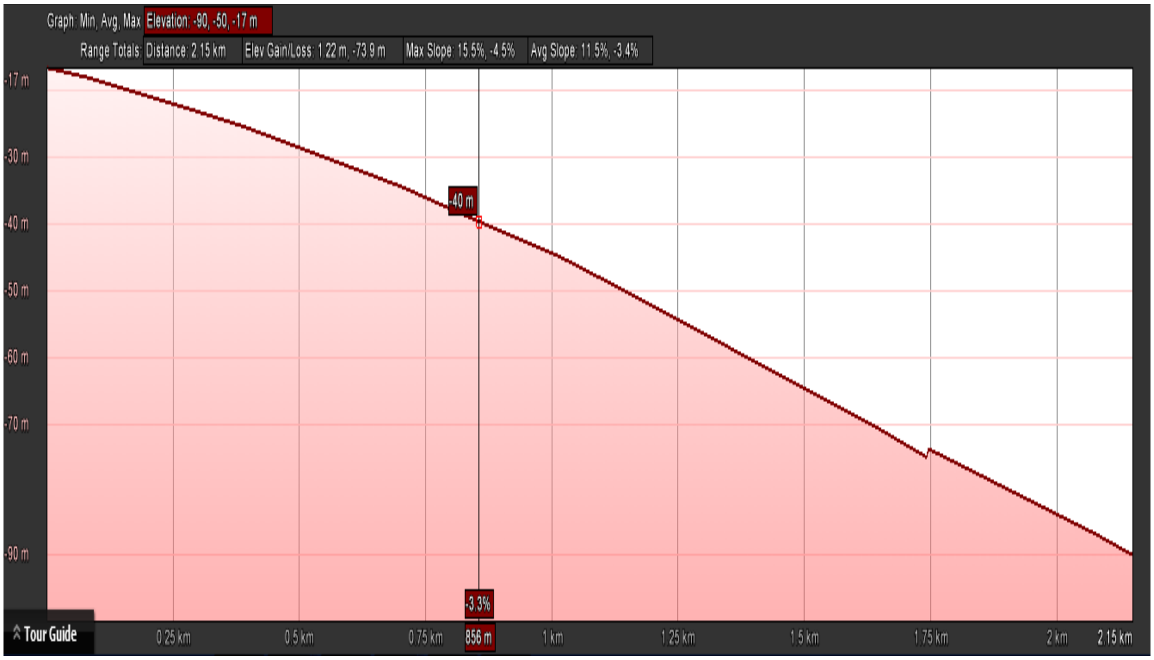


Figure 30: Channel 1 near Gawadar Port

The coordinates data of selected channel near GAWADAR region is 25°03'17.58"N 62°25'28.87"E to 25° 02' 44.62"N 62°25'45.01"E. Figure 19 representing the bottom surface of the selected region which has depth deviation of 73.9m and transmission range of 2.5km.

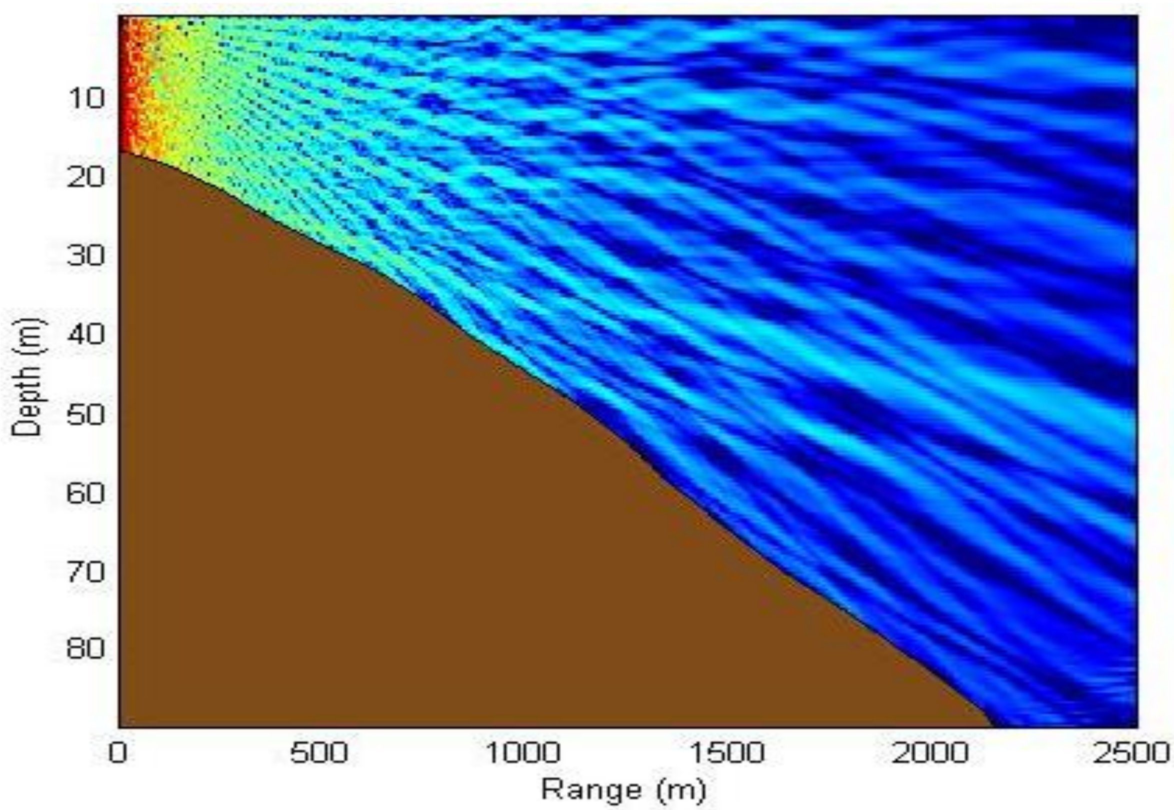


Figure 31: Acoustic pressure profile of channel in 2D

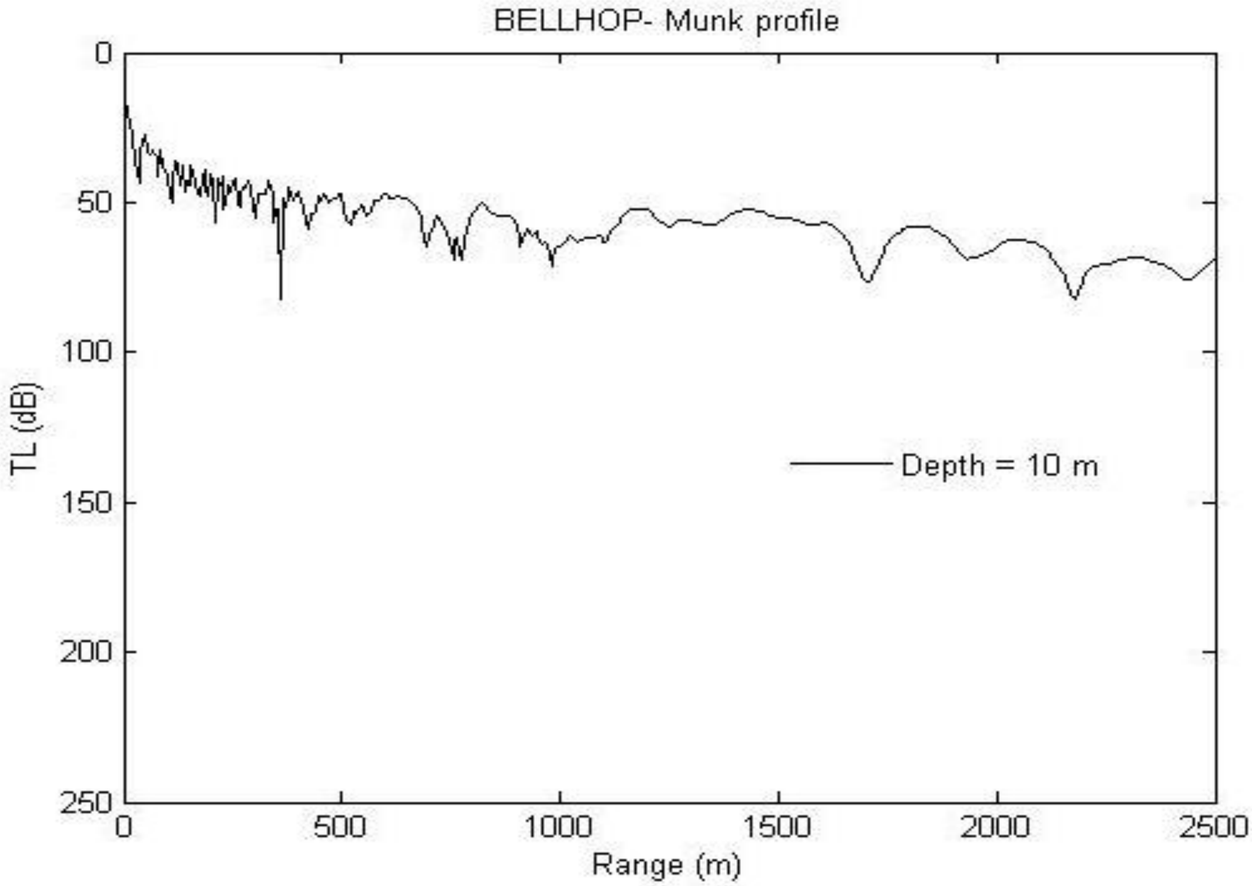


Figure 32: Range Tranismission losses

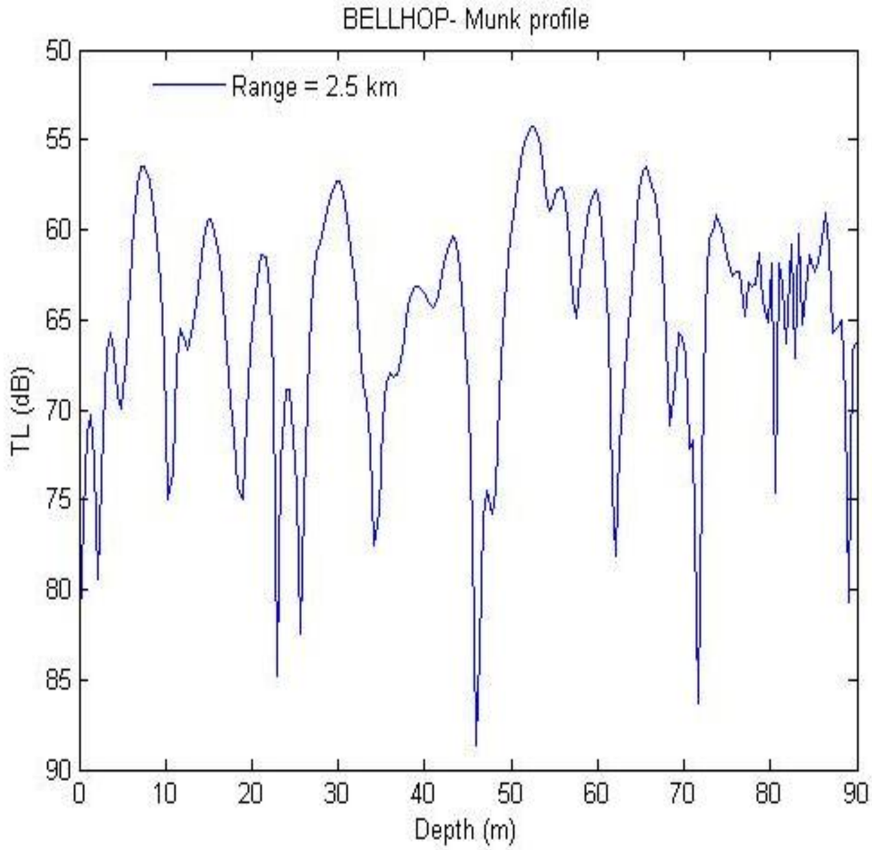


Figure 33: Depth transmission losses

Table 5: SNR for Rang and depth of selected underwater channel

Type	SNR
Range of channel	23db to 65db
Depth of channel	55db to 85db

7.2 Transmission Data Generation:

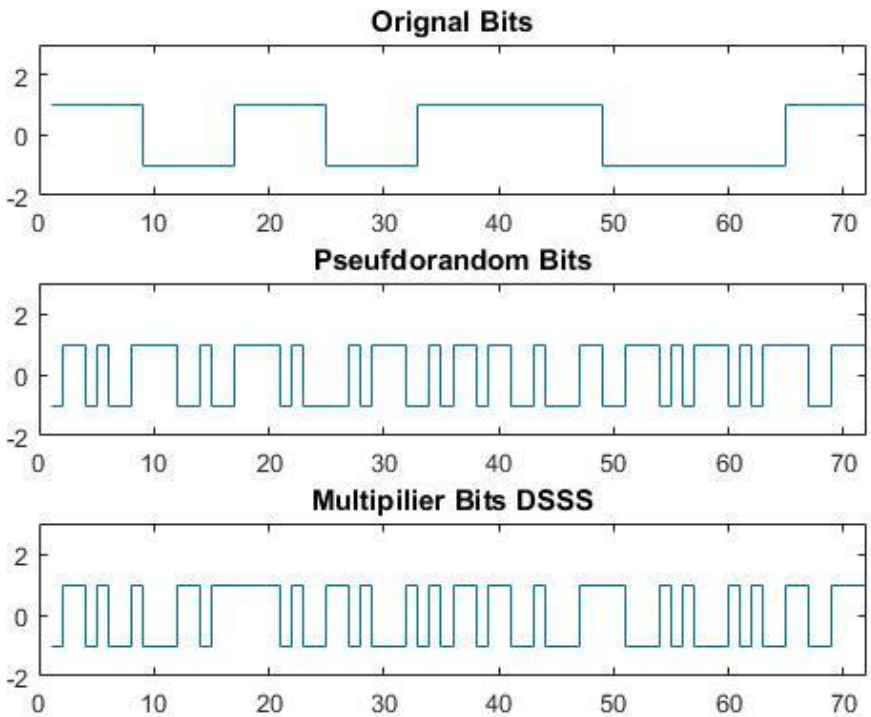


Figure 34: Original signal with PN Signal

DSSS signal is acquired by mixing an input signal with PN random sequence. PN sequence should be a true random binary sequence. The DSSS signal is concisely explained in above Figure 34. For the input data bits which are 9, we first transform binary data into 1 and −1 as shown in first graph of figure. The duration of the bit is 7.77 milliseconds. In the second graph of the figure is PN sequence with a length of 8 chips. It is important to notice that 8 chips occupy a time duration of 1.25 milliseconds as per duration of one input bit. In order to generate DSSS signal we modulate these two binary waves as shown in the last graph of the figure. DSSS signal is further modulated to convert it in to an analog signal to transmit it over UWA channel that we designed in first part of the simulation.

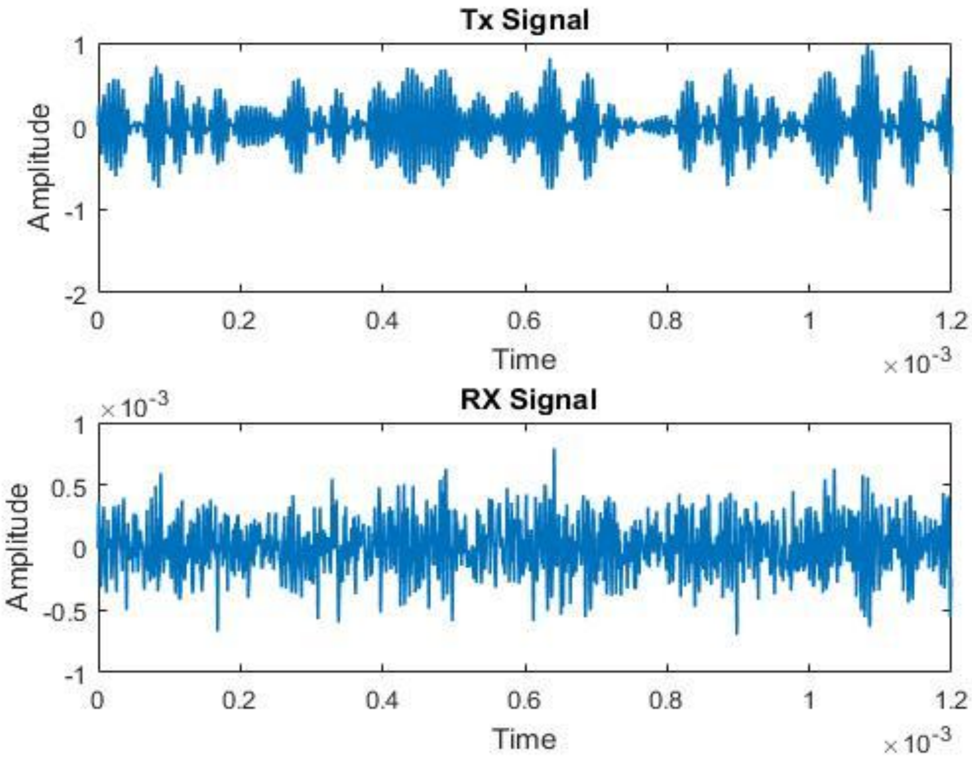


Figure 35: QAM signal

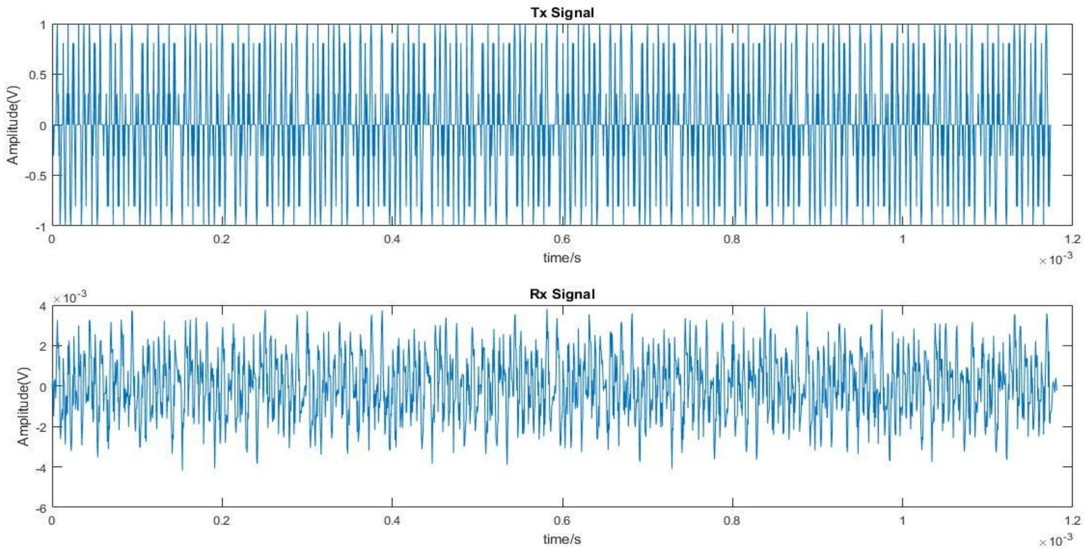


Figure 36: BPSK Modulated Signal

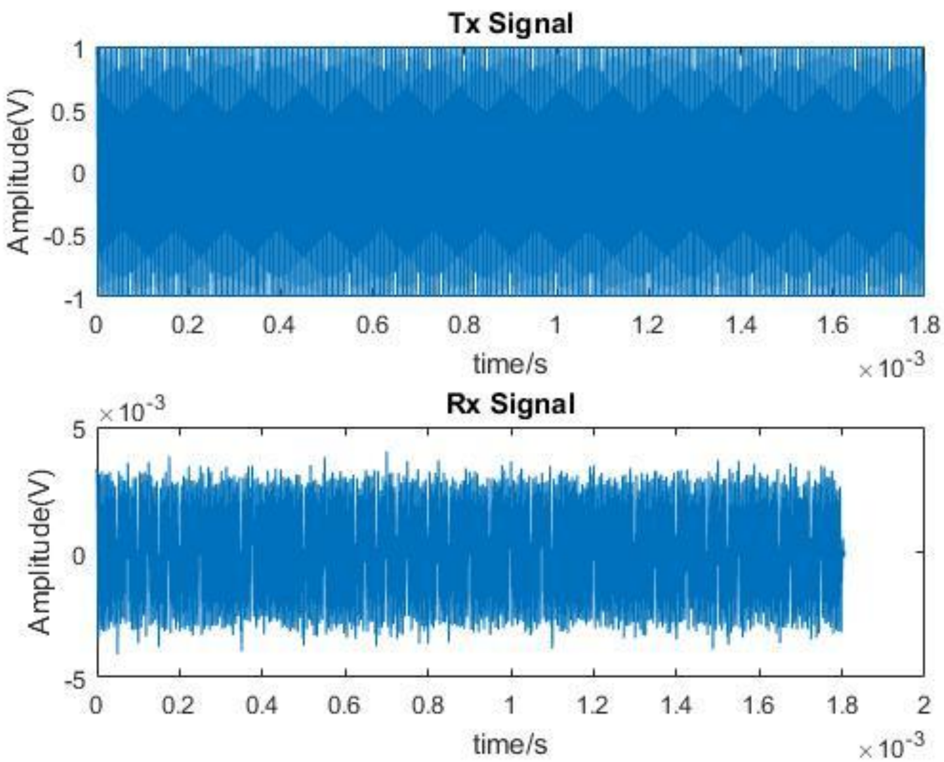


Figure 37: QPSK modulated signal

The DSSS waveform is modulated with a carrier of 160 kHz, we generated three different modulated signals; DSSS-QAM, DSSS-BPSK and DSSS-QPSK which are shown in first graph of figures 35, 36 and 37. As duration of chip is 1.25 milliseconds, that is 6 times smaller than bit duration. In this simulation length of spreading code is comparatively small practically much longer PN sequences is used sometimes 2047 Gold codes. In second graph of figures 35, 36 and 37 shows the effect of channel over the modulation schemes.

7.3 Transmission over underwater acoustic channel:

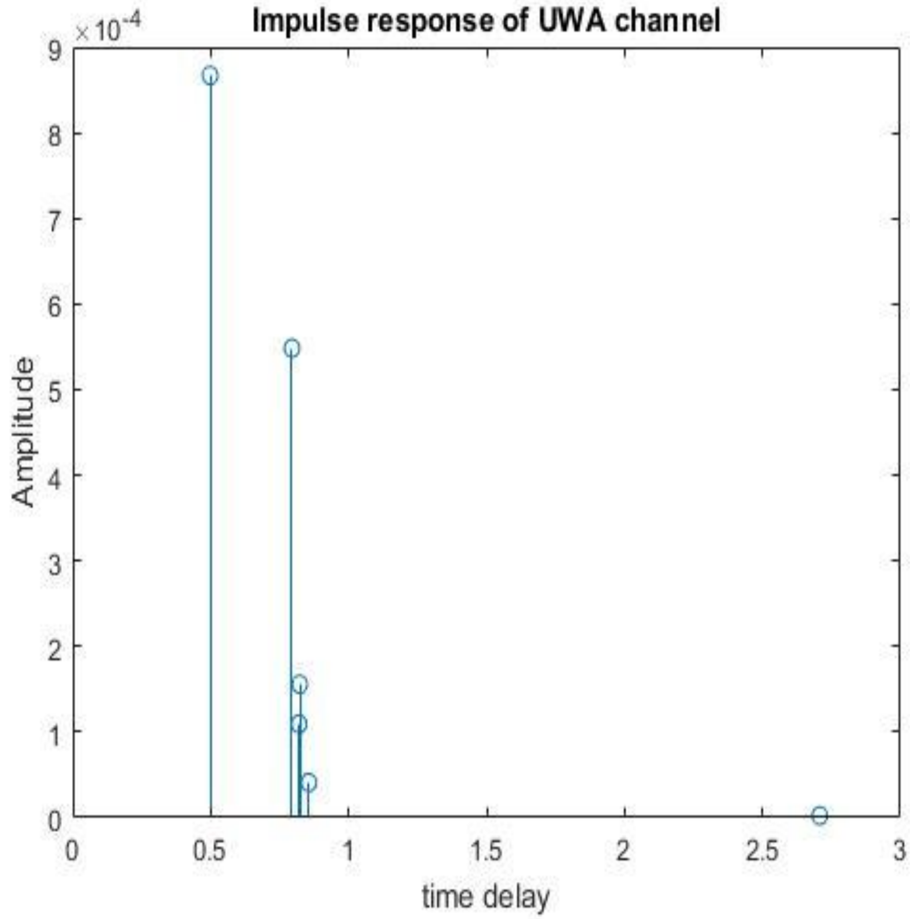


Figure 38: Impulse response of UWA channel

The above Figure 38 illustrate the impulse response of multipath propagation profile of underwater channel. We considered six numbers of tracing paths, where above channel impulse shows two dominant paths with time delays 0.5 and 0.75 milliseconds respectively. The first path is stronger than other, but before processing the impulse response we took out Doppler component.

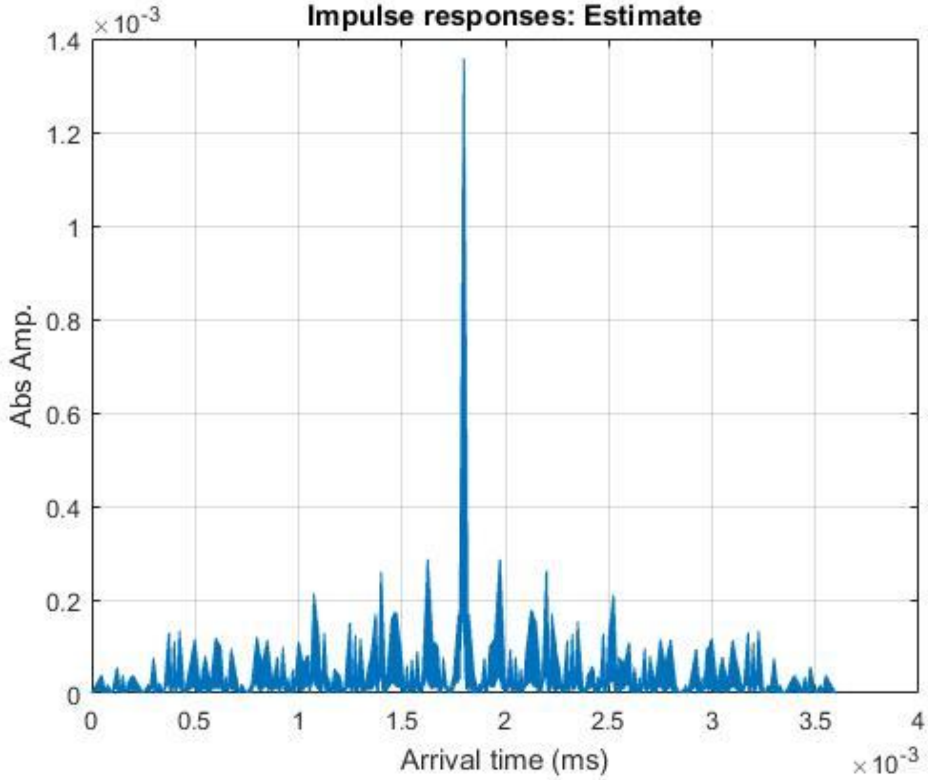


Figure 39: Estimated impulse response of Bellhop

Figure 39 are impulse response of UWA channel, using arrival data from Bellhop ray tracing tool we draw the impulse responses. Arrival file by bellhop contain amplitude, time delay, source angle, receiver angel, top reflection and bottom reflection data. For our simulation we only extract the amplitude and delay information. Estimated impulse response is showing the combined effect of all six rays over the transmitted signal.

7.4 Bit Error Rate of received signal

We compared multiple modulation techniques to study the effect of modulation schemes over short range underwater channel, we simulated the modulation techniques over AWGN channel to compare the theoretical results with simulation. Result of the first simulation part, it represent the DSSS-QAM BER of 5x10^-1 average, as Signal to noise ratio is increasing the BER is also increasing.

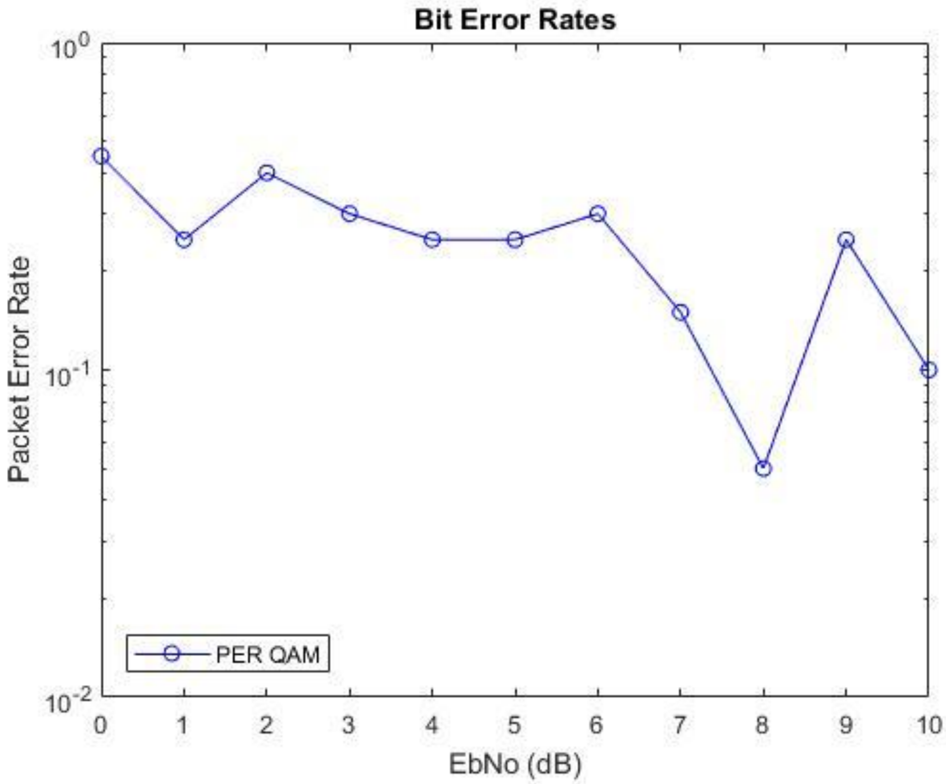


Figure 40: 16 QAM BER resutls

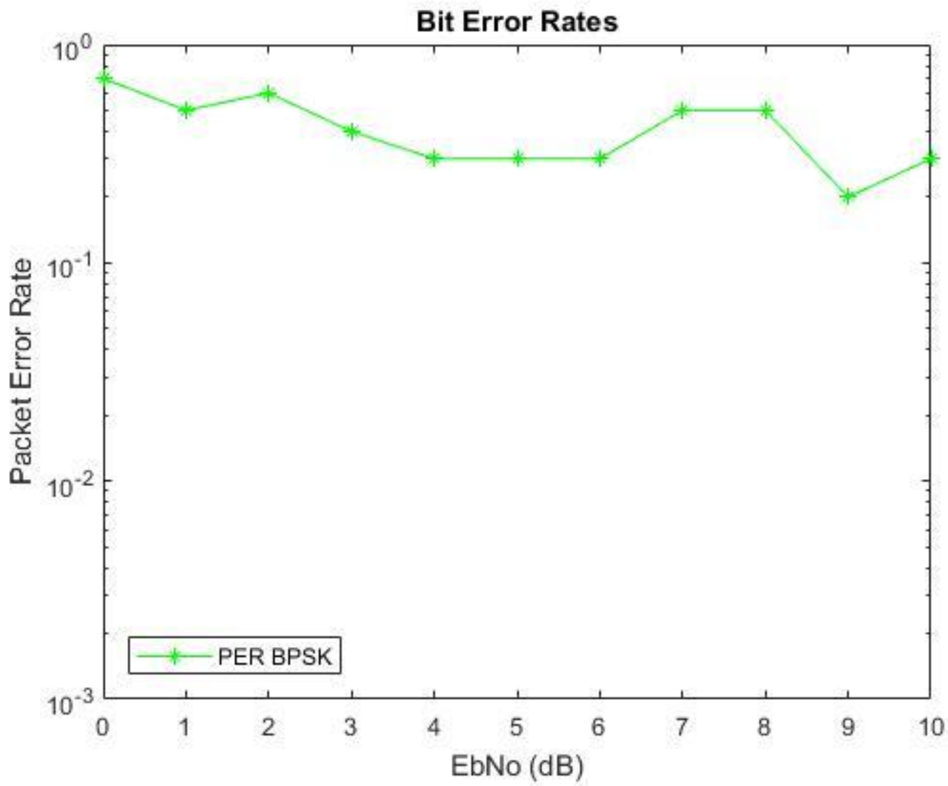


Figure 41: BPSK BER results

In second simulation we have implemented BPSK modulation technique over transmission signal, having BER of 3x10-1. This technique is better than the previous modulation technique, BPSK highly implanted modulation technique as signal attenuation doesn't much effect the performance of this technique.

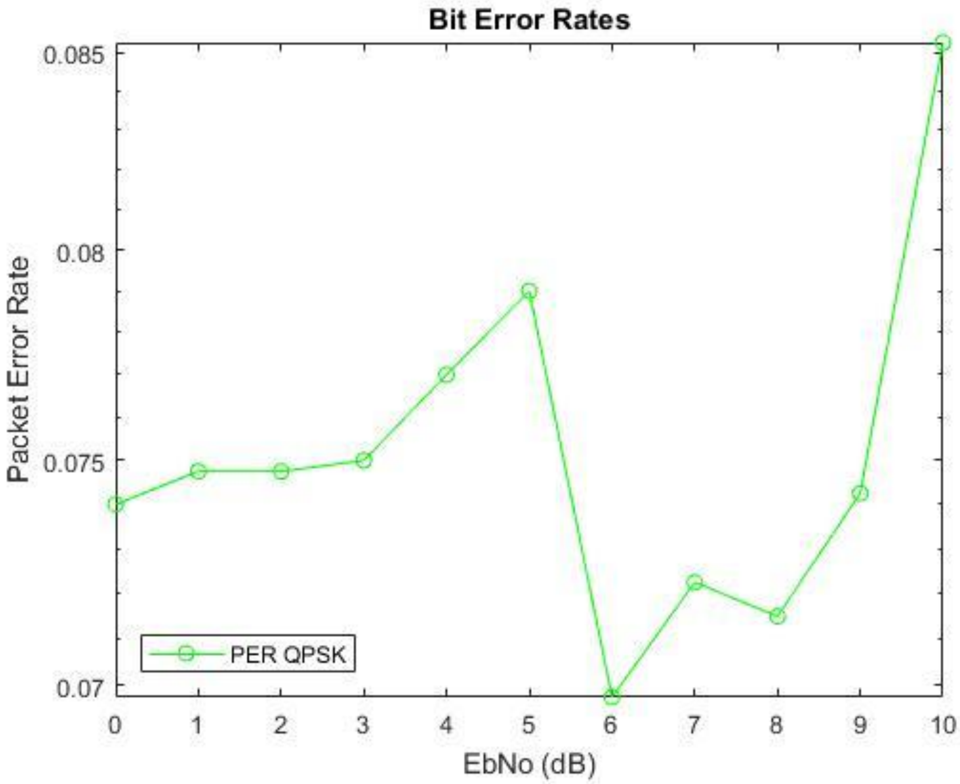


Figure 42: QPSK BER results

In third simulation we have implemented QPSK, the BER is 7.5x10-2 for QPSK modulation. The BER we are getting through this technique is much better than the other techniques, but as we increase the order of the modulation scheme the complexity of the system will also increase.

Comparison of simulated data with theoretical data

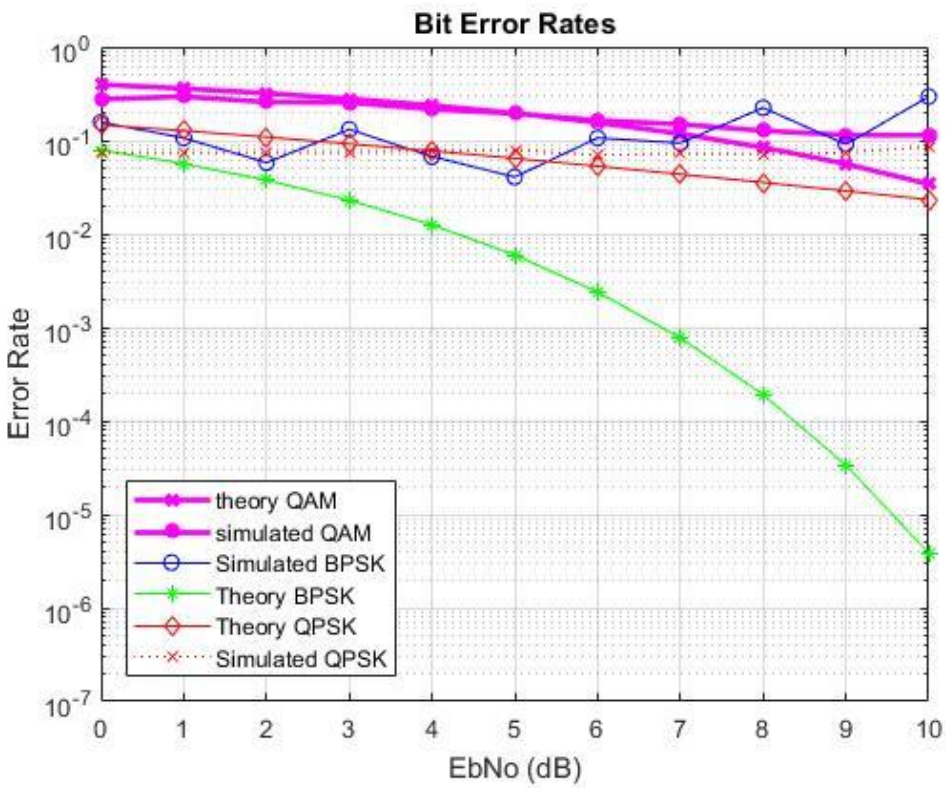


Figure 43: Comparison of theoretical and simulated results

In this section we have compared theoretical results with simulated results of DSSS-QAM, DSSS-BPSK and DSSS-QPSK. Figure 43 represents the comparison between all three simulations with their theoretical results. Simulation result for QAM is nearly same as the theoretical result. Where BPSK and QPSK modulation BER are better than theoretical results. since before simulation we eliminated the Doppler Effect and we only consider the time delay and amplitude for impulse response.

Table 6: Table of Parameters used for BER calculation

Source Power	85db
Range Transmission Losses	23db to 65db
Depth Transmission Losses	55db to 85db
Number of Path	6
SNR	10db (strongest path - noise)
Energy per bit	1
Num of bits	3500
Num of packet	100
Wind Speed	5m/s
Data from .arr file considered	Amplitude and delay
Carrier frequency	160e3

Using the parameters mentioned in table 6 simulation result for QAM is nearly same as the theoretical result since we only considered the amplitude and delay for impulse response from the arrival file from bellhop ray tracing tool, no surface and bottom refection and phase shift is considered, before simulation we also eliminated the Doppler Effect and we only consider. Where BPSK and QPSK modulation BER are better than theoretical results

Conclusion

The study about concatenation of two modulation techniques for short range underwater acoustic channel is made in this work regards to achieve encrypted and robust underwater wireless communication systems with low probability of interception and detection. System represents both software and theoretical based understanding of DSSS and digital modulations based system efficiency over a shallow underwater acoustic channel.

Designed system successfully encrypted the data and transferred the signal over an underwater channel with ambient noise. We have performed two modulation techniques in our structure as DSSS modulation provided the low probability interception which made the data bits undetectable for intruders, where digital modulation encrypted the data for noisy channel. Signal to noise ratio (SNR) is considered as the key parameter to represent the performance of digital modulations over the channel. The simulation is implement using underwater channel impulse response generated by Bellhop ray tracing tool. Bellhop gives effective predictions of acoustic signal so an efficient receiving range can be determine for communication or area surveillance. Using the arrival file generated by the bellhop for the UWA channel we studied the impact of channel over the modulated signal.

Since smaller the value of SNR shows low quality communication since more number of errors are encountered. Whereas bigger value of SNR indicates good quality communication since signal becomes robust compared to noise. As the bandwidth of underwater channel is limited so we selected QAM, BPSK and QPSK modulation techniques as they require low bandwidth for transmission.

The simulating results are pretty satisfactory as for 10db SNR they are accurate for QPSK modulation, as for simulation of underwater channel we didn’t consider the Doppler Effect and time variability.

Lastly, we described each signal modulation assisted a different purpose to determine the effect of channel on acoustic signal. The different modulated signal transmission provided us the opportunity to inspect further ways of underwater channel estimation.

Modulation	*Advantages*	*Disadvantages*
16QAM	• Simple implementation • Low bandwidth utilization • Simple circuitry makes it cost effective. • Bit rate is high • ¼ bits rate	• Since QAM is based on amplitude variation and the underwater channel is too complex it has limited transmission rage. • As we increase the order data will get more effected by noise • 4.5 BER • 4bits per Hz
BPSK	• Low bandwidth utilization • Based on phase variation which makes it more reliable in underwater environment. • Less transmission power required • Bandwidth efficiency 1bit/Hz	• Low Bit rate • 1 bit rate • Synchronous detection required • 0.9 BER
QPSK	• High bit rate • Low bandwidth utilization • Immune to underwater noise • ½ bit rate • 0 BER	• Complex modulation and demodulation. • 2bits per Hz

List of Acronyms and Abbreviations

AT	Acoustic Toolbox
ASK	Amplitude Shift Keying
AWGN	Addition white Gaussian Noise
BER	Bit Error Rate
DSC	Deep Sound Channel
DSSS	Discrete Sequence Spread Spectrum
EM	Electromagnetic
ISI	Inter Symbolic Interference
LPD	Low Probability Detection

LPI	Low Probability Interception
PSD	Power Spectrum Density
PSK	Phase Shift Keying
SL	Source Level
SNR	Signal to Noise Ratio
SSP	Sound Speed Profile
TL	Transmission Loss

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